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Best Available Techniques (BAT) Reference Document for the Smitheries and Foundries Industry

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

JOINT RESEARCH CENTRE
Directorate B – Fair and Sustainable
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This document is one from the series of foreseen documents listed below (at the time of writing, not all documents have been drafted):

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

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

PREFACE

1. Status of this document

Unless otherwise stated, references to ‘the Directive’ in this document refer to Directive 2010/75/EU of the European Parliament and 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

This document contains six main chapters:

Sections 1.1 and 2.1 provide general information on the industrial sectors concerned and their key environmental issues (KEIs).

Sections 1.2 and 2.2 provide information on the industrial processes and techniques used within these sectors.

Sections 1.3 and 2.3 provide data and information concerning the environmental performance of installations within the smitheries and foundries sectors, and in operation at the time of writing, in terms of current emissions to air and to water, consumption of raw materials, water and energy and the generation of waste.

Chapter 3 describes in more detail the techniques to prevent or, where this is not practicable, to reduce the environmental impact of installations in these sectors 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 3 is structured as follows:

- Section 3.1: Common techniques to consider in the determination of BAT for smitheries and foundries;
- Section 3.2: Techniques to consider in the determination of BAT for foundries;
- Section 3.3: Techniques to consider in the determination of BAT for smitheries.

Chapter 4 presents the BAT conclusions as defined in Article 3(12) of the Directive.

Chapter 5 presents the identified emerging techniques for both smitheries and foundries.

Concluding remarks and recommendations for future work regarding smitheries and foundries are presented in Chapter 6.

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 sectors on smitheries and foundries,
- 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 3. These data give some 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

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WORKING DRAFT IN PROGRESS

SCOPE

The BREF for the smitheries and foundries industry concerns the following activities specified in Annex I to Directive 2010/75/EU:

- 2.3. Processing of ferrous metals:
 - (b) operation of smitheries with hammers the energy of which exceeds 50 kilojoule per hammer, where the calorific power used exceeds 20 MW.
- 2.4. Operation of ferrous metal foundries with a production capacity exceeding 20 tonnes per day.
- 2.5. Processing of non-ferrous metals:
 - (b) melting, including the alloyage, of non-ferrous metals, including recovered products, and operation of non-ferrous metal foundries, with a melting capacity exceeding 4 tonnes per day for lead and cadmium or 20 tonnes per day for all other metals.
- 6.11 Independently operated treatment of waste water not covered by Directive 91/271/EEC¹, provided that the main pollutant load originates from the activities covered by these BAT conclusions.

This document also covers the following:

- Ferrous metal foundries employing continuous casting processes for the production of grey or nodular iron castings at or near their final shape.
- Non-ferrous metal foundries using alloyed ingots, scrap, recovered products or liquid metal for the production of castings at or near their final shape.
- 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.
- The coating of moulds and cores in ferrous and non-ferrous metal foundries.
- The storage, transfer and handling of materials, including the storage and handling of scrap and sand in foundries.
- Combustion processes directly associated with the activities covered by these BAT conclusions provided that the gaseous products of combustion are put into direct contact with material (such as direct feedstock heating or direct feedstock drying).

This document does not cover the following:

- The continuous casting of iron and/or steel (i.e. to produce thin slabs, thin strips, and sheets). This is covered by the BAT conclusions for Iron and Steel Production (IS).
- The production of semi-finished non-ferrous metal products requiring further forming. This is covered by the BAT conclusions for the Non-Ferrous Metals Industries (NFM).
- Cadmium, titanium and precious metal foundries, as well as bell and art casting.
- The coating of castings. This may be covered by the BAT conclusions for Surface Treatment Using Organic Solvents including Wood and Wood Products Preservation with Chemicals.
- Forging presses.
- Waste water from indirect cooling systems. This may be covered by the BAT conclusions for Industrial Cooling Systems (ICS).
- Rolling mills. This is covered by the BAT conclusions for the Ferrous Metals Processing Industry (FMP).

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

Scope

- 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) 2015/2193 of the European Parliament and of the Council².

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

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

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 SMITHERIES

This chapter summarises the results of an exchange of information on the activities covered under activity 2.3 (b) of Annex I to the IED (i.e. ‘2.3 Installations for the processing of ferrous metals: (b) smitheries with hammers the energy of which exceeds 50 kilojoule per hammer, where the calorific power used exceeds 20 MW’).

This chapter on smitheries does not focus on the use of presses or rolling mills. Information on the rolling process can be found in the FMP BREF. [\[168, COM 2022\]](#)

1.1 General information

Forging is a process where prepared metal workpieces are heated and then transformed into a component part by using hammers or presses. The metal is pressed, pounded or squeezed under great pressure into high-strength parts.

It should be noted that, in the forging process, the metal used to make forged parts is never melted and poured (as in the casting process). The forging process is entirely different from the casting (or foundry) process (see Section 2.2). Furthermore, the forging process can create parts that are stronger than those manufactured by any other metalworking process. [\[156, FIA 2021\]](#)

Ferrous forgings are produced using principally the following main production processes:

- Closed-die forging process: Closed-die forging utilises pressure to compress a workpiece in an enclosed die. Closed-die forging is the main manufacturing process to produce small steel forgings.
- Open-die forging process: It involves deforming a piece of metal between multiple dies that do not completely enclose the workpiece. Usually, metal billets are deformed using hammers or presses delivering successive blows or press operations with very high compressive forces. This process is mostly used for the production of large steel forgings.

Regarding the forging temperature the following classification applies:

- Hot forging process: Hot forging takes place at temperatures of approximately 950 °C to 1 300 °C, i.e. at a temperature where recovery processes and recrystallisation processes take place during and after transformation.
- Warm forging process: Warm forging takes place at a temperature range of approximately 600 °C to 950 °C.
- Cold forging process: Cold forging takes place at room temperature. A workpiece is inserted between two dies and is pressed with high pressure until it has adopted the die shapes.

The choice of the production technique used depends on different criteria: shape, size, weight, batch size, material, cost-effectiveness, lead time, etc. [\[137, Herbertz et al., 2013\]](#)

In this document, only forging installations using hammers, either for closed or open-die forging applications, are considered because these installations are covered under Annex I to the IED (Activity 2.3). Such installations are designated as smitheries in this document.

There is a higher number of forging installations in Europe that use press forging rather than forging hammers. Such plants are usually designated as forging presses; however, they are not currently covered under the IED and therefore are not described in great detail in this document. Also, hot rolling mills (e.g. ring rolling mills in particular), which are covered in the Ferrous Metals Processing Industry BREF, are not covered in this document.

1.1.1 Sector overview

1.1.1.1 Size of the industrial sector

In 2019, the European forging industry is the second largest in the world with a production volume of 21 %, as shown in Figure 1.1. In the EU-27, 44 % of the forging production volume is produced in Germany, and Italy has a production volume of 21 %. The total production of die-forging products varies in the various European countries. The EU forging industry is present in several EU Member States and involves the use of forging hammers and presses.

However, there are a small amount of smitheries installations using forging hammers that meet the threshold of IED Annex I (Directive 2010/75/EU).

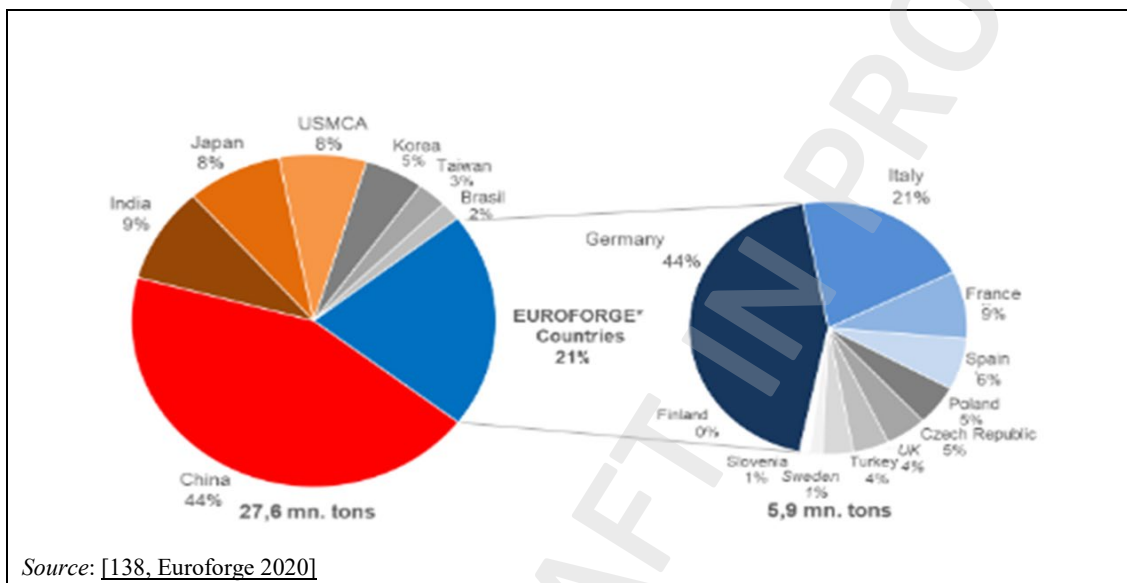


Figure 1.1: Figures on global and European forging industries in 2019

The following table (Table 1.1) shows a survey regarding the production volume of forgings for different countries of the world and the countries affiliated to Euroforge in 2018. It shows from which industry sector the production of forgings comes from. Globally, China produced the highest volume, around six times more than Japan or India. Countries affiliated to Euroforge produce about half the volume of China. [154, Euroforge 2022]

The European forging production figures for 2018 are shown in Table 1.2. The countries affiliated to Euroforge consist of the following: Spain, Germany, Finland, Norway, UK, France, Belgium, Czech Republic, Poland, Slovenia, Italy and Turkey. Germany is the biggest producer of forgings, followed by Italy, France, Spain, Poland and the Czech Republic. [154, Euroforge 2022]

Table 1.1: 2021 production volumes of forgings and 2022 forecast – World and Europe (countries affiliated to EUROFORGE)

PRODUCTION VOLUME OF FORGINGS (metric net tonnes x 1 000)	Countries affiliated to Euroforge*		Japan		USA, Canada, Mexico		China		India		Brazil		Korea		Taiwan		World	
	2021	FC 2022	2021	FC 2022	2021	FC 2022	2021	FC 2022	2021	FC 2022	2021	FC 2022	2021	FC 2022	2021	FC 2022	2021	FC 2022
CLOSED-DIE FORGING TOTAL	4 144	4 052	1 876	1 680	1 941	2 404	9 406	8 936	1 900	1 900	498	498	1 379	1 450	893	780	22 034	21 700
• of which production of forging industry (subcontracting)	2 955	2 849	-	-	-	-	-	-	1 900	1 900	460	460	1 379	1 450	893	780	7 587	7 439
• of which in-house production of the automotive industry	182	170	-	-	-	-	-	-	-	-	-	-	-	-	-	-	182	170
• of which in-house production of the finished assembly subcontracting	197	196	-	-	-	-	-	-	-	-	36	36	-	-	-	-	233	232
• of which catalogue items (flanges and fittings, pipes, connectors, armatures, tools, etc.)	389	396	-	-	-	-	-	-	-	-	2	2	-	-	-	-	391	398
COLD FORGING TOTAL	638	666	105	102	0	0	0	0	250	250	3	3	142	150	102	93	1 240	1 264
• of which production of cold forging industry (subcontracting)	525	542	-	-	-	-	-	-	250	250	2	2	142	150	102	93	1 021	1 037
• of which in-house production of final customer industries	70	80	-	-	-	-	-	-	-	-	1	1	-	-	-	-	71	81
OPEN-DIE FORGING TOTAL	1 134	1 200	368	341	465	514	4 626	4 626	375	375	0	0	0	0	15	14	6 983	7 071
• of which ring rolling	413	437	252	240	318	348	1 070	1 000	125	125	-	-	-	-	5	5	2 183	2 155
• of which other open-die forging (excluding steel bars, blanks and railway stacks)	567	601	116	101	-	-	-	-	250	250	-	-	-	-	10	9	4 498	4 587
CLOSED-DIE FORGING NON-FERROUS	216	215	51	51	-	-	-	-	160	160	-	-	44	-	33	43	504	469
TOTAL FORGING PRODUCTION VOLUME	6 131	6 133	2 397	2 174	2 407	2 918	14 032	13 562	2 685	2 685	501	501	1 565	1 600	1 043	930	30 760	30 501

* Countries affiliated to Euroforge: Belgium, Czech Republic, Finland, France, Germany, Great Britain, Norway, Italy, Poland, Slovenia, Spain and Turkey.
NB: FC: Forecast.
Source: [154, Euroforge 2022]

Table 1.2: European survey of 2021 production volume of forgings and 2022 forecast

PRODUCTION VOLUME OF FORGINGS (metric net tonnes x 1 000)	Germany		Italy		France		Spain		Sweden		Czech Republic		Poland		Slovenia		Finland		Countries affiliated to Euroforge*	
	2021	FC 2022	2021	FC 2022	2021	FC 2022	2021	FC 2022	2021	FC 2022	2021	FC 2022	2021	FC 2022	2021	FC 2022	2021	FC 2022	2021	FC 2022
CLOSED-DIE FORGING TOTAL	1 359	1 300	961	946	251	253	263	270	73	73	617	555	170	188	59	60	8	8	4 144	4 052
• of which production of forging industry (subcontracting)	980	930	793	785	-	-	247	250	73	73	482	414	-	-	57	56	3	3	2 955	2 849
• of which in-house production of the automotive industry	150	140	-	-	-	-	-	-	-	-	32	30	-	-	-	-	-	-	182	170
• of which in-house production of the finished assembly subcontracting	85	80	84	80	-	-	-	-	-	-	7	7	-	-	2	4	-	-	197	196
• of which catalogue items (flanges and fittings, pipes, connectors, armatures, tools, etc.)	144	150	84	81	-	-	16	20	-	-	96	104	-	-	-	-	5	5	389	396
COLD FORGING TOTAL	555	580	0	0	32	32	19	20	0	0	0	0	0	0	10	11	5	5	638	666
• of which production of cold forging industry (subcontracting)	485	500	-	-	-	-	19	20	-	-	-	-	-	-	-	-	5	5	525	542
• of which in-house production of final customer industries	70	80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	70	80
OPEN-DIE FORGING TOTAL	332	365	248	260	51	52	5	6	161	161	164	167	103	110	0	0	0	0	1 134	1 200
• of which ring rolling	154	175	71	70	-	-	5	6	10	10	151	154	-	-	-	-	-	-	413	437
• of which other open-die forging (excluding steel bars, blanks and railway stacks)	178	190	177	190	-	-	-	-	151	151	13	13	-	-	-	-	-	-	567	601
CLOSED-DIE FORGING NON-FERROUS	80	75	-	-	130	134	-	-	-	-	2	2	-	-	-	-	-	-	216	215

PRODUCTION VOLUME OF FORGINGS (metric net tonnes x 1 000)	Germany		Italy		France		Spain		Sweden		Czech Republic		Poland		Slovenia		Finland		Countries affiliated to Euroforge*	
	2021	FC 2022	2021	FC 2022	2021	FC 2022	2021	FC 2022	2021	FC 2022	2021	FC 2022	2021	FC 2022	2021	FC 2022	2021	FC 2022	2021	FC 2022
TOTAL FORGING PRODUCTION VOLUME	2 325	2 320	1 209	1 206	464	471	287	296	234	234	783	724	273	298	69	71	13	13	6 131	6 133

* Countries affiliated to Euroforge: Spain, Germany, Finland, Norway, Great Britain, France, Belgium, Czech Republic, Poland, Slovenia, Italy and Turkey.
 NB: FC: Forecast.
 Source: [154, Euroforge 2022]

In 2023, at the time of writing this document, there were three smitheries installations reported to be using hammers and meeting the capacity threshold of activity 2.3 (b) of Annex I to the IED. These installations are located in Germany, Poland and Spain. However, in the EU-27, there are more smitheries using hammers which did not meet the capacity threshold of Annex I to the IED. [169, TWG 2021]

Many workpieces can only be produced using a hammer. These include workpieces that require a large forging force or that have to be forged quickly because of the risk of cooling. For example, the warm forging of aluminium parts requires a fast deforming process. Especially flat workpiece shapes can often only be achieved by using hammers. Also, effects on the microstructure of the material and tribological aspects due to the shorter contact time between tool and workpiece are considered when choosing a hammer. Other workpieces can be forged both by hammer and by press. Although a comparison is only possible to a limited extent, reference values are given for the allocation of press size and hammer size. [152, DE VDI/ADB 1973], [148, Euroforge 2021], [155, Euroforge 2020]

Hammers are usually used for flattish parts, like con-rods, knives or tools. For these parts, due to the short contact time and high forging speed, they allow the material flow to fill the flat die sufficiently with comparable low force.

In order to achieve the same effect with a press (if possible at all), it would be necessary to use a much bigger press with a much higher pressing power, which would result in much higher investment/costs (per machine and therefore per part) and energy input.

Furthermore, as hammers are mostly fed manually, this allows the last blow to be in the central part of the die which avoids a bending of the flat workpiece. With a press, the different pressing steps are arranged in a linear flow which leads to a non-centric pressure at the last step and could lead to a bending of the part. [155, Euroforge 2020]

1.1.1.2 Type of products and applications

The forging industry supplies a number of industrial sectors with simple or complex forgings. Typical products include blocks, bars, blanks, disc or shafts. More complex forgings, e.g. rings, cylinders, punched bosses and stepped shafts, require the use of additional, auxiliary tools such as fullers, swages, punches and drifts.



Source: [148, Euroforge 2021]

Figure 1.2: Forging products

Forging products have always been of great significance in many sectors as they are used in a wide variety of applications. Further product design opportunities have been created by the development of processes and process combinations, basic/raw materials, tool engineering and equipment used. [137, Herbertz et al., 2013]

The production of forgings ranges from a few units to series of millions.

Forgings are used:

- to transfer forces, moments and movements;
- for highly static and dynamic loads;
- in the event of major wear and tear loads;
- for space- and weight-saving designs,
- for high safety, reliability and availability standards,
- for sustainable resource conservation, recycling potential and environmental conservation.

Forging products are mostly employed in the following applications:

- Automotive and trucks: A number of forged components are commonly found at points of shock and stress and include crankshafts, transmission shafts and gears, differential gears, drive shafts and clutch hubs.
- Aerospace: Both ferrous and non-ferrous forgings are used in aerospace applications (e.g. helicopters, aircrafts). In this sector, a very high number of forged parts are employed such as bulkheads, wing roots and spars, hinges, engine mounts, brackets, beams, shafts, bell cranks, landing-gear cylinders and struts, wheels, brake carriers and discs.
- Off-road and agricultural vehicles: these off-road vehicles require a number of engine and transmission parts and forgings are used for example for gears, sprockets, levers, shafts, wheel hubs and axle beams.
- Military equipment: Forgings are used in many types of military equipment (e.g. rifles, tanks and fighting vehicles, submarine drive shafts).
- Valves and fittings: A high number of corrosion- and heat-resistant forgings are used for example for flanges, valve bodies and stems, elbows and saddles.
- Hardware and tools: Forgings are used to produce hand tools such as pliers, hammers, sledges, wrenches and garden tools.
- Energy.
- Wind energy.
- Ship-building.
- Heavy machinery. [156, FIA 2021]

The forging industry is an important supplier to the high-tech industries in Europe and internationally. [146, Ade 2017], [156, FIA 2021]

The specifications of the features of the parts include material quality, micro-structure and size/shape of the workpiece. Furthermore, forged products are used due to their properties and characteristics, e.g.:

- durability;
- strength;
- ductility;
- material efficiency due to near net shape;
- materials in use cannot be processed in any other way.

The resilience potential of solid forged components is very high due to the availability of a large number of formable materials, which can be used to provide a wide range of strength and toughness in conjunction with the various heat treatment processes. This high resilience potential provides a further basis for lightweight material construction. [148, Euroforge 2021]

1.1.2 Key environmental issues

Depending on the production processes, smitheries cause emissions to air. Additionally, the environment can be affected by noise and vibrations. The type and quantity of air pollution, residues and waste water depend on different parameters such as the heating technology, furnace type, batch size and product features due to energy-intensive forging processes.

Furthermore, processes might have an effect on water and land (residues).

1.1.2.1 Emissions to air, water, soil, noise emissions and vibrations

Emissions to air as well as noise emissions and vibrations have been defined as key environmental issues (KEIs) for smitheries.

Emissions to air: gaseous emissions arise during heating, reheating, heat treatment and processing of products. Carbon monoxide and nitrogen oxides are of particular importance among the gaseous emissions. Noise emissions and vibrations occur during several smitheries processes, especially during the hammering process.

Dust may arise from the handling or processing of raw materials or product processing and finishing; however, these emissions were not identified as key environmental issues (KEIs) at the Kick-off Meeting (KoM).

Emissions to water: these emissions occur in rare cases in the forging process, but mainly during the cooling processes and during cleaning processes. Apart from this, rainwater and sanitary waste water may contribute to the emissions to water from the plant. However, emissions to water were not identified as a KEI at the KoM.

1.1.2.2 Energy efficiency

For the smitheries sector, energy is a crucial production factor. [146, Ade 2017]

Both the hot and warm forging processes are energy-intensive processes.

Process heat from heating/reheating can partly be reused for heat treatment if this process is not outsourced. Also, the distance between different process steps/installations and the non-continuous pattern of production processes can limit the possibilities of reusing process heat.

Excess heat from the heating/reheating process can be reused for the heating of the combustion air. [137, Herbertz et al., 2013],

1.1.2.3 Material/resource efficiency – residues, reuse, recycling

Residues/process losses/waste originating from smitheries operation mainly arise from raw material preparation, such as metals from cutting and sawing, other losses arise from closed-die forging, i.e. deburring, and forging scale may arise. Furthermore, residues may consist of packaging waste (plastic, wood, metal, paper, etc.).

Raw materials are particularly important in the smitheries sector. The recycling potential of solid forged products is very high. All solid forged products (steel, aluminium, other non-ferrous materials) and the excess production material can be recycled almost up to 100 % and can be reused endlessly, e.g.:

- metallic waste and by-products;
- swarf from raw material preparation, such as sawing and cutting (causes a loss of material);

- the pieces of both beginning and end of the bars from raw material preparation and cutting/shearing, slitting/cleaving;
- flash from closed-die forging;
- forging scale.

[137, Herbertz et al., 2013]

According to the conclusions of the kick-off meeting for this BREF, residues/process losses/waste was not identified as key environmental issues.

WORKING DRAFT IN PROGRESS

1.2 Applied processes and techniques in smitheries

1.2.1 Overview

Forging in general, is a metal-shaping process in which a malleable metal part, known as a blank, billet or workpiece, is worked to a certain shape by one or more processes such as hammering, upsetting, pressing, rolling etc.. [147, Total Materia 2010]

For the purposes of this document, forging is defined as a deformation and metal-shaping process using heating and hammers (e.g. pneumatic, steam-driven, mechanical, electrical, hydraulic).

The following process steps are applied in smitheries:

- raw material and auxiliaries storage and handling;
- raw material preparation;
- heating before forging;
- forging (i.e. hammering);
- heat treatment (e.g. reheating, carburisation, hardening, cooling, quenching, tempering);
- mechanical processing (e.g. machining, finishing).

A simplified flow diagram of the smitheries process is given in the following figure (adapted from information submitted by plants DE004 and DE007 in the data collection).

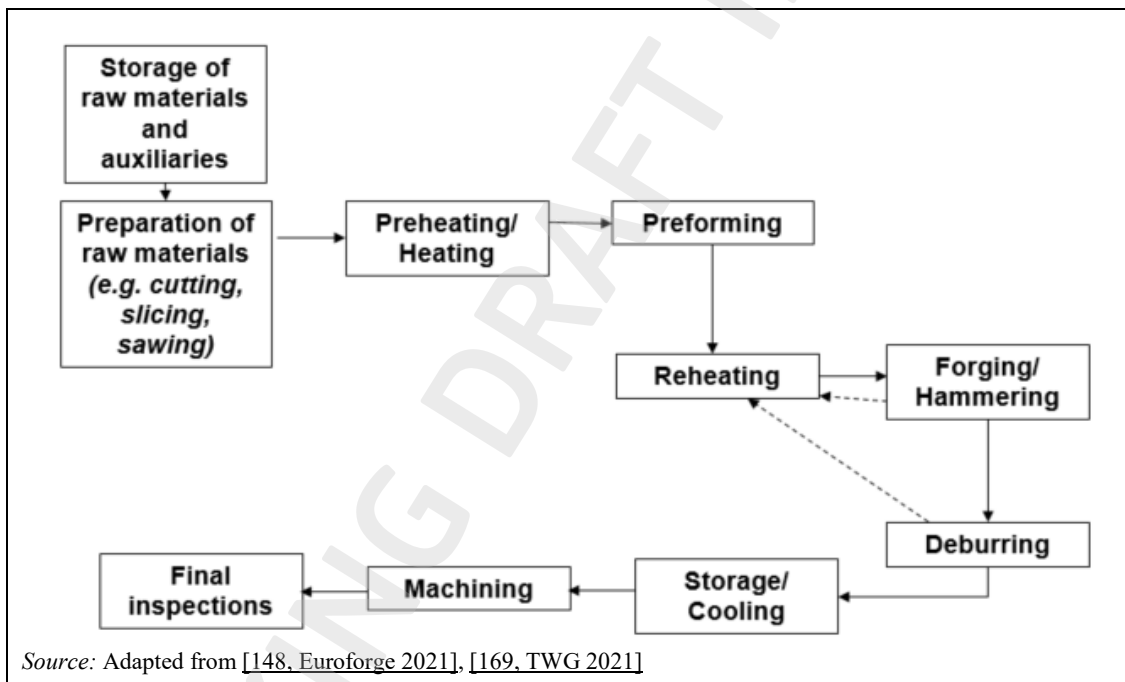


Figure 1.3: Simplified flow diagram of a smitheries process

The individual processes consist of several process steps which can be linked in terms of both time and space to each other within a production unit. Some process steps can also take place separated in time and space; however, heating and forging cannot be separated in time. [137, Herbertz et al., 2013]

The process steps are logically separated if the production performance of each process step is very different. For example, preparation and separation of the workpieces (e.g. cutting, sawing) could be carried out independently from the rest of the process chain. It is also possible to merge individual process steps, e.g. the heat treatment processes called ‘hardened and

tempered/quenched and tempered/heat-treated from forged heat' and 'controlled cooling from hot forging' are directly linked to the transformation process.

Hammer mills can be used for the production of specially shaped parts in order to form the rods, rings, shafts or stubs. The weight of hammered products can range from 100 g up to several tonnes. [148, Euroforge 2021]

Hammering is used in both open- and closed-die forging methods. [137, Herbertz et al., 2013]

In addition to the production-specific equipment, handling, transport (belt-type conveyers, vehicles, forklift trucks, etc.) and sorting/separation systems (vibration spiral conveyors) are applied. [139, Probst 2006]

1.2.2 Raw materials and auxiliaries

The forging sector can use just about any metal feedstock that can be forged as raw material. Some of the most common metals include: carbon, alloy and stainless steels; very hard tool steels; aluminium; titanium; brass and copper; and high-temperature alloys which contain cobalt, nickel or molybdenum. Each metal has distinct strength or weight characteristics that best apply to specific parts as determined by the customer. [156, FIA 2021]

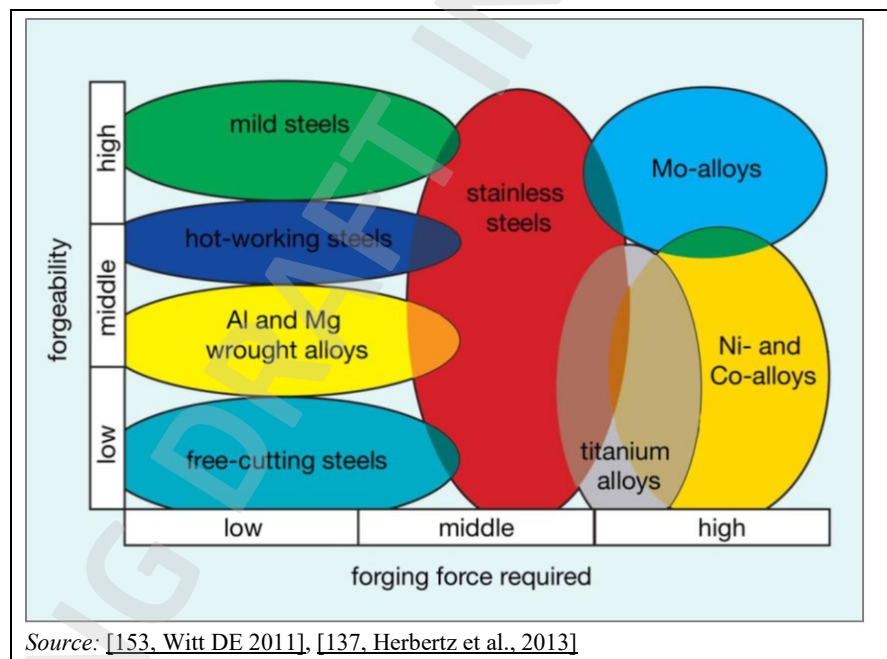


Figure 1.4: Suitable types of raw materials

In addition to the material group, the forging temperature has a very significant influence on the forging (shape-changing) behaviour.

A large group of materials used are structural steels. These steels have a very high capacity for forging with low energy/power and operational requirements while nickel and cobalt alloys act in exactly the opposite way.

Raw material (metal input) is provided in the form of blooms, billets and blanks, for example. [210, TWG 2022]

In terms of areas of use and production volume, the main material group for solid forging is the group of steel materials. In combination with the various heat treatment processes, a very wide range of tensile strength and toughness properties can be set.

For the cold forging process, only steel grades with a carbon content limited to approximately 0.5 wt-% and alloying constituents limited to approximately 5 wt-% are suitable. Even within these limits, the transforming capacity is significantly lower than in the case of the hot forging process.

For the warm forging process, all steel alloys are suitable, except the precipitation-hardening ferritic-pearlitic (AFP) steels and stainless steels. However, the transforming capacity is lower than in the case of the hot forging process.

It has to be noted that hot forging cannot generally be replaced by warm forging as the range of shapes is limited and the microstructure features of the products are also limited when the higher temperature range is not reached. Therefore, a limited capacity is available. [148, Euroforge 2021]

A large variety of materials can be used for forging.

The product range is generally known for its variety. It is based upon supplies from steel manufacturers with ISO certification:

1. high-grade structural steels;
2. case-hardening steels;
3. quenched and tempered (QT) steels;
4. nitriding steels;
5. creep-resistant steels;
6. low-temperature steels;
7. roller-bearing steels;
8. steels for surface hardening;
9. ferritic, stainless steels;
10. stainless, acid- and heat-resistant steels;
11. tool steels;
12. modified special steels on demand;
13. nickel and cobalt super alloys;
14. aluminium;
15. high-alloy steel;
16. low-alloyed steel;
17. unalloyed steel;
18. heat-resistant steels;
19. high-grade carbon and alloy steel components.

[149, HWE DE 2020], [150, Stooss AG DE 2020]

Lubricants

Lubricants are used in hot and warm forging. In 2020, lubricants often include water-based dispersions of graphite. Graphite can support the metal-forming process and can resist high pressures applied perpendicularly to the planes, avoiding metal-to-metal contact between the workpiece and dies, thus minimising die wear. However, there are also disadvantages. An issue with water-based graphite lubricants is the effect of galvanic corrosion, which is supported by the conductivity of graphite. However, there is a clear trend to replace graphite-based die lubricants with synthetic lubricants. This is driven by the need for cleaner work environment, easier handling and to avoid graphite-induced galvanic corrosion of equipment. [164, Heidari et al. 2011]

Lubricants have to be selected in a proper way in order to ensure a successful forging process and to increase productivity. For hot forging, the following main types of die lubricants are used: oil-based graphite, water-based graphite and water-based synthetics or non-graphite. The majority of

the lubricants used are water-based graphite (approximately 60 %) while approximately 25 % are oil-based graphite lubricants and approximately 15 % are synthetic or non-graphite lubricants. [166, Goodchild, S. 2015]

The use of graphite-free lubricants may reduce costs since they help to improve the die life which also leads to improved productivity. [167, Shenoy, S. P. 2013]

The concentrations of the lubricants are specific to the different forging geometries. In open-die forges, lubricants or coolants are not used. [210, TWG 2022]

1.2.3 Raw material preparation

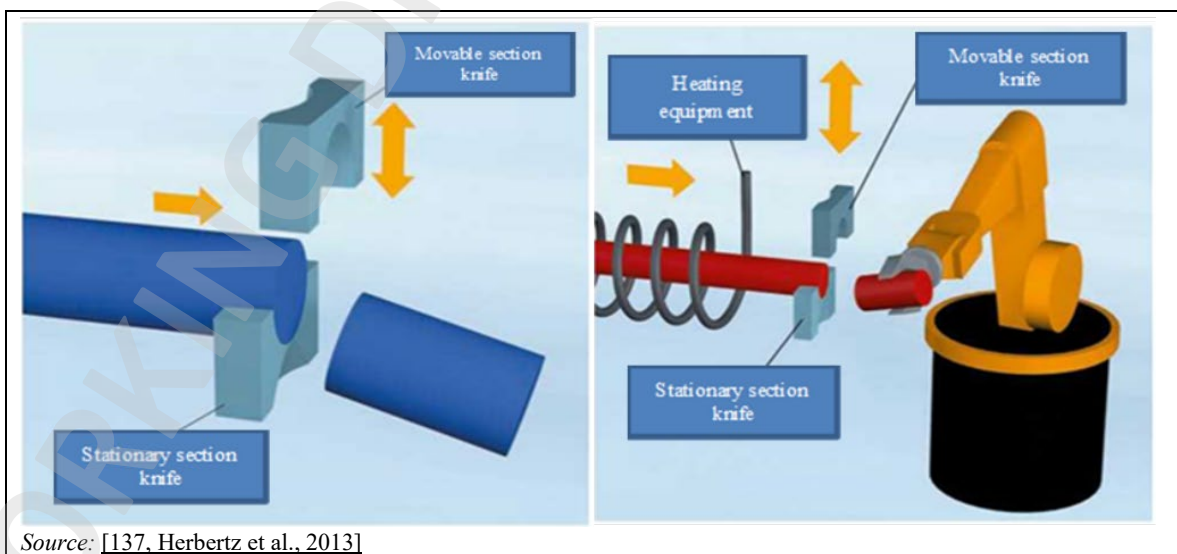
[137, Herbertz et al., 2013]

The raw material is delivered by the steelworks.

The raw material is prepared, i.e. the basic input material is cut and sliced, e.g. by cold-shearing, into individual sections, which are weighed due to very high weight accuracy requirements. It is very important to produce products that are precise in length or in weight. If the cutting surface is located inside the component during the subsequent forging step, a perfect cutting surface quality is of great importance. Otherwise, it may lead to a defective product. Depending on the hardness of the material, the cross-section and the separation speed, different separation methods are used, such as cutting using scissors, saws, sawmills, knives as well as blasting and splitting tools for accurate and efficient material separation. Depending on the separation method, e.g. sawing, cleaving, material losses can occur which lead to residues/waste.

Cutting

In the case of cutting a workpiece, a movable section knife is passed over to a stationary section knife around the section width. The material is cut and separated. Cutting consists of an initial cutting process before the final separation is performed by breaking the residual cross-section. The procedure may be used as cold cutting or hot cutting (see Figure 1.5). Hot cutting takes place in the range of the cure temperature of the material, immediately before the forging process.



Source: [137, Herbertz et al., 2013]

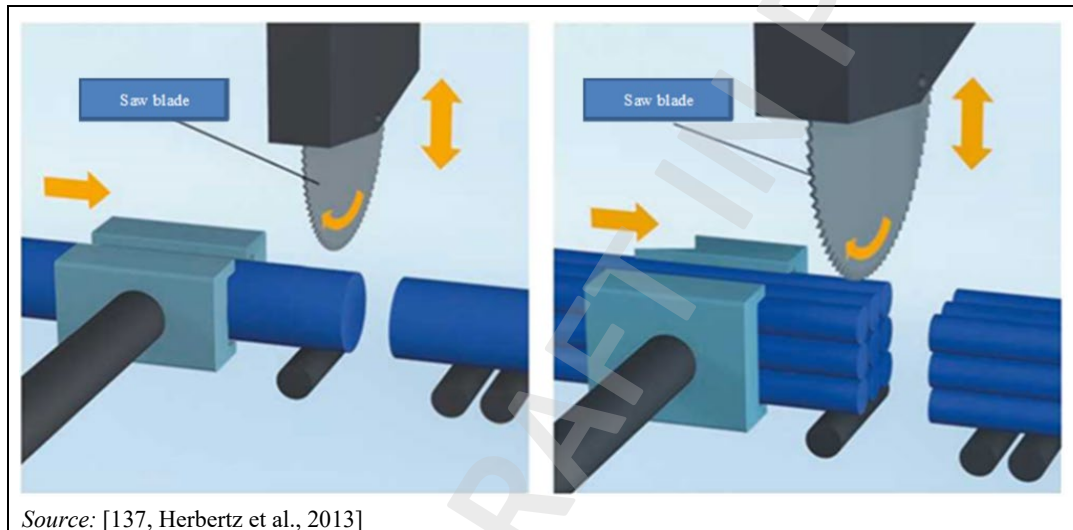
Figure 1.5: Cold cutting and hot cutting

Chapter 1

Advantages	Carried out without a loss of material, except the pieces of both beginning and end of the bars. Low cycle times ensure a high productivity.
Disadvantages	Due to the combination of cutting and breaking, the cutting surfaces could be uneven and may have surface imperfections. Not appropriate for 'soft' materials, e.g. aluminium.
Applications	Used to separate the workpiece for diameters or edge lengths up to approximately 120 mm. It is independent of the hardness of the material. It is applicable for integration in fast-moving automated forging processes or in case of using materials with large cross-sections.
<i>Source:</i> [137, Herbertz et al., 2013]	

Sawing

Sawing is a chip-removing cutting process. Each separation cut is associated with loss of material. Sawing can also be used for materials with smaller cross-sections in order to separate whole bundles of bars (see Figure 1.6).



Source: [137, Herbertz et al., 2013]

Figure 1.6: Sawing a bar and a bundle of bars

Advantages	Allows the achievement of precise and repeatable section lengths with a high-quality cut surface. Applicable for processing workpieces with very large cross-sections. Furthermore, it is applicable to all material qualities and material varieties. Usually, there is no need to change a cutting tool when sawing workpieces with different cross-sections.
Disadvantages	Chip-removing cutting process which requires more time than scissoring and therefore leads to a lower productivity/efficiency. Causes a loss of material which increases in percentage with decreasing product length.
Applications	Manufacture of products from soft materials, such as aluminium or in the case of high requirements on length accuracy of the product, such as flashless forging, and/or high requirements on the surface quality of the cut surfaces. Separating workpieces for diameters or edge lengths greater than 120 mm. Manufacture of workpieces with a small length/diameter ratio.
<i>Source:</i> [137, Herbertz et al., 2013]	

Cleaving

Usually, cleaving corresponds to shear cutting and it is a combination of a splitting process along with mass pre-distribution. The workpiece is split without losses from a sheet metal strip, with the exception of the beginning and the end of the workpieces (see Figure 1.7).

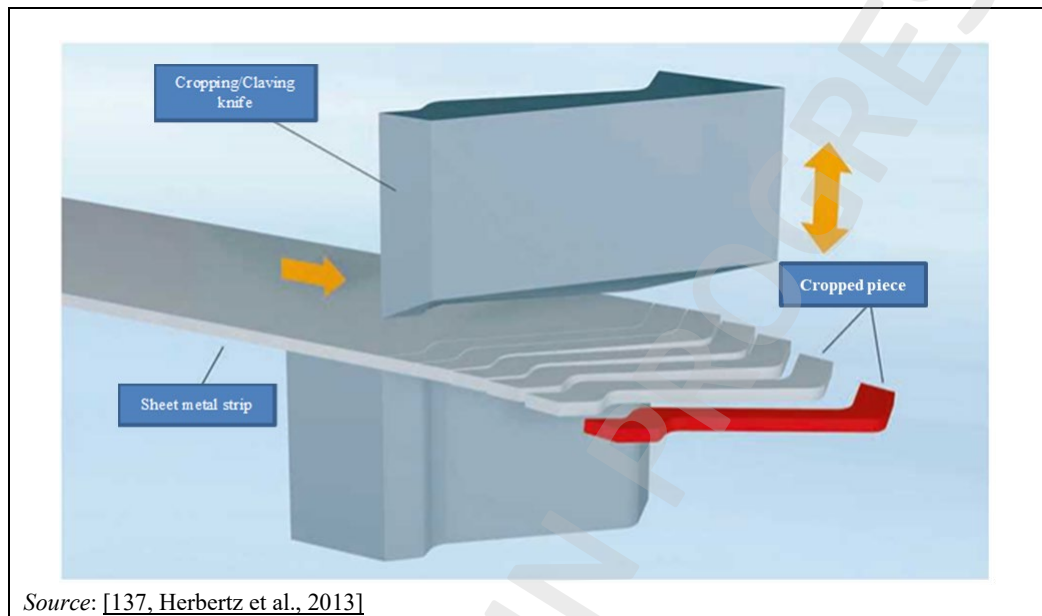


Figure 1.7: Slitting

Advantages	No generation of material losses, except of beginning and end of the workpieces. Allows a simultaneous mass distribution of the workpiece.
Disadvantages	The fibre pattern of the cleaved piece cannot be adapted optimally to the shape of the forging piece. The beginning and the end of the workpieces may be discarded as material losses (residue/waste).
Applications	Manufacture of workpieces for long and flat pieces such as screw keys, pliers, knife blades, scissors.
<i>Source: [137, Herbertz et al., 2013]</i>	

1.2.4 Metal forging processes

[137, Herbertz et al., 2013]

Metal forging (plastic deformation, shaping) is carried out by plastically changing the shape of a solid body.

Transforming is the process that changes the shape of a solid body in a visual (plastic) way; both mass and cohesion will be maintained.

There are no general recommendations available for each of the three forging processes, i.e. the hot, warm or cold forging process. Each of these processes has their own specific advantages and disadvantages. A technically and economically rational selection of a given method can only be made on a component-specific basis, taking into account the geometry of the component, the desired shape and dimensional accuracy, the material used and the mechanical properties of the component as well as the production quantity.

Different types of transforming processes are used for forging procedures:

- forgings (hot forging);
- extruding (cold forging),
- combined methods (hot and cold forging);
- free moulds (hot forging) and ring rollers (hot forging).

Fundamental methods for solid forging are the following:

- rolling:
 - rectangle rollers, transverse wedges, ring rollers;
- open-die forging:
 - rectangles, round kneads, crushing/heading method;
- closed-die forging:
 - closed-die forging with burr,
 - closed-die forging without burr;
- extruding presses;
- specific methods for specific products.

The rolling processes are described and covered by the FMP BREF. Further information can be found under the section on hot rolling in the FMP BREF. [168, COM 2022]

The basic principles of the three forging methods are presented below:

Hot forging process

In the case of hot forging of steel materials, the transformation process takes place at temperatures of approximately 950 °C to 1300 °C, i.e. at a temperature where recovery processes and recrystallisation processes take place during and after transformation. The main characteristics of the hot forging process are:

- high energy demand for heating (useable for heat treatment where appropriate);
- low power and energy demand for transformation;
- suitable for nearly all types of metallic materials;
- very large transformation capacity of the materials;
- pronounced scaling in many steels;
- the surfaces have a high roughness;
- possible changes in shape and dimensions due to thermal shrinkage and bending.

Warm forging process

Warm forging of steel materials combines the advantages of the cold forging process and the hot forging process by choosing a material-specific transformation temperature. However, the formation of the scaling has not yet started or has not started significantly. Technically and economically, it makes sense to have a temperature range of approximately 600 °C to 950 °C. The main characteristics of the warm forging process are:

- average energy demand for heating;
- average power and energy demand during transformation;
- higher alloyed materials can be used than those used in the cold forging process but lower than in hot forging;
- higher material forming capacity than that of the cold forging process but lower than in hot forging;
- higher geometrical flexibility than in the cold forging process but lower than in hot forging;
- low scaling;
- better surface quality than in the hot forging process but lower than in cold forging;
- higher shape and dimension accuracy than in the hot forging process but lower than in cold forging.

It should be noted that some geometries cannot be achieved using the warm forging process. [148, Euroforge 2021]

Cold forging process

In the case of cold forging of steel materials, the transformation process takes place at or near room temperature. The main characteristics of cold forging are:

- no or low energy demand for heating;
- large power and energy requirements for transformation;
- low transformation capacity of materials;
- limited geometrical flexibility;
- where appropriate, cold solidification may be used; however, often heat treatment is also necessary;
- no scaling;
- the surfaces have a low roughness;
- high shape and dimensional accuracy, up to and including functional surfaces ready for installation;
- specific pretreatment of the raw material in terms of structural properties and surface area is required.

Prefabrication steps for cold forging

The cold forging of steel requires special pretreatment of the components in order to optimise the structure and surface for the subsequent transformation. The pretreatment consists, for example, of annealing (soft annealing), abrasive blasting and lubrication/coating. The coating of the components is necessary to prevent oxidation and, during subsequent transformation, cold welding between the tool and the workpiece. The pressure-resistant solid lubricants are graphite, molybdenum disulphide, special soaps or waxes. Developments in materials and process technology aim to achieve the desired structure without annealing and to carry out the necessary coating of the raw materials exclusively with more environmentally friendly products.

1.2.5 Workpiece heating

1.2.5.1 Heating options

[137, Herbertz et al., 2013]

Heating is needed for hot and warm forging processes. The purpose of the heating process is to get a homogeneously heated workpiece across its cross-section and the longitudinal axis in the area of deformation.

A stable production process requires reproducible and energy-efficient heating. In order to minimise surface oxidation (scaling) and lateral decarbonisation, heating should take place within the shortest possible time period.

Before shaping, the workpieces can be heated by using different heating processes, such as indirect or direct heating. Reheating is necessary when the workpiece is becoming too cold for deforming (due to long forging processes or forging in different steps). Also, some effects in the grain structure can only be achieved in certain defined temperature windows.

Indirect heating

Heating is carried out by convection, heat radiation and heat transmission either in chamber furnaces or in continuous furnaces. The thermal energy is generated by the combustion of natural gas or liquid fuels. Use of electric furnaces is also possible.

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Advantages	Capable of heating large volume workpieces. Low energy costs associated with the use of primary energy. Always applicable irrespective of the geometry of the workpiece.
Disadvantages	Increased scaling and surface decarburisation of the workpiece as a result of relatively long warm periods (due to the chemical reaction of the workpiece surface and the furnace atmosphere).
Applications	Heating of large workpieces. Heating of bulk materials.
<i>Source:</i> [137, Herbertz et al., 2013]	

Direct heating

Direct heating is based on electrical energy and can be carried out by using inductive heating or conductive heating. The heat is produced inside the workpiece.

Inductive heating

During inductive heating, the workpieces are heated using an induction coil/inductor. A high-frequency alternating current circulates through the induction coil which is generating an electromagnetic field. Within the workpiece, this alternating field induces an electrical voltage that leads to the formation of eddy currents. These eddy currents cause heating of the workpiece due to the specific electrical resistance of the material.

Advantages	Short heating time of the workpiece. The start-up time of an induction furnace after a plant shutdown is relatively short. Good reproducibility of the pre-product temperature. Low space requirement for heater units. 'Tailored' heating possible in some cases. High automation potential of feeding processes.
Disadvantages	In order to ensure optimum heating efficiency and thorough heating of the workpiece, the induction coil has to be adapted to the cross-section of the workpieces. In the event of significant change of the workpiece cross-section, a change of the induction coil is generally required. The investment costs for various induction coils of different sizes and the time needed to change the coil are a disadvantage.
Applications	Heating of all common circular and square materials with small to medium cross-sectional dimensions.
<i>Source:</i> [137, Herbertz et al., 2013]	

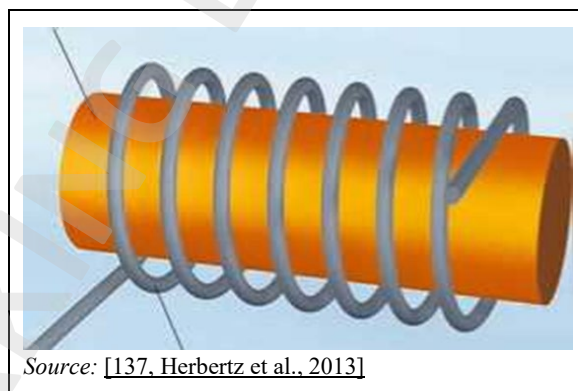


Figure 1.8: Direct heating by induction

Conductive heating

During conductive heating, the prepared raw material forms part of the electrical circuit. Electricity is directly passed through the product and heats the material because of its electrical resistance. Conductive heating is therefore also referred to as resistance heating.

Advantages	Very short heating time. Improved energy efficiency compared to inductive heating. No start-up losses.
Disadvantages	Short workpieces should not be heated conductively due to heat losses on the cooled electrodes. The workpiece length-to-diameter ratio should be higher than 2.5. The transmission of the high current values requires a good surface quality (depth of roughness/surface roughness, rust, scaling, contamination) of the contact surfaces of the workpiece, which could require sawing instead of cutting/shearing the material which again needs more energy and process time. Complex/extensive automation, as the workpiece must always be fixed individually between the electrodes. The necessary cool parts of the workpiece in the contact area lead to excess material or require specific workpiece shapes/geometries. The heating process leads to extreme peaks in the electricity demand. Only applicable up to diameters over approximately 50 mm.
Applications	Heating of long and thin bars. In practice, conductive heating is not often used.
<i>Source:</i> [137, Herbertz et al., 2013]	

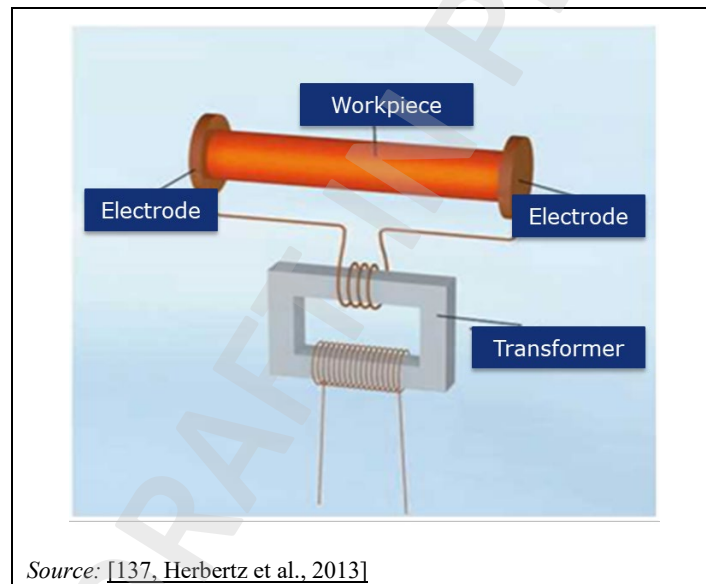


Figure 1.9: Conductive heating by induction

1.2.5.2 Furnaces

[137, Herbertz et al., 2013], [158, IspatGuru 2013]

The selection of furnaces depends on the heating process, such as heating/reheating and/or heat treatment.

The following energy sources are typically used:

- LPG (propane, butane);
- natural gas;
- electricity;
- fuel oil.

In addition to fuel-fired furnaces, electric induction and conduction furnaces are available for heating the workpiece, which ensure a precise process temperature.

Heating/reheating furnaces can be classified according to [158, IspatGuru 2013]:

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- the method of heating;
- the method of charging the furnace;
- the movement of the material in the furnace;
- the heat recovery methods.

As batch type or continuous type, the furnaces are classified depending on the charging method [158, IspatGuru 2013]:

- batch type furnace:
 - batch annealing furnace;
- continuous furnace:
 - pusher furnace;
 - walking beam furnace;
 - rotary hearth furnace;
 - walking hearth furnace;
 - roller hearth furnace.
- chamber furnace;
- bogie hearth furnace/shuttle kiln.

Batch type furnace

For heating and reheating, batch type furnaces are mostly used.

This type of furnace can be used with or without direct firing by using natural gas or electricity. The material is often fed through a single door or a slot into the furnace. [159, McGraw-Hill Dictionary et al. 2003] However, the use of electrical furnaces is limited by the low flexibility and performance of this type of furnace. [148, Euroforge 2021]

Continuous furnace

In continuous furnaces the feedstock is pushed through the furnace by the following stock (pusher furnace) or is moved through by walking beams (walking beam furnace), a rotary hearth (rotary hearth furnace) or on/between rollers (roller hearth furnace). In a walking hearth furnace, the feedstock is moved by a lift and shift mechanism. [169, TWG 2021]

Continuous furnaces are used less as the continuous flow does not support the process flow. They are more commonly used in the heat treatment. [148, Euroforge 2021]

Chamber furnace

This type of furnace is used for open-die and drop forging in single part production or short-run production. [211, M. Greger 2014]

Since 2014, gas heating furnaces have been developed and upgraded in terms of the furnace lining used (e.g. use of specific ceramic mats), new construction of high-pressure burners, installing automatic control systems for the heating process (to keep the heating process precise and efficient). [211, M. Greger 2014]

Furnace systems can largely be integrated into the master computer systems of the automated forging lines, where they are controlled and monitored.

In the case of individual furnace systems, control can also be decentralised to the respective switchgear for setting the heating parameters. [169, TWG 2021], [210, TWG 2022]

More information and descriptions of different furnace types for heat treatment can be found in the foundries chapter of this document, Section 2.2.8.2.

More information, descriptions and details of furnace types used in smitheries can also be found in the FMP BREF.

1.2.6 Hammering

[137, Herbertz et al., 2013]

Generally, forging machines are applied to:

- provide high forging forces and high forging energy;
- accurately manage forging tools against forging forces, the forging momentum and to direct forging tools as precisely as possible to a defined final position.

These requirements entail robust and efficient forging machines, leading to high investment costs.

A further requirement is derived from the high investment costs: forging machines need to have high productivity so that the high investment costs are distributed as much as possible to the components produced.

1.2.6.1 Hammers

Hammers deform the workpiece by the kinetic energy of the forging hammer ram. [160, Altan et al. 2005] The impact strain is used to deform the material. Hammers are classified in single-action (drop forging), double-action and counterblow hammers, depending on the drive of the ram movement. Hammers are very flexible and polyvalent tools, and therefore dedicated mostly to small and medium series production. However, automatic hammers have been developed to produce automotive parts in big series such as connecting rods for automotive and trucks engines. Hammers are particularly suited to the forging of thin components (such as con rods, airfoils) and heavy parts, made of steel, nickel-based alloys or titanium. [214, Farinia 2022]

Different types of forging hammers are available, such as air-driven and hydraulically driven hammers, steam-driven hammers, gravity-drop hammers, power-drop hammers, die forger hammers, counterblow hammers, and computer-controlled hammers. There are three basic designs of high-energy-rate forging (HERF) machines available: the ram and inner frame, two-ram, and controlled energy flow. [160, Altan et al. 2005]

Air- and hydraulically driven hammers

These hammers deliver an impact blow and are used for hot forging. Together, the moving parts, lifting system, falling weight (ram) and upper die are returned to the top of the stroke by a mechanical system composed of a piston in a cylinder. This system adds a downwards force to the effect of gravity, at the moment of impact.

The nature of the process requires rapid mechanical working for the deformation of hot metal.

Every air-operated hammer (power driven) should have a means to cushion, or safely arrest, the motion of the piston at the top of the cylinder. This device may be of the direct-cushion type integral with the main cylinder or it may be of the separate-cushion type whereby a constant supply of air is applied behind a separate piston adjacent to the main cylinder. A spring, suitably constrained, may also be employed.

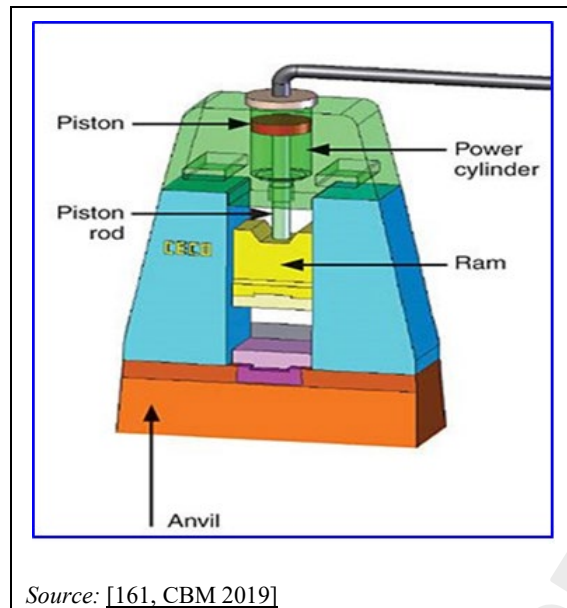


Figure 1.10: Air-driven hammer

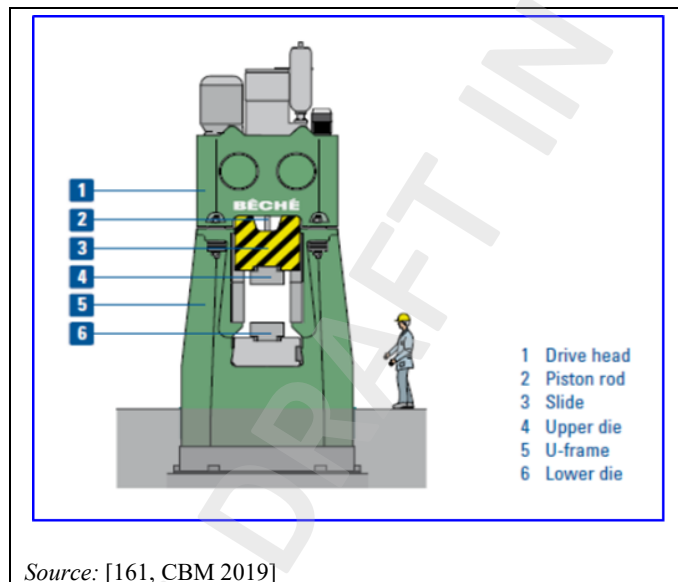


Figure 1.11: Hydraulically driven hammer

Double-action hammer/steam-powered accelerated hammer

The energy of hammers consists of hydraulic or pneumatic top pressure energy and drop energy.

The typical characteristics of hammers are:
 [137, Herbertz et al., 2013]

- relatively low investment cost;
- very short stroke sequencing time;
- very short contact time between forging tool and workpiece;
- high and well-controlled impact energy which, in the case of short forming distances, is converted into extremely high transformation forces;
- in most cases, several blows/strokes (lifts) are required for completion of the formed component;
- high noise emissions, the impact of which needs to be reduced by protective measures.

Counterblow hammer

These machines deliver an impact blow and are used for hot forging. The moving parts are composed of two different subsets of tools that approach each other simultaneously. The links that provide these movements can be mechanical or hydraulic. [161, CBM 2019]

The production of very large and heavy forged metal parts requires a correspondingly large amount of forming energy. Double-acting hammers are not suitable for this task. Instead, counterblow hammers do not have scrapheads, but two hammer heads (lower and upper hammer head) that move towards each other. As an advantage, the vibrations of the machinery system are reduced and the hard blows are no longer transferred to the base and from there to the ground. [137, Herberitz et al., 2013]

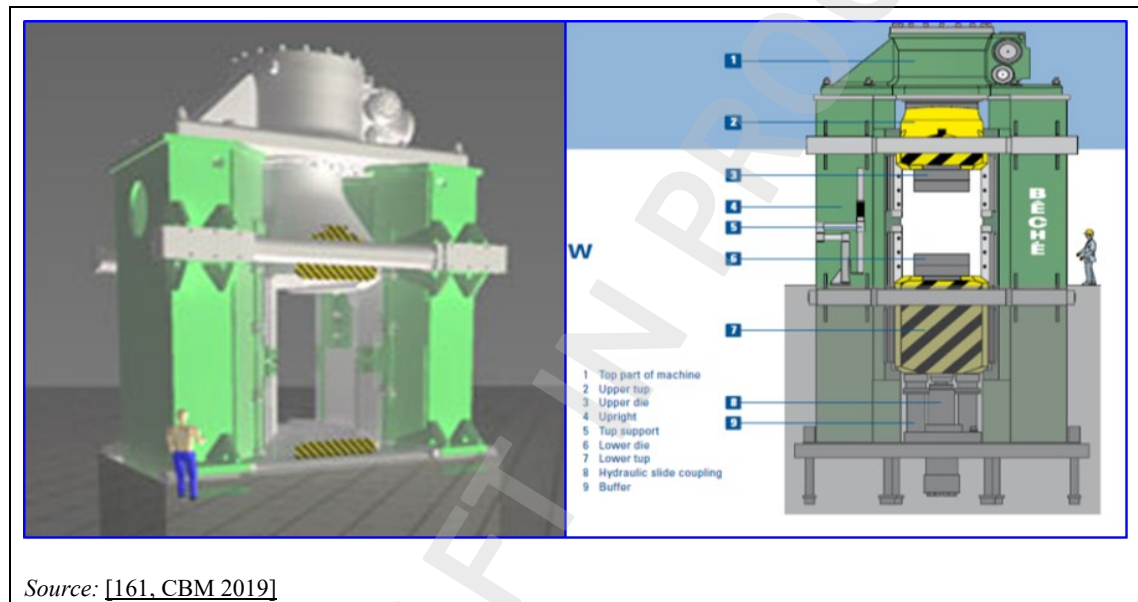


Figure 1.12: Counterblow hammer

As reported in the questionnaire of the SF data collection, the following types of hammers are used in the EU-27:

- freefall hammer;
- counterblow hammer; (hot-air-driven counterblow hammers in band and hydraulically coupled design, such as belt clutched counterblow hammer and hydraulic clutched counterblow hammer (DE006).
- steam hammer;
- double-acting hammer

1.2.6.2 Open-die forging and closed-die forging

The open-die forging process is also known as free forging. The piece of metal is deformed between multiple dies that do not enclose the metal entirely. The dies hammer or stamp the metal through a series of movements to alter its dimensions until the desired shape is achieved.

The closed-die forging process is also referred to as impression forging. During this process, a piece of metal is compressed under high pressure to fill an enclosed-die impression. For some special shapes, a second forging operation is required to achieve final shapes and dimensions. [157, Grillo 2017]

The techniques of open-die forging and closed-die forging are different, as shown in Figure 1.13. In general, for closed-die forging, first the moulding dies are made. The metal bars are then placed into the dies and forged to the desired shapes.

The closed-die forging technique utilises very little or no machining throughout the process. Also, net shape end products can be achieved.

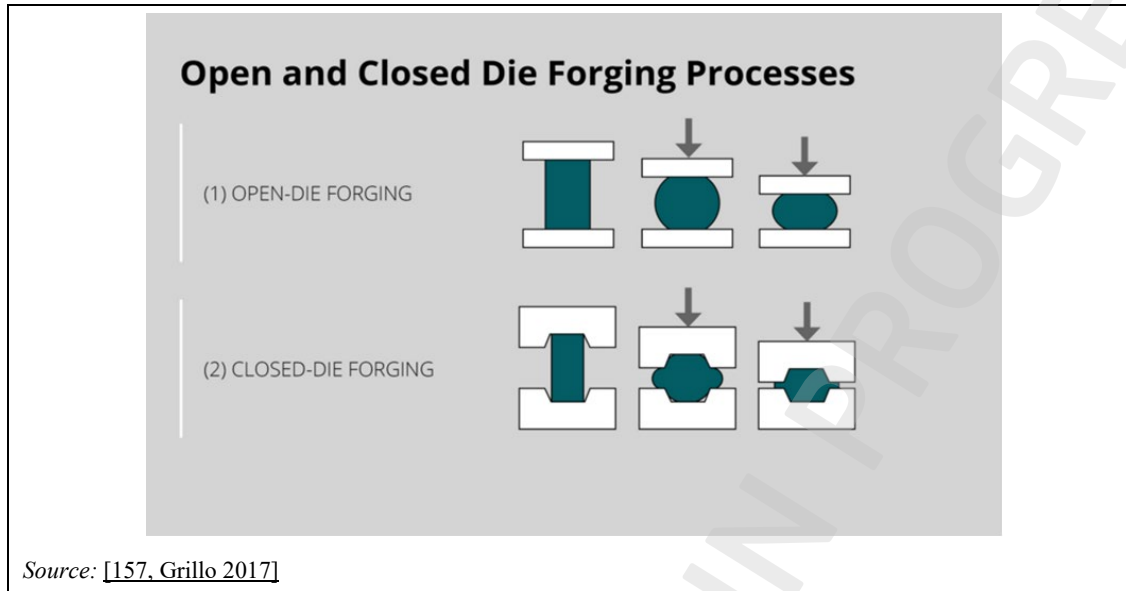


Figure 1.13: Open-die and closed-die forging

For open-die forging, very high compressive forces are imposed by the continuous strike of a forging hammer or repeated press operations to deform the metal billets or ingots.

The forged components obtained by open-die and closed-die forging have different end uses.

A rough precision machining is further required after the open-die forging process as imprecise dimensions are achieved by hammering. The open-die forging is more suitable for large parts of up to several tonnes, but the weight of the workpieces can start at 10–15 kg. Generally, the products in this category of forging include forged long shafts, forged rollers, forged cylinders, forged bars, discs, punched discs, hubs, blocks, plates (forged three-dimensionally), forged tubes, cylinders and other hollow forgings, forge rings, seamless rolled rings and flame-cut forgings. They are utilised in several sectors, e.g. rail, aircraft, ship building, windpower, power generation and heavy machinery. [151, Dirostahl DE 2020], [137, Hertz et al., 2013]

Closed-die forging can go up to a workpiece weight of 1 – 1.5 t.

The batch size of the production is important for choosing the forging method. For a production batch of one to five workpieces it is not worth preparing a die in closed-die forging. [148, Euroforge 2021]

However, for small parts, closed-die forging is preferred as higher precision is obtained in the process. It is often used to produce forged fittings, forged flanges, forged automotive parts, etc. Oilfield, automotive and mining are some of the industries that rely on closed-die forged parts. [157, Grillo 2017] However, mining and oilfield are also typical sectors for open-die forged parts. [148, Euroforge 2021]

1.2.7 Post-treatment

After the forging process, several additional treatment and machining processes are carried out. These treatment processes are important to achieve a certain product quality.

1.2.7.1 Heat treatment

The material condition of the workpieces after forging does not generally meet all the requirements for their intended use. It is therefore necessary to modify the state of the material in such a way that, for example, hardness, strength, toughness or wear resistance are optimally adapted to the different conditions of the particular application. This is done by heat treatment, a time- and temperature-controlled process aimed at achieving certain material properties. [137, Herbertz et al., 2013]

A heat treatment is essential to improve the physical properties of the products. Precisely controlled heat treatment achieves the physical properties that are required by the customer or prescribed by the standard. Modern measuring and control instruments determine or control and optimise the material-appropriate thermal treatments, such as normalising, tempering or soft annealing, in order the product to achieve the physical properties (hardness, high strength) that are required. [150, Stooss AG DE 2020]

The component is then cleaned by surface treatment. The quality check of the workpiece is usually carried out after cleaning, but is also occasionally carried out between the process steps.

Regarding surface treatment processes, further information can be found in the Reference Document on Best Available Techniques for the Surface Treatment of Metals and Plastics (STM BREF).

Achieving certain material properties can be done both by adapting to the functional characteristics of the component, such as tensile strength and toughness, and by preparing for a subsequent handling process/process chain, such as cold forging or machining. The process of heat treatment may be integrated into the production process or separated in time and space from the transformation process. [137, Herbertz et al., 2013]

The following heat treatment processes act over the entire cross-section of the workpiece:

- normalising (annealing);
- hardening and tempering/heat treatment;
- controlled/monitored cooling after hot forging;
- ferritic-pearlitic annealing/isothermal annealing;
- soft annealing;
- stress-relief annealing;
- recrystallisation annealing;
- solution annealing.

The following processes have an effect on the properties of the component surfaces:

- surface hardening;
- case/pack hardening;
- plasma-nitriding.

The heat treatment processes are essentially defined by the following parameters:

- temperature of heat treatment;
- heating and holding time;

- furnace atmosphere;
- cooling.

The temperature used depends on the material and the heat treatment result that is required. For example, for steel with 0.8 wt-% carbon, a typical heat treatment temperature is 723 °C. If the temperature is higher, the structural material undergoes a transformative phase that can only be selectively modified through an appropriate cooling process. If the temperature is lower, the heat treatment continues or the relaxation process begins to mitigate the brittleness resulting from the hardening process. Depending on the temperature and the material, different tensile strength values of the workpieces may be achieved.

The heating time has to be calculated in a way that the increase in temperature occurs as constantly/consistently as possible throughout the entire workpiece. This avoids or reduces the deformation/warping of the workpiece.

The holding time should be chosen at a specified temperature range, so that the desired structural changes occur or the elemental carbon (for case/pack hardening) or nitrogen (for nitrogen hardening) can diffuse into the material.

By selecting appropriate furnace conditions, discoloration and scaling on the surface of the workpiece during heat treatment can be avoided. In this case, the oxygen which is responsible for discoloration and scaling of the product is replaced by inert cover gases or a vacuum is created.

By quenching or cooling, a change in the structural conditions of the material to a new hard structure (martensite/bainite) is achieved.

Normalising

The objective is the production of a fine-grained, uniform texture. By normalising, the microstructure produced is of the best combination of strength and toughness properties, at least in the case of non-alloyed steels. It refers to a normal structure of a steel. The normal structure is produced by this heat treatment in a targeted and reproducible manner.

Hardening and tempering

For a particular application, a specific combination of strength and toughness should be achieved. This process is a two-stage heat treatment process consisting of both hardening and subsequent curing/tempering. A high hardness/tensile strength and low toughness of the product is achieved by hardening. When tempering after the forging heat stage, hardening is carried out by quenching. The elimination of a separate hardening process step offers cost advantages and energy savings.

Controlled/monitored cooling from hot forging

The required strength and toughness should be achieved.

The forged workpieces are cooled down in a controlled manner with a required temperature-time sequence/schedule.

The workpieces are cooled, either by air or water cooling. In order to reduce the internal stress of the forged workpiece when using air cooling, the following methods are used: piles in open air, metal boxes or pits, insulating fillings, furnaces. [211, M. Greger 2014]

Several types of cooling systems might be used, such as direct once-through cooling system, once-through cooling system with cooling tower or indirect once-through cooling [213, COM 2001] as well as closed cooling system (closed recirculating system/dry cooling tower).

By application of a direct once-through cooling system, a certain high amount of water from a source (e.g. a river, lake, sea or estuary) is used. The heat of the workpiece is transferred to the coolant (water) and is directly discharged back to the surface water. Indirect once-through cooling

systems are similar to direct ones with the difference that there is no direct transfer from the process fluid/vapour to the coolant that is discharged. [213, COM 2001]

The main aspects for the selection of the cooling system are:

- minimisation of energy use;
- minimisation of heat emissions;
- minimisation of emissions to water;
- minimisation of noise emissions. [213, COM 2001]

More information on the cooling systems mentioned above can be found in the Reference Document on the application of Best Available Techniques to Industrial Cooling Systems (the ICS BREF). For once-through cooling systems, see Section 2.3; for closed circuit cooling systems, see Section 2.5 of the ICS BREF. [213, COM 2001]

Quenching

Quenching is a process of rapidly cooling forged workpieces. In ferrous alloys (such as alloy steel, carbon steel and some stainless steels), this will often produce a harder metal by transforming the austenite to martensite, while non-ferrous alloys (brass, aluminum, some stainless steels, and superalloys etc.) will usually become softer than normal. [215, CFS Forge 2017]

Different media can be used for quenching, i.e. water, oil or compressed air, which may vary in terms of environmental impact, cost and effects on the metal workpiece.

Ferritic-pearlitic annealing/isothermal annealing

The purpose is the generation of a uniform structure of the product with good grindability/machinability. Ferritic-pearlitic annealing/isothermal annealing means treatment on a ferrite-perlite texture/structure. After heating at the temperature range of the normal annealing temperature, rapid cooling to the isothermal annealing temperature is carried out.

Soft annealing

The purpose is to ensure that the steel is as soft as possible. A soft steel facilitates the machining/metal cutting/chip removal process or the subsequent cold forming of the material.

Stress-relief annealing

Minimising the internal component stress factor without affecting the essential mechanical properties is the purpose of this type of annealing. Internal stresses/tensions may arise as a result of the cold forging process or irregular/non-uniform cooling after the hot forging process or after the heat treatment process.

Recrystallisation annealing

The solidification/hardening of the material caused by the cold forging should be reversed.

The annealing temperature largely depends on the initial structure of the material and the deformation degree during cold forging and it generally ranges from 600 °C to 700 °C. Heating takes place relatively quickly and cooling is usually carried out by stationary/still air.

Solution annealing

This process is carried out in order to obtain uniform and homogeneous structural and material properties. Annealing is carried out at a temperature range of 950 °C to 1 200 °C. Cooling is carried out by quenching in water or, in the case of thin material cross sections, by rapid air cooling.

Surface hardening

Surface hardening aims to the hardening the surface of the metal object while allowing the metal underneath to remain soft, thus forming a thin layer of harder metal at the surface.

The near-surface coating is heated to hardening temperature by means of a space-limited heat input and subsequently quenched.

Case/pack hardening

The aim is to harden the surface without reducing the ductility/toughness of the workpiece core. Case/pack hardening is one of the thermochemical processes. As part of this process, the edge layer of components and tools is carburised with a carbon-emitting medium and subsequently quenched.

Plasma-nitriding

Besides hardening of the surface, the improvement of friction properties and sliding properties and the creation of corrosion-resistant coatings are also important. Plasma-nitriding is one of the thermochemical heat treatment processes carried out at temperatures between 350 °C and 600 °C. An increase in hardness is achieved by the formation of very hard nitrogen compounds in the edge layer of the workpiece. [170, REESE 2020]

The process takes place in a gas mixture of nitrogen and hydrogen. If necessary, a carbon-donating gas can also be used. The necessary temperature is relatively low. In addition, voltage is created between the wall of the furnace and its chamber. This leads directly to the creation of an ionised atmosphere in the furnace chamber, the so-called plasma. There, the ions hit the surface of the component and generate nitrogen-rich nitrides. As soon as these disintegrate, the surface of the material is enriched with atomic nitrogen. Depending on the composition of the gas mixture, different surfaces and degrees of hardness can be created.

[137, Herbertz et al., 2013]

1.2.7.2 Mechanical processing

Mechanical processing methods are characterised by:

- very high accuracy; and
- very good surface quality of the machining surfaces.

A combination of solid-forging processes and mechanical treatment processes enables the specific advantages of both processes to be used in order to economically produce a ready-to-use component with almost any type of geometry and the highest possible quality. Forged products are usually turned into ready-to-use components by subsequent metal-cutting machining.



Source: [137, Herbertz et al., 2013]

Figure 1.14: Forging before (left) and after mechanical processing (right)

Usually, the main part of the component remains unprocessed; only a few functional surfaces, such as the reference/locating points at bearing positions and the fixing points, are processed by subsequent metal-cutting treatment.

For mechanical treatment, the treatment processes, cutting materials and cutting parameters which are selected depend on:

- the raw material workpiece;
- its composition and heat treatment condition;
- the volume and required quality of the surfaces treated.

Standard treatment methods are applied, such as turning, drilling and milling as well as special processes/technologies. [137, Herbertz et al., 2013]

1.2.7.2.1 Scale removal

During the heating process, high temperatures of up to 1 300 °C cause surface oxidation of the workpiece. It also depends on the duration of the heating process. The resulting scale layer would result in surface defects in the forged workpiece and increased tool wear. Descaling/scale removal is used in the hot or warm forging process of steel materials.

The purpose is the removal of the loosely adhering layer of the scale from the surface of the heated workpiece. Scale removal can be carried out by shaping/forming, e.g. upsetting or other compression processes, by pressurised water or brushes.

[137, Herbertz et al., 2013]

Scale removal (descaling) by upsetting (compression)

As a result of upsetting (compression), the workpiece is slightly transformed, thus paving the brittle/refractory layer of scale/oxide layer as shown in the following figure.

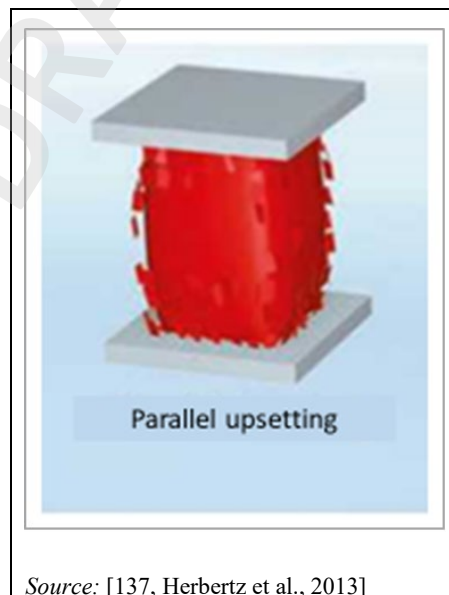


Figure 1.15: Descaling by upsetting

Chapter 1

Advantages	By carrying out a slight forming, scale removal is already possible. At the same time, upsetting can also be used for mass pre-distribution.
Disadvantages	Scale removal is not always fully achieved on the entire workpiece surface.
Applications	Forging processes in which no forging rolls or other pre-forging operations are carried out upstream of the process.
<i>Source:</i> [137, Herbertz et al., 2013]	

Scale removal using pressurised water

When scale removal is carried out with pressurised water, water at a pressure of up to 500 Bars is sprayed on the hot workpiece. The evaporating water, the thermal superficial shrinkage and the mechanical energy of the water jet remove the loosely attached oxide layer. [137, Herbertz et al., 2013]

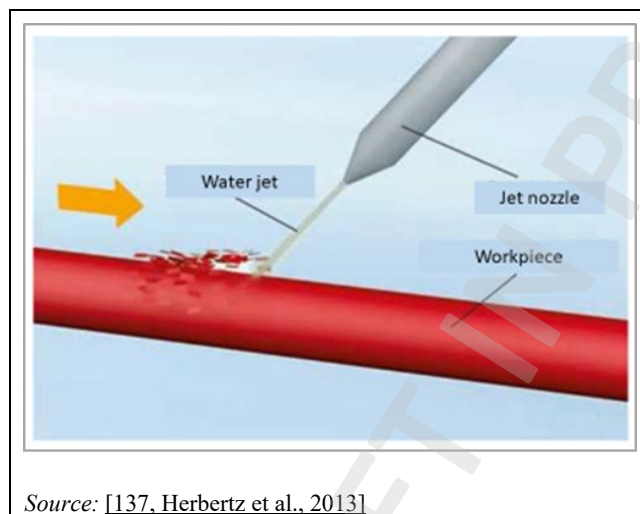


Figure 1.16: Scale removal using pressurised water

Advantages	Scale removal can be well integrated into the process chain.
Disadvantages	In the case of small cross-sections, the workpiece can cool down too much. Applicable only to larger workpieces that can remain stable. The bearing area of the product is only partially descaled.
Applications	Pressurised water scaling is mainly used for workpieces with a high charge weight.
<i>Source:</i> [137, Herbertz et al., 2013]	

Scale removal using brushes

When scale removal is carried out using brushes, the loose adhering scaling/oxide layer and other impurities on the surface are mechanically removed by rotating steel wire brushes (see figure below). [137, Herbertz et al., 2013]

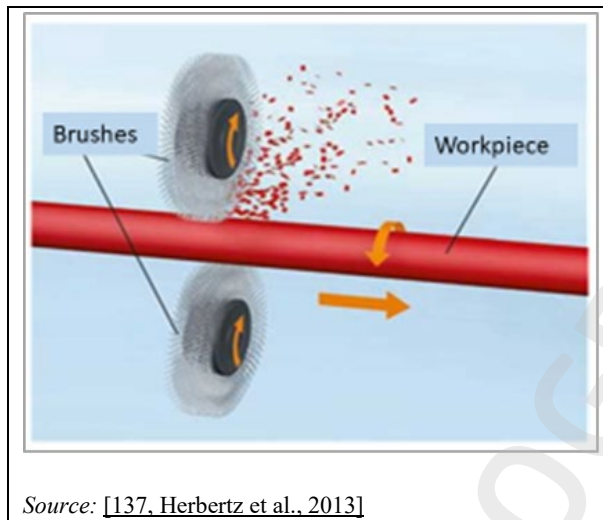


Figure 1.17: Scale removal using brushes

Advantages	Scale removal can be carried out automatically with a continuous process.
Disadvantages	Wear of the brushes which have to be adjusted or replaced depending on the degree of wear.
Applications	Due to the severe wear of the steel wires, the brushes are preferably partially used for the conductive heating process in order to clean the ends of the material sections and to remove slight burrs. In order to avoid current peaks at the electrodes of the conductive unit/system, it is necessary to keep the contact surface clean and free from burrs. In practice, it is not often used. [148, Euroforge 2021]
<i>Source:</i> [137, Herbertz et al., 2013]	

1.2.7.2.2 Blasting

Blasting is primarily used to clean the surface of the component, but can also be used to increase the durability of the components.

The workpieces are treated by descaling using balls or cut wire/wire pellets/shots. As a result of the surface solidification associated with descaling and the internal/residual compressive stress of the workpiece, the dynamic resistance of descaling can be increased. The main descaling technique applied is the shot blasting wheel.

During the process of airless blast cleaning, the abrasive is accelerated by a high-speed shot blasting wheel and is blasted at high speed to the surface of the component. The kinetic energy of the steel particles removes the scale or oxide layer and, given that correspondingly high energy is available, it causes local plastic deformation of the workpiece surface. The rotating cylinder of the shot blasting unit ensures continuous movement of the workpieces within the cylinder so that all workpieces and the entire surface of the workpieces are covered by the blasting cone.

The blasting/abrasive material is selected depending on the surface quality requirements. The metallic blasting agent usually used is available in an angular shape or spherical shape, in a variety of particle sizes and in different degrees of hardness.

[137, Herbertz et al., 2013]

1.2.7.2.3 Deburring and punching

In the case of deburring, the external burrs of the forging are removed. During the punching process, the inner flash (mirror area) is removed. A distinction is made between the cold deburring process and the hot deburring process.

Multi-purpose tools and machinery, e.g. progression tool, are commonly used in order to combine both deburring and punching/piercing processes. [137, Herbertz et al., 2013]

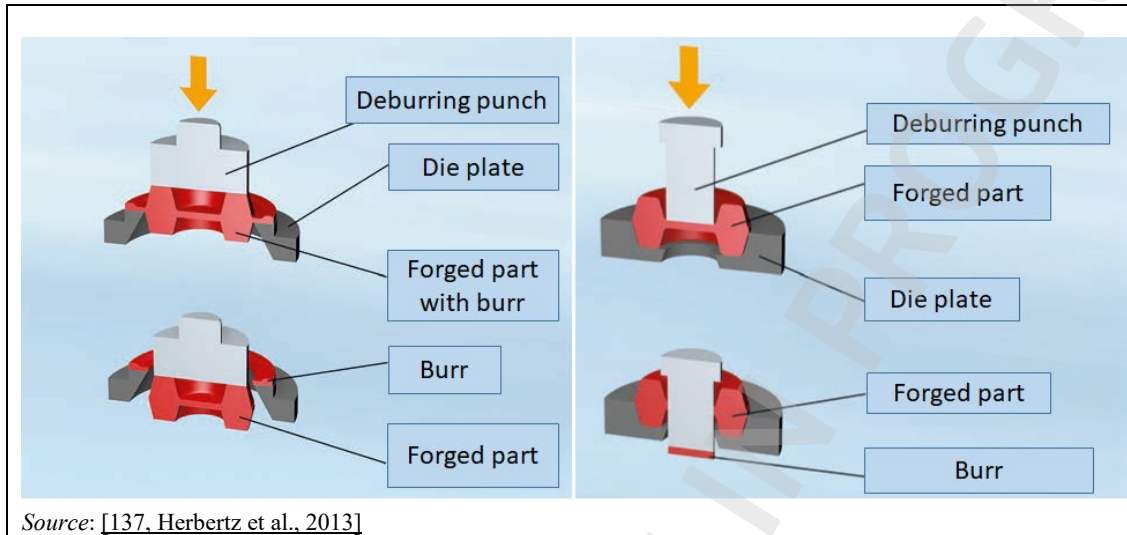


Figure 1.18: Deburring and punching

Hot and cold deburring process

Hot deburring	Advantages	The hot deburring process is integrated into the production line. The cutting forces are low due to the high temperature.
	Disadvantages	Spread component temperatures cause dimensional variations in component geometry and may have a negative impact on the quality of the deburring and hole cuts. Integration into the production line increases the investment of setting (set-up) efforts and correction efforts during hot operation.
Cold deburring	Advantages	The decoupling of the cold deburring process from the working step within the forging line allows a higher volume output of deburring.
	Disadvantages	The decoupled operation requires intermediate buffering and therefore multiple handling of the components.
Hot and cold deburring	Applications	Forging parts with all types of burrs and punch mirrors.
Source: [137, Herbertz et al., 2013]		

1.2.7.3 Finishing

A coating may be necessary for process reasons or for prevention of corrosion of the workpieces. However, coating can also be carried out for surface finishing reasons. The coating application is mainly carried out by dipping or spray coating. The selection of the coating material depends on the purpose of the coating. [137, Herbertz et al., 2013]

1.3 Current emission and consumption levels in smitheries

Emissions to air, noise emissions and vibrations arise during the smitheries process. Furthermore, residues/process losses/waste generation and, in rare cases, emissions to water also occur.

Figure 1.19 and Figure 1.20 show process flow sheets and possible emission points and types of emissions as well as the use of energy (adapted from information/flow-sheets provided by plants DE004 and DE006). Energy (electrical and/or heat) is consumed within all steps of the process. Furthermore, the input and output flow is shown in Figure 1.21 (adapted from information/flow-sheets provided by plant DE006).

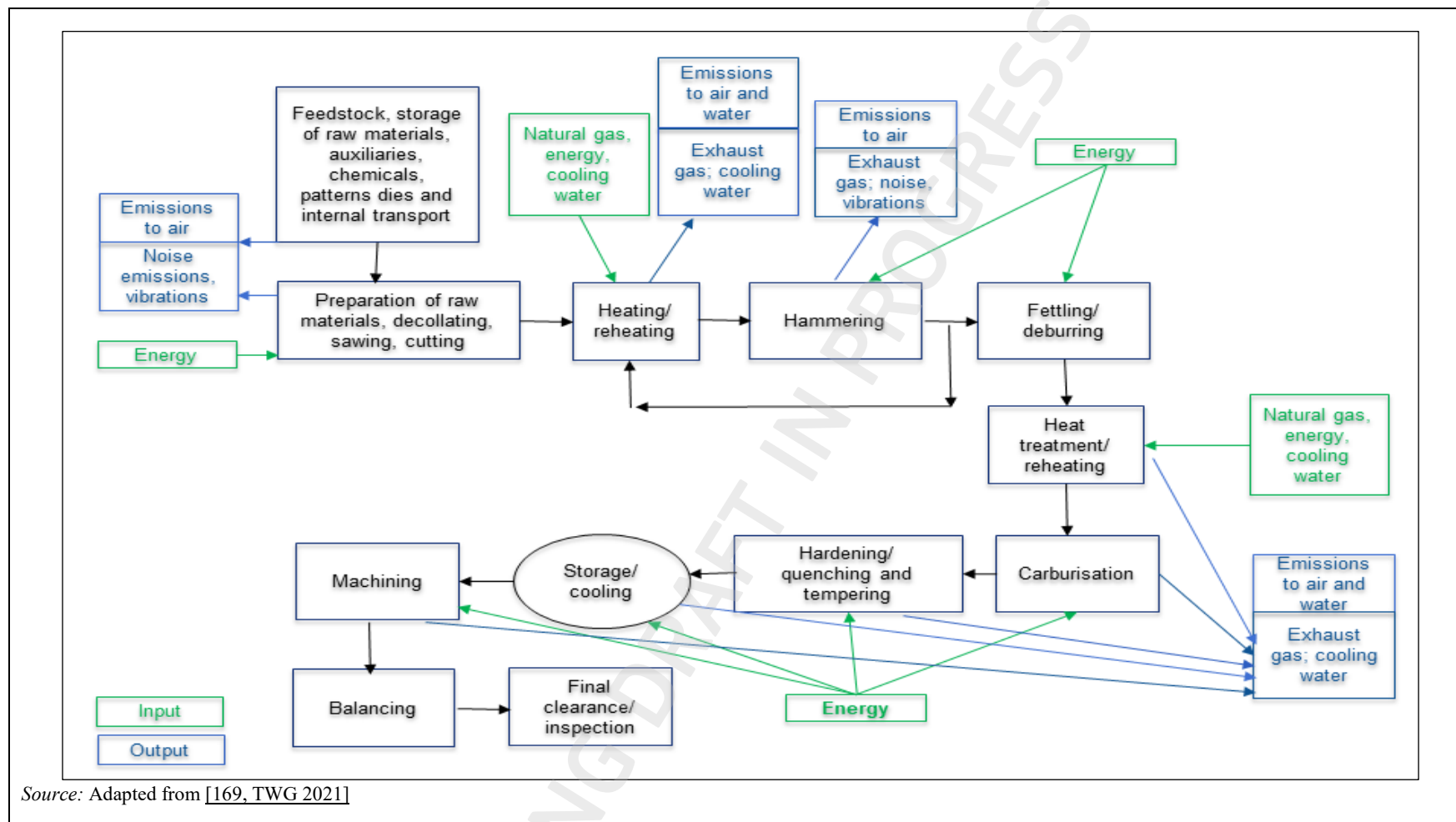


Figure 1.19: Example of a simplified flow diagram of a smitheries process along with emissions which may arise and the use of energy at process level

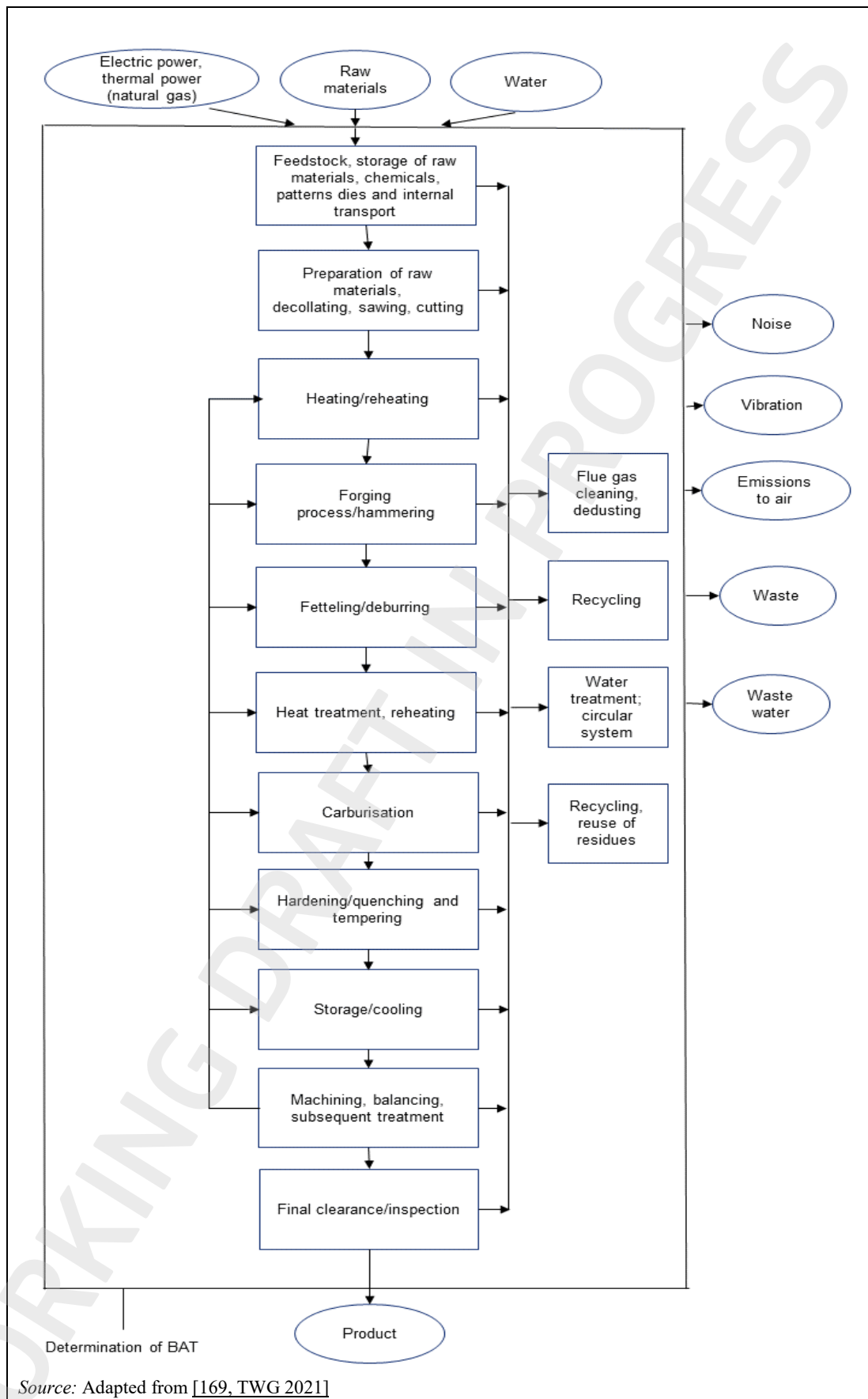


Figure 1.20: Smitheries process flow chart including possible types of emissions

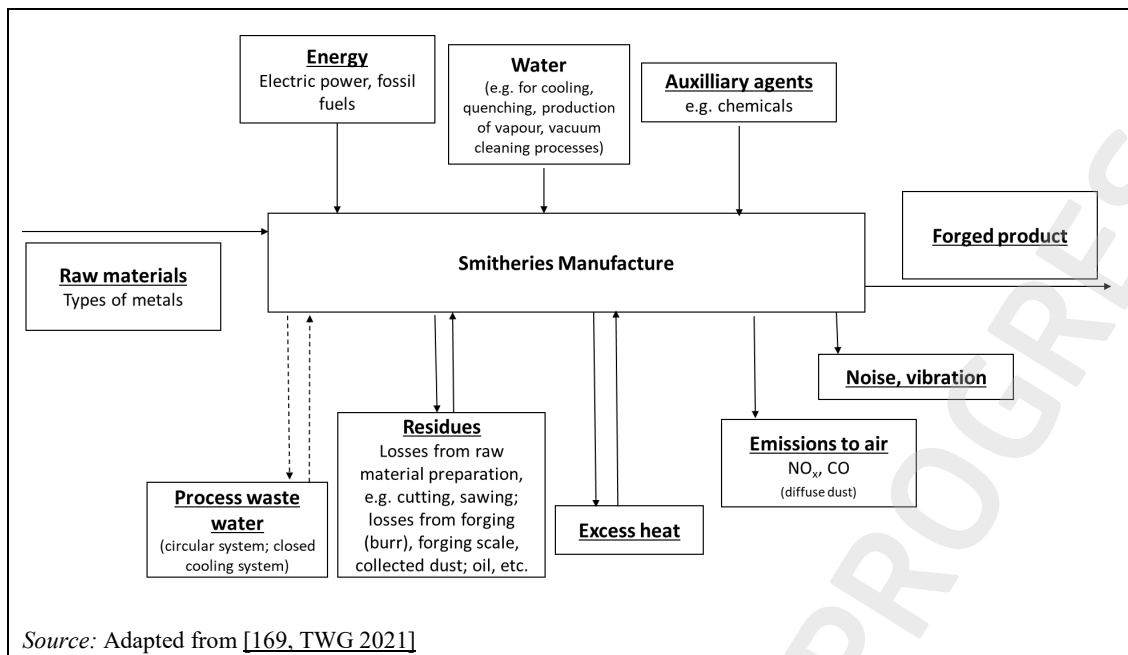


Figure 1.21: Smitheries input and output flow

1.3.1 Water consumption

Water is used in different stages of the production process as well as for cleaning procedures, e.g.:

- for cooling and quenching;
- as auxiliary water, e.g. for the production of vapour and vacuum and the production of steam;
- for cleaning processes.

As reported by Plants DE001, DE002, DE005, DE007, ES008 and PL009, closed cooling circuits/systems are applied in order to minimise water consumption. [169, TWG 2021]

As decided at the KoM, water consumption is not a key environmental issue (KEI) in smitheries.

1.3.2 Material consumption – material efficiency

[137, Herbertz et al., 2013]

All metals and metal alloys are suitable for solid forging (see Section 1.2.2). A large group of structural steels are used.

The raw material is mainly delivered as circular or square bar material. The length of the bars is up to 12 m. For small-diameter circular sections, the workpiece can be wrapped on coils as continuous material.

The development of the steel material for forging components is ongoing. Improved property profiles will be developed through new alloys and process routes, leading to lower costs or improved performance for specific applications. Both the well-known steel groups, such as heat-treated steels or precipitation-hardening ferritic-pearlitic steels, will be further optimised and new steel groups, such as the bainitic steels, will be developed.

The use of a computer-aided design (CAD) system can optimise the amount of raw materials used. Among other things, the simulation of the forging processes reduces forging tests and the forging geometry can be optimised, which may lead to efficient use of raw materials. [210, TWG

2022] Errors and mistakes during the design process for products may lead to residues/waste material at a later process stage. By using CAD, a minimisation of errors could be achieved down to zero, which also increases material efficiency, e.g. the use of a reduced amount of raw materials and/or the reduction of residues/waste material.

1.3.3 Energy consumption – energy efficiency

The smitheries industry is a high-energy-consuming industry, depending on the process used. Fuels and electricity are the two main types of energy used in smitheries manufacture. Energy efficiency (both thermal and electrical) has always been a priority for the European smitheries industry as part of the overall business decisions which are driven by economic and technological needs.

Smitheries require electrical and thermal energy for virtually every step of the process, e.g. raw material preparation, heating/reheating, heat treatment, hammering, mechanical processing and finishing. Electricity is needed for process control of the installation, for heating, the driving power for machinery including forging and (induction) heating equipment as well as for lighting. Also, machining following the forging process uses electrical energy. [148, Euroforge 2021]

Electricity is usually generated and supplied by utility companies. When steam and electricity are generated on site, the efficiency factor can be considerably higher. Fuel-based energy is needed for heating processing lines/forging furnaces and buildings. [168, COM 2022]

The energy consumption of the furnaces depends on several parameters such as:

- the furnace type (pusher-type, bogie hearth, chamber-type, walking beam, etc.);
- throughput and shift patterns (operating time);
- the burner design;
- the use of regenerative or recuperative burners;
- the production capacity of the furnace;
- the heating zone arrangement;
- the charging temperature of the stock;
- the heating and discharging temperature;
- the accuracy of the thermal regulation;
- the degree of insulation of the furnace;
- the O₂ content in the furnace atmosphere;
- the size of product. [168, COM 2022]

In hot forging, almost 33 % of the total energy input is used for the heating process, 11 % for the forging process, 26 % for heat treatment, 1 % for toolmaking, 2 % for mechanical processing as well as 27 % on other installation areas and processes, e.g. heating of production halls. [146, Ade 2017]

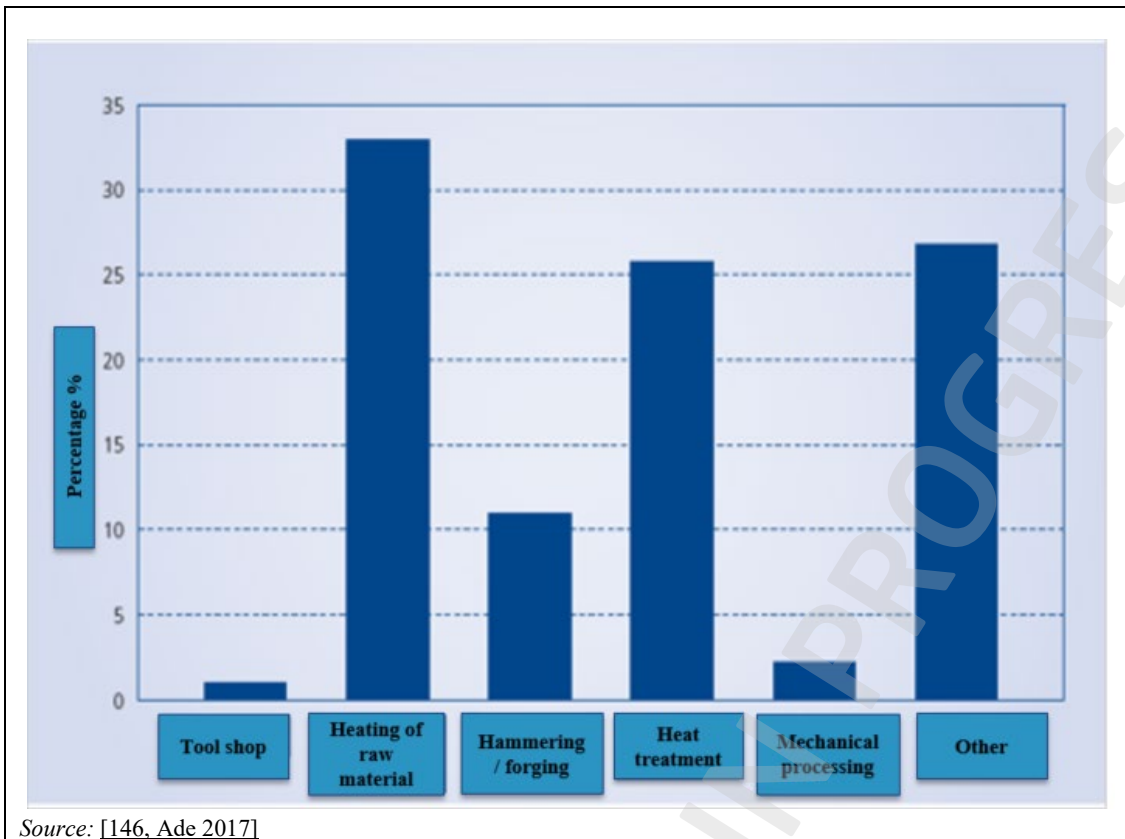


Figure 1.22: Percentage of energy consumption for process steps in hot forging

The use of energy varies considerably with regard to the heating energy and the need for post-processing also have to be taken into account when considering the total energy requirement.

The main users of electricity are the heating furnaces used to heat and reheat the workpieces by inductive or conductive heating.

To heat a tonne of steel to the forging temperature of 1 200 °C using electrical inductive heating, electrical energy consumption of 400 kWh to 500 kWh is required. Compared to this, gas fired furnaces require between 1 200 kWh/t and 2 500 kWh/t to provide the same forging temperature. [146, Ade 2017]

For hot forging, energy consumption of 900 kWh to 4 500 kWh per tonne of finished product is needed, depending on the component produced.

Figure 1.23 compares the energy consumption of smitheries with other production processes.

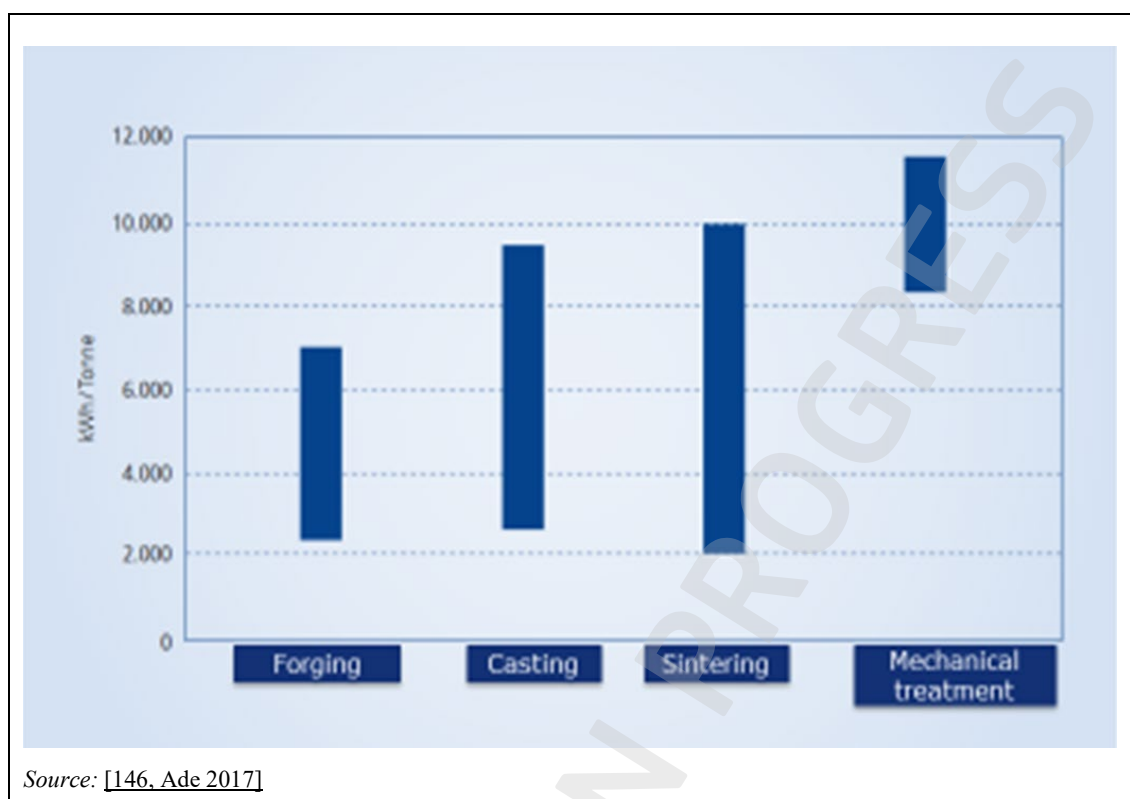


Figure 1.23: Energy consumption of different processes in kWh/tonne

Specific energy consumption data were reported for the years 2017, 2018 and 2019. [169, TWG 2021]

Handling of Confidential Business Information (CBI)

Energy consumption data were considered CBI by the plant operators. In order to maintain data confidentiality, plant names are not directly mentioned in the graphs describing energy consumption but are replaced with anonymised and randomly attributed CBI codes. In addition, no contextual information (e.g. process parameters or techniques applied) is included as this could reveal the identity of the plants. All the consumption figures are presented in ascending order of the maximum specific energy consumption values.

1.3.3.1 Specific energy consumption at plant level

The reported levels for specific net energy consumption at plant level are presented in Figure 1.24.

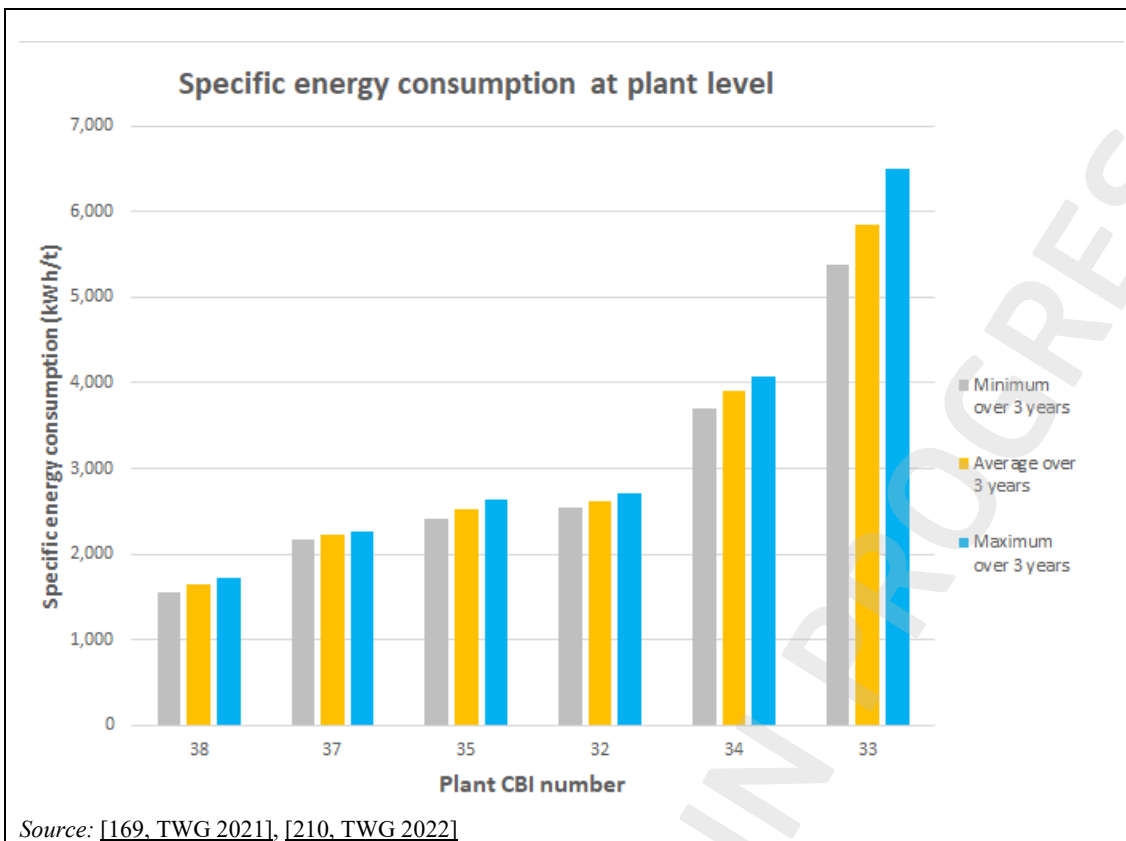


Figure 1.24: Specific net energy consumption at plant level (in kWh/t of input material) by plant CBI number

The reported specific electricity consumption at plant level are presented in Figure 1.25.

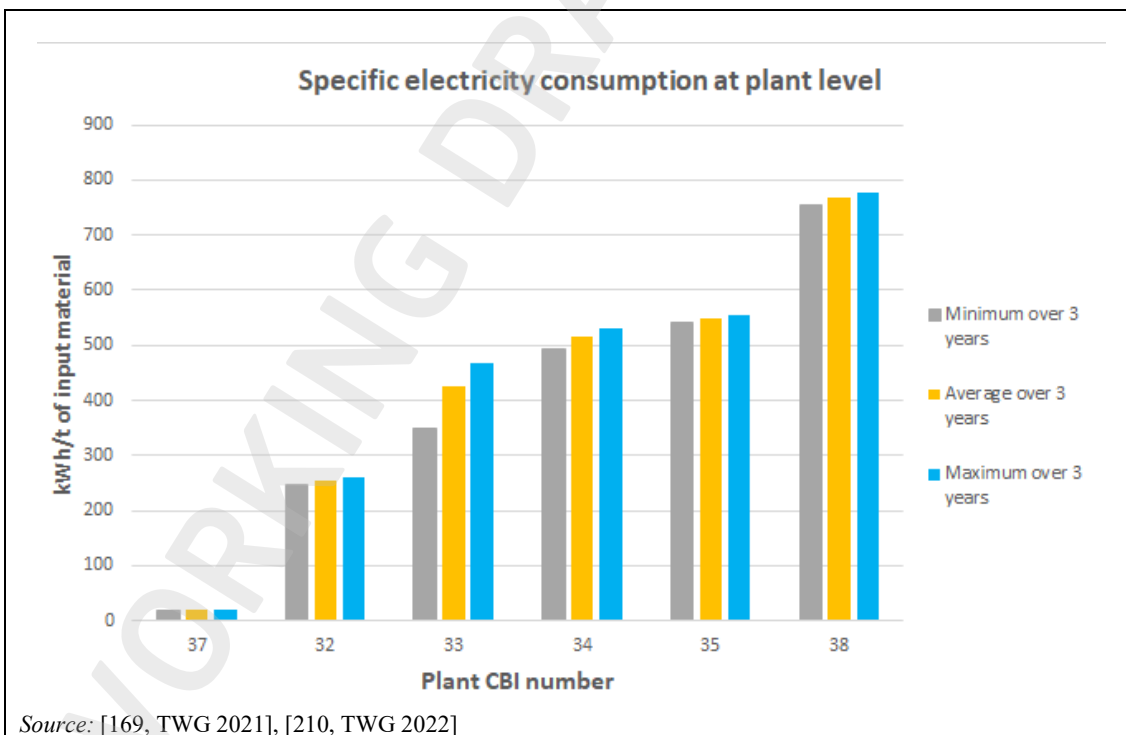


Figure 1.25: Specific electricity consumption at plant level (in kWh/t of input material)

1.3.3.2 Specific energy consumption at process level

Hammering

The reported specific net energy consumption for hammering are presented in Figure 1.26.

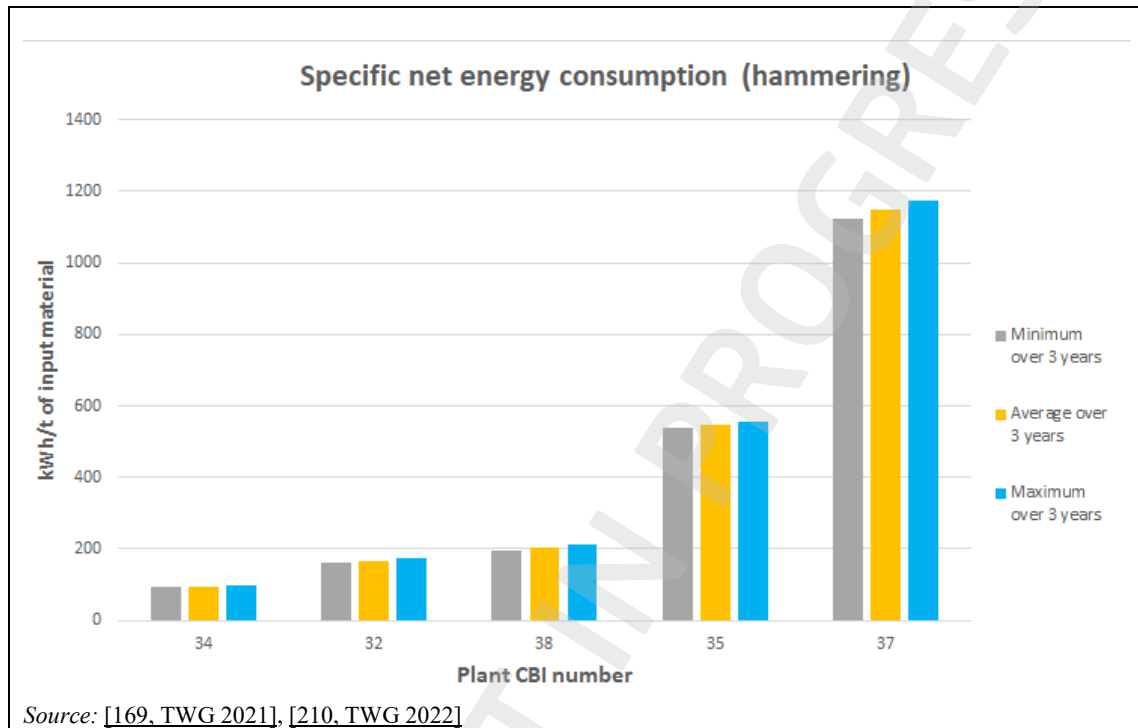


Figure 1.26: Specific net energy consumption for hammering (in kWh/t of input material)

The reported specific electricity consumption for hammering are presented in Figure 1.27.

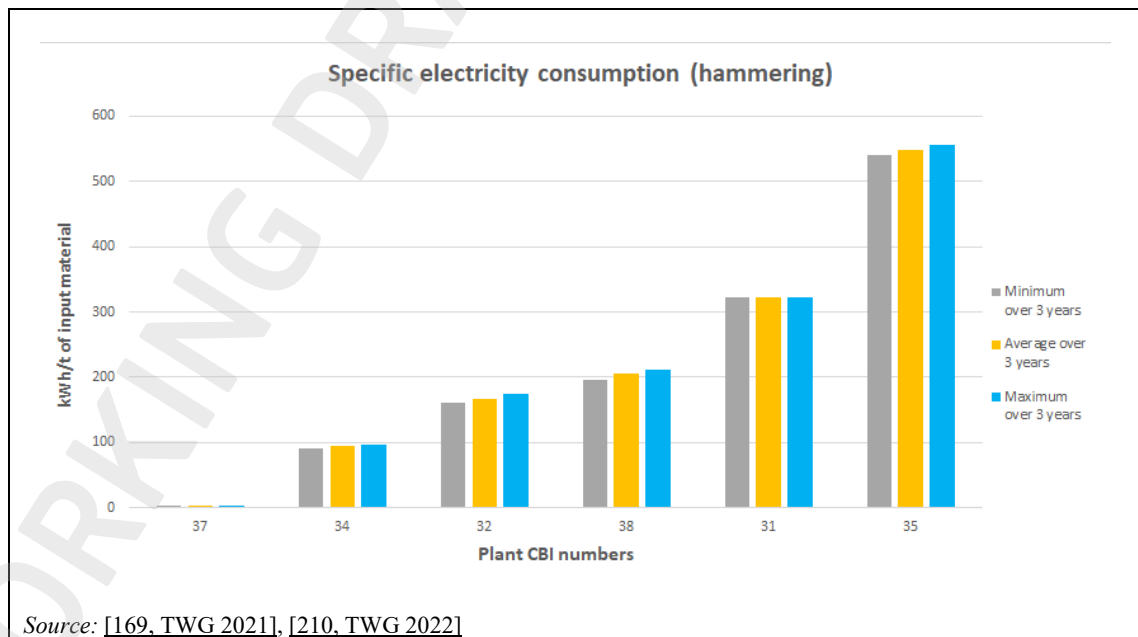


Figure 1.27: Specific electricity consumption for hammering (in kWh/t of input material)

Heating/reheating

The reported specific net energy consumption for heating/reheating are presented in Figure 1.28.

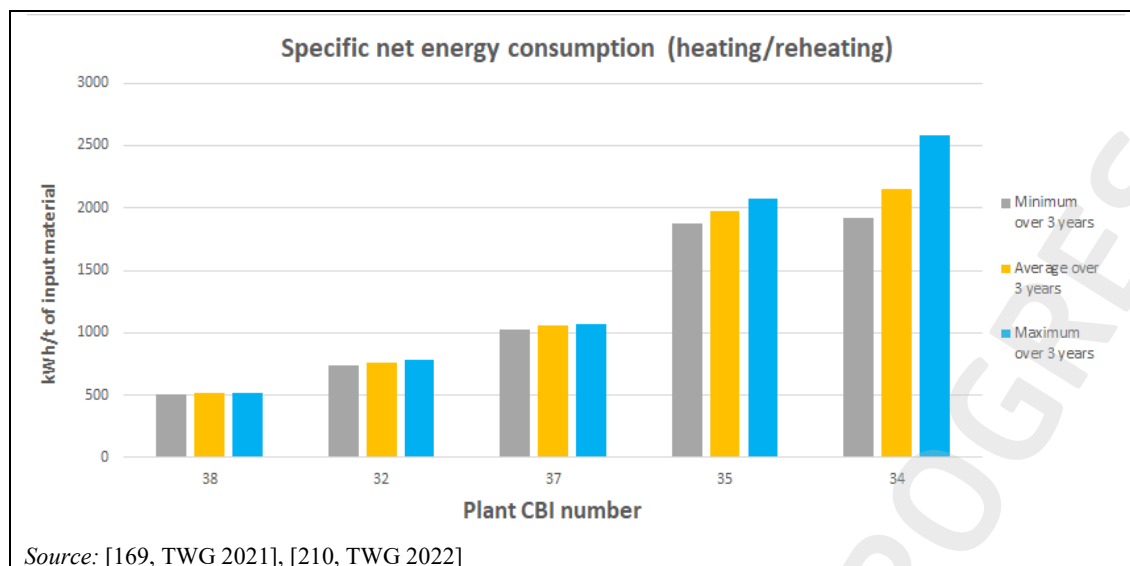


Figure 1.28: Specific net energy consumption for heating/reheating (in kWh/t of input material)

The reported specific electricity consumption for heating/reheating are presented in Figure 1.29.

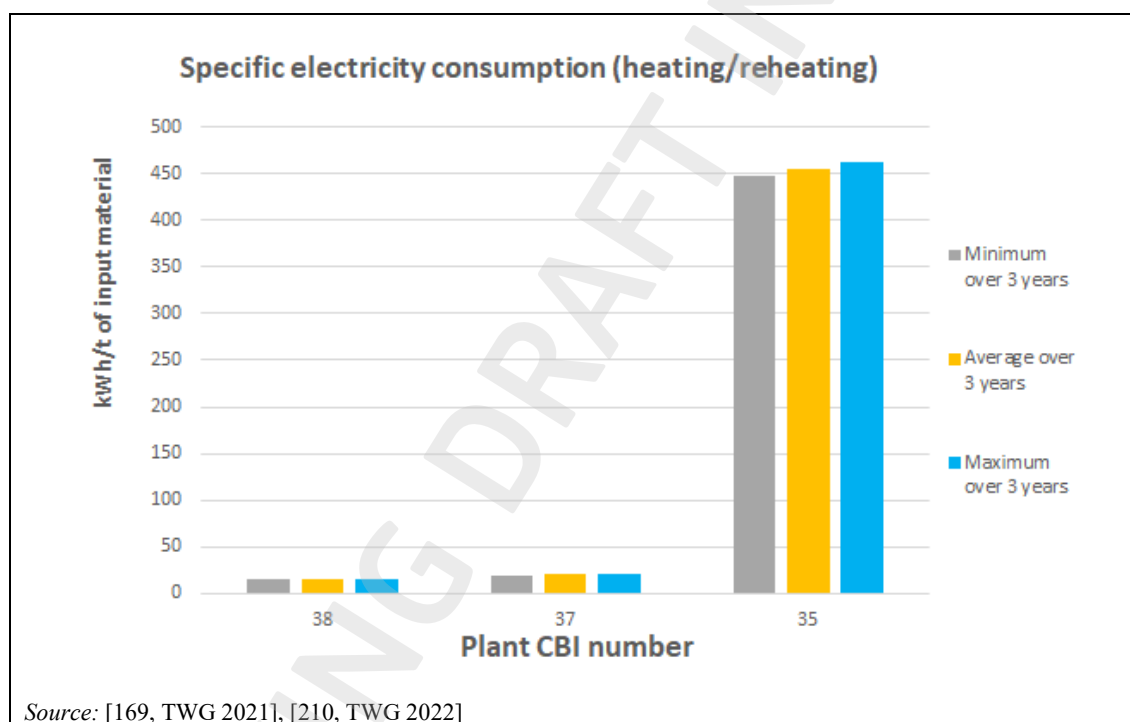


Figure 1.29: Specific electricity consumption for heating/reheating (in kWh/t of input material)

The reported specific fossil fuel energy consumption for heating/reheating are presented in Figure 1.30.

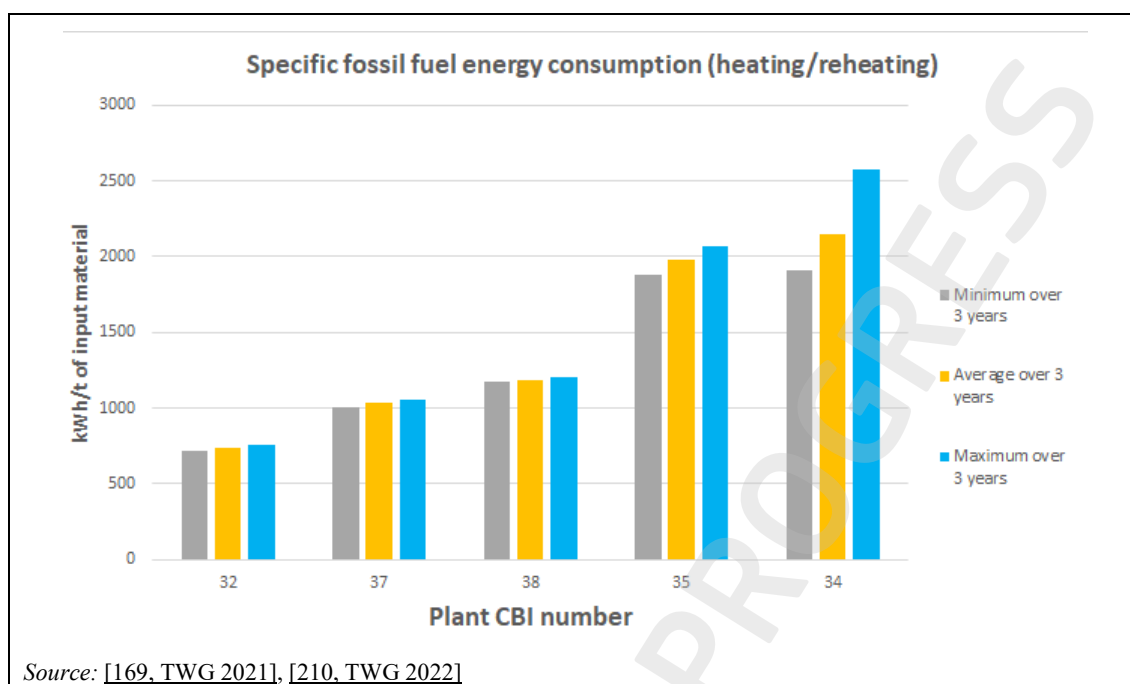


Figure 1.30: Specific fossil fuel energy consumption for heating/reheating (in kWh/t of input material)

Heat treatment

The reported specific net energy consumption, electricity consumption and fossil fuel energy consumption for heat treatment are presented in Table 1.3. Figure 1.31 shows the specific net energy consumption for heat treatment.

Table 1.3 : Reported specific energy consumption for heat treatment

Plant CBI number	Net energy (kWh/t of input material)			Electricity (kWh/t of input material)			Fossil fuel energy (kWh/t of input material)		
	Max.	Average	Min.	Max.	Average	Min.	Max.	Average	Min.
38	863	836	814	56	51	46	807	785	767
34	672	662	651	-	-	-	672	662	651
32	1 700	1 624	1 560	-	-	-	1 700	1 624	1 560

Source: [169, TWG 2021], [210, TWG 2022]

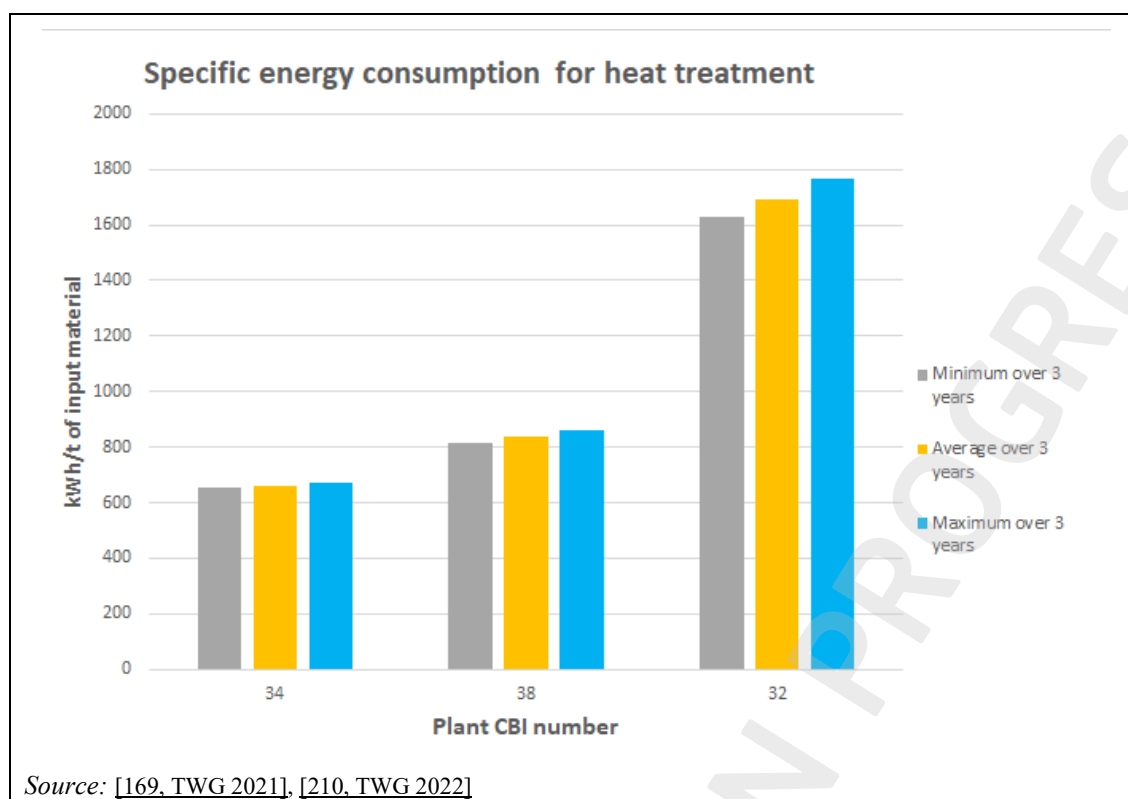


Figure 1.31: Specific net energy consumption for heat treatment (in kWh/t of input material)

1.3.3.3 Hammer energy and calorific power of furnaces

Hammer energy by type of hammer was reported during the SF BREF data collection via questionnaires. Energy data at plant level and process level are presented in Sections 1.3.3.1 and 1.3.3.2. [169, TWG 2021]

For non IED-plants, the reported energy per hammer ranged from 25 kJ to 630 kJ.

For IED plants, the reported energy per hammer ranged from 25 kJ to 400 kJ. The plant total calorific power for the IED smitheries ranged from 15.75 MWth to 47 MWth.

The total calorific power of the plant refers to/covers both pre- and post-treatment heating processes.

Table 1.4: Reported hammer energy and total calorific power of plants which participated in the data collection

Plant	Number of hammers	Energy per hammer (kJ)	Total calorific power of the plant (MWth)
DE001	2	400; 160	3,85 (for production of 3 t/h)
DE002	2	80; 160	0.9
DE003	4	179; 84; 54; 53	21.82
DE004	2	630; 450	14.84
DE005	2	55; 50	1.37
DE006	6	350; 350; 250; 200; 200; 100	15.21
DE007	2	360; 400	25.59
ES008	2	313; 313	15.75
PL009	4	68; 51; 34; 25	47

Source: [169, TWG 2021]

Thermal capacities and electrical power of types of furnaces used were reported by plant. Usually and in most cases, natural gas is used as fuel. Electricity was also reported to be used.

Table 1.5: Reported data on total calorific power of all furnaces for the plants participated in the data collection

Type of furnace	Natural gas (NG) / electricity (E)	Thermal capacity MWth	Electrical power MWel
Pusher furnace, heating	NG	0.46 – 4.26	0.021 – 0.034
Pusher furnace, heating	E	-	0.8 – 2.0
Batch type furnace, heating	NG	0.87 – 3	0.018 – 0.023
Rotary hearth furnace, heating	NG	1.6 – 3.185	0.030 – 0.04
Continuous furnace, heating	NG	NI	0.8
Induction heater, heating	E	0.42 – 1.35	1.12 – 3
Batch annealing furnace	NG	1.11 – 2.54	NI
Heating furnace	NG	0.65 – 1.17	NI
Bogie hearth furnace, post-heat treatment	NG	0.75 – 3.71	0.019 – 0.03
Pusher furnace, post-heat treatment	NG	0.523 – 1.15	NI
Continuous furnace, post-heat treatment	NG	1.45	NI

Source: [169, TWG 2021]

The reported data show a thermal capacity of the heating furnaces ranging between 0.42 MWth and 4.26 MWth.

The following table shows reported data on the total calorific power calculated as the sum of calorific power of all furnaces by plant. Furthermore, the electrical power of furnaces is shown as it was reported by the TWG via questionnaires in 2020.

Table 1.6: Reported data as sum of calorific power of all furnaces by plants which participated in the data collection

Plant CBI number	Number of furnaces	Total calorific power (MWth) calculated as the sum of calorific power of all furnaces	Reported total calorific power (MWth)	Reported total electrical power of all furnaces (MWel)
DE001	9	-	3.85	4.4
DE002	3	3.45	-	3.2
DE003	11	21.82	-	0
DE004	6	14.84	14.84	0
DE005	2	1.37	1.37	0
DE006	6	13.152	15.21	0.6446
DE007	15	25.59	26.51	1.428
ES008	11	14.331	15.75	11.125
PL009	17	25.77	47.205	-

Source: [169, TWG 2021], [210, TWG 2022]

1.3.4 Noise emissions and vibrations

[169, TWG 2021], [139, Probst 2006]

Noise occurs in several steps during the smitheries process, mainly due to operation of noise-generating machinery and by carrying out noisy working procedures. Noise emissions may occur from all smitheries processes, such as:

- material storage and transportation of raw materials;
- preparing and processing raw materials;
- material feeding to the sawing machines (billet feeder);
- cutting and sawing;
- heating/reheating and metal treatment;
- machining (e.g. hammering and any operations involving hammering) and finishing;
- dispatch and shipping of the final products;
- pouring of scrap from containers of the plant into containers of the scrap disposal companies.

The heavy machinery and large fans, blowers and roof ventilators used in various parts of the smitheries manufacturing process can give rise to noise and/or vibration emissions. [139, Probst 2006], [169, TWG 2021]

The magnitude of these emissions can be significant if the steps of the smitheries process are not well engineered or maintained and therefore noise emission can lead to local nuisance problems.

Plants are required to comply with national legislation and noise reduction standards. Noise surveys are conducted and evaluated in the context of immission control and workplace safety. At the process/hammering hall, the windows and doors are closed during operation. Natural noise barriers, such as office buildings, walls, trees or bushes are used in the smitheries industry to reduce noise emissions.

For on-site transportation, noise-reduced equipment is used, such as noise-reduced forklifts.

In the data collection, permitted noise emission levels and measured noise emission data were provided via questionnaire. Furthermore, techniques applied in the plants in order to reduce noise emissions and vibrations were also reported.

One German plant (DE004) reported noise emissions data (measured before and after the installation of noise silencers) at three measurement points situated at the boundary of the installation. Silencers were installed at the air exhaust points associated with two counterblow hammers (630 kJ and 450 kJ). The monitoring data are presented in the following table.

Table 1.7: Noise emission data before and after the installation of noise silencers (Plant DE004)

	Noise measurements		
	Noise measurement point 1	Noise measurement point 2	Noise measurement point 3
Before installation of silencers	65 dB(A)	76 dB(A)	68 dB(A)
After installation of silencers	<62 dB(A)	66 dB(A)	<62 dB(A)
<i>Source: [169, TWG 2021], [219, DE 2019]</i>			

One Spanish plant (ES008) installed acoustic screens in order to reduce the noise impact from the installation on nearby sensitive receptors [220, ES 2019]. Noise measurements were carried out at two points at the new installed acoustic screen. During inspections, a hammer was detected as a noise source (daytime and nighttime). Furthermore, two other noise sources were detected that are only active during the day, namely pressure washing and loading and unloading, which were considered relevant regarding noise emissions. Noise measurements for both daytime (07:00 – 19:00 h) and nighttime (23:00 – 07:00 h) have been provided by this plant including background noise levels, as shown in the tables below.

Table 1.8: Noise levels during the night reported by an ES plant

Measurement Point	Noise source	$L_{Aeq, T, \text{background}}$ (dB) maximum background noise	$L_{Aeq, T}$ (dB) measured noise	$L_{Aeq, T, \text{corr}}$ (dB) corrected for background noise	External emission level $L_{K_{eq, T}}$ (dBA)
A	Without hammer (Pressurised washing, loading and unloading)	49.3	50.6	-	50.6
			51.3	-	51.3
			50.4	-	50.4
	With hammer ⁽¹⁾ (Pressurised washing, loading and unloading)	49.3	57.9	57.3	60.3
			57.5	56.8	59.8
B	Without hammer (Pressurised washing, loading and unloading)	47.4	54.2	53.2	62.2
			53.4	52.1	61.1
			54.1	53.1	62.2
	With hammer ⁽¹⁾ (Pressurised washing, loading and unloading)	47.4	60.1	60.1	63.1
			61.6	61.6	64.6
			62.2	62.2	65.2

NB:
 $L_{Aeq, T, \text{bottom}}$: weighted equivalent continuous sound pressure level, corresponding to the measured background noise.
 $L_{Aeq, T}$: weighted equivalent continuous sound pressure level, corresponding to the noise registered with the activity and/or the machinery to be evaluated in operation.
 $L_{Aeq, T, \text{corr}}$: weighted equivalent continuous sound pressure level, corresponding to the noise registered with the activity and/or the machinery to be evaluated in operation and corrected for background noise.
 $L_{K_{eq, T}}$: weighted equivalent continuous pressure level, and corrected for background noise, sound elements, low frequency and/or pulsed components which corresponds to the final noise level to be evaluated.
⁽¹⁾ Occasional source of noise.
Source: [169, TWG 2021], [220, ES 2019]

Table 1.9: Noise levels during the day reported by an ES plant (ES008)

Measurement Point	Noise source	$L_{Aeq, T, \text{background}}$ (dB) maximum background noise	$L_{Aeq, T}$ (dB) measured noise	$L_{Aeq, T, \text{corr}}$ (dB) corrected for background noise	External emission level $L_{K_{eq, T}}$ (dBA)
A	Without hammer	51.9	51.9	-	50.6 ⁽¹⁾
			52.0	-	51.3 ⁽¹⁾
			52.4	-	50.4 ⁽¹⁾
	With hammer	51.9	58.4	57.3	60.3
			62.0	62.0	59.8
			61.0	60.4	62.4
B	Without hammer	53.1	55.8	-	62.2 ⁽¹⁾
			55.2	-	61.1 ⁽¹⁾
			55.3	-	62.2 ⁽¹⁾
	With hammer	53.1	63.5	63.5	63.1
			62.8	62.3	64.6
			62.4	61.9	65.2

NB:
 $L_{Aeq, T, \text{bottom}}$: weighted equivalent continuous sound pressure level, corresponding to the measured background noise.
 $L_{Aeq, T}$: weighted equivalent continuous sound pressure level, corresponding to the noise registered with the activity and/or the machinery to be evaluated in operation.
 $L_{Aeq, T, \text{corr}}$: weighted equivalent continuous sound pressure level, corresponding to the noise registered with the activity and/or the machinery to be evaluated in operation and corrected for background noise.
 $L_{K_{eq, T}}$: weighted equivalent continuous pressure level, and corrected for background noise, sound elements, low frequency and/or pulsed components which corresponds to the final noise level to be evaluated.
⁽¹⁾ The measured noise level is similar to background noise (less than 3 dB difference), so it is not appropriate to make corrections for background noise or sound, pulsed or low-frequency components. Therefore, the direct value measured there is used as a reference for the noise level $L_{Aeq, T}$.
Source: [169, TWG 2021], [220, ES 2019]

Forging hammers produce powerful short-period impact loads. This type of shock-producing machine generates powerful dynamic effects that are relatively short in duration and can be

characterised as pulses. Only a part of the shock energy is utilised in the intended machine function and the rest is dissipated in the foundation, causing intense vibration. Heavy shocks imparted to the foundation can cause alignment problems (i.e. reduce operating life), neighbour complaints and prohibit proper operation of adjacent equipment. Different levels of vibration are generated depending on the technology used (e.g. drop hammer, counterblow hammer, forging press) and to a large extent on the soil properties. In individual cases, low-energy hammer plants can also cause a nuisance to residents due to vibrations. The main objectives are to reduce the vibration amplitudes and the forces transmitted to the soil and/or to minimise any disturbance to the neighbourhood and surroundings. [164, Heidari et al. 2011], [210, TWG 2022] For insulation or minimisation of the vibration transfer, several types of foundation and insulation equipment are available and may be considered, such as equipment with spring-damper elements (for new plants). [210, TWG 2022]

Where where a smithery is located close to residential areas, the planning of new buildings at the smithery installation is connected with a necessity to reduce noise emissions and vibrations.

1.3.5 Emissions to air

In this section, data on emissions to air are presented, especially for heating furnaces using exclusively natural gas. The IED includes in Annex II a general indicative list of the main polluting substances emitted to air and water to be taken into account, if they are relevant for setting emission limit values. It was concluded at the Kick-off Meeting of the SF BREF review (KoM) that emissions to air were key environmental issues (KEIs). The following parameters are relevant for the smitheries processes:

- oxides of nitrogen (NO_x);
- carbon monoxide (CO) as an indicator for combustion efficiency.

It should be noted that the emission levels presented in this section refer to standard conditions (temperature of 273 K, pressure of 1 013 hPa, dry gas) and corrected to a reference oxygen level of 3 %.

The nature and concentration of the emissions is influenced by several factors, such as:

- type of furnace and design;
- operating or process conditions;
- quality of the raw material;
- the fuels used;
- abatement techniques for emissions reduction.

Emission data and bulk information were collected via questionnaires from three IED plants and six non-IED plants located in the EU-27. Data have been reported for the most recent 3-year reporting period, e.g. the years 2019, 2018 and 2017, if available. If data were not available for these years, data for other years could be reported. [169, TWG 2021]

Waste gas characteristics – O₂ content/level

A variety of reported O₂ content/level values was reported. Reported O₂ content in waste gases are in the range of 5 % to around 20 %. For all plants but one, the reported O₂ level associated with the reported emission levels is the same as the O₂ content in waste gases. Therefore, reported emission levels were also associated with a reference O₂ level in the range of 5 % to 20 %. [169, TWG 2021], [210, TWG 2022].

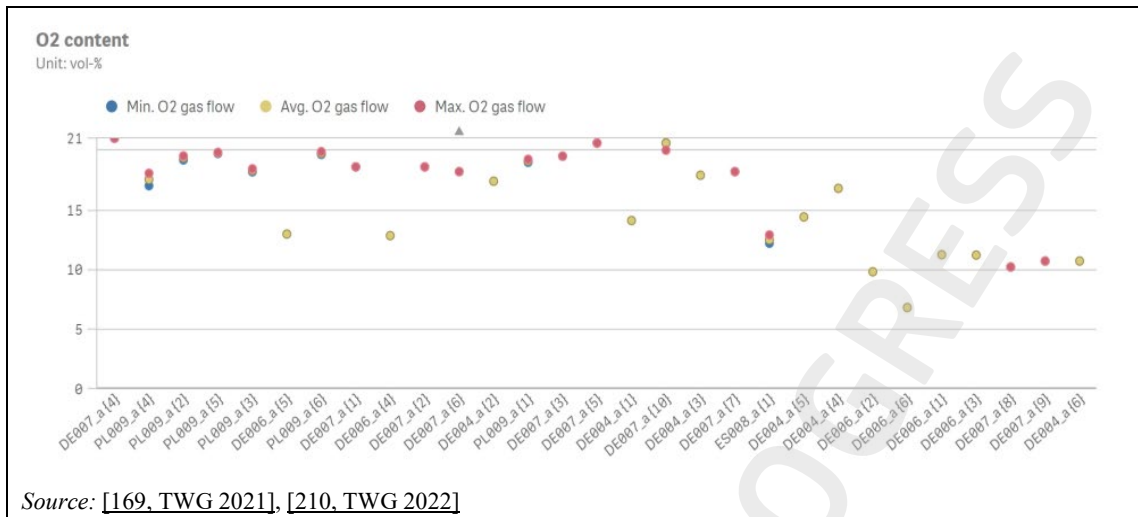


Figure 1.32: Reported O₂ content per Emission Point (EP) – IED and non-IED plants

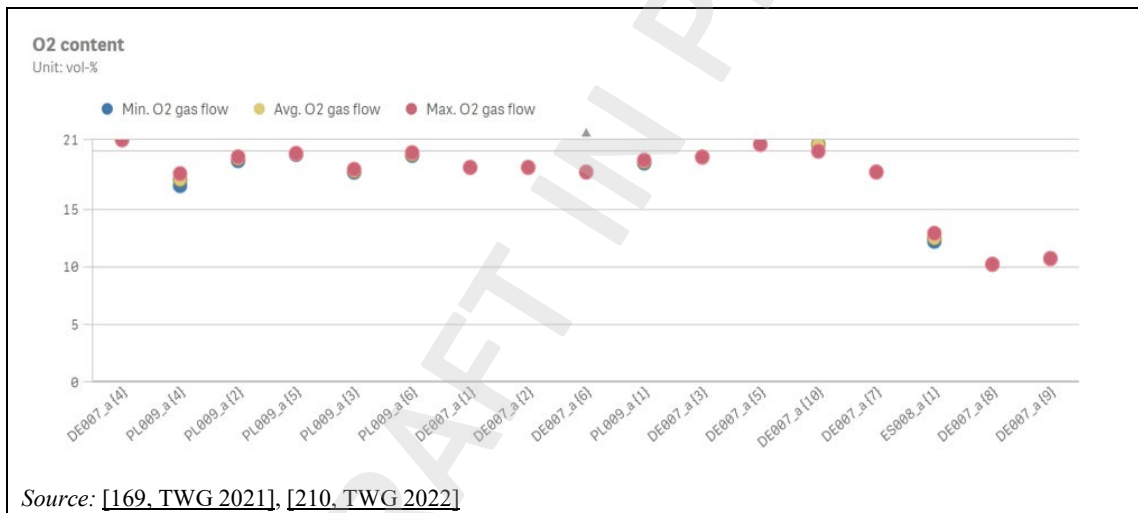


Figure 1.33: Reported O₂ content per EP – IED plants

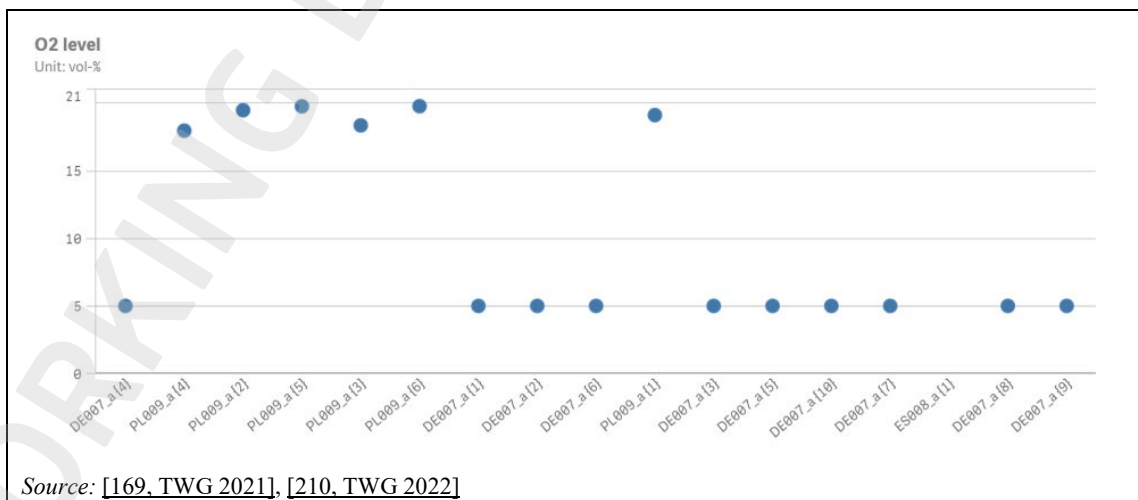


Figure 1.34: Reported O₂ level per EP – IED plants

1.3.5.1 Emissions of nitrogen oxides (NO_x)

IED and non-IED plants reported data on NO_x emissions via questionnaires. The emission levels presented in this section refer to emissions to air from feedstock heating (i.e. heating/reheating and heat treatment). NO_x emission levels were reported from 29 emission points (EPs). For the majority of the plants, the emission levels were reported with no correction to a standard O₂ reference level. One plant (DE007) reported NO_x concentrations corrected to a 5 % O₂ reference level. For Plant PL009, submitted information indicates that the high O₂ content in waste gases (19.8 %) is due to the fact that the flue-gas extraction of the furnaces/burners is not a closed system. The off-gases from the burners pass through an opening of about 15 cm before entering the off-gas exhaust system. Furthermore, fumes are sucked by blowing them off with air. The flue-gases from three furnaces are also cooled down by blowing air into the flue-gas stream, in order to protect the chimney lining from the high temperatures (more than 1000 °C) of flue-gases [224, PL 2023].

As reported in the questionnaires, in some cases recuperative burners are applied (DE002, DE003), waste heat is directly used (PL009) or is reused via a central recuperator (DE004). [169, TWG 2021]. PL009 reported the use of burners with internal recuperation: the gas and combustion air flow through the inner tube of the burner, while the flue-gases from the furnace are routed outside the burner (i.e. the furnace does not have a typical flue-gas outlet, but a chimney hole inside the furnace). The air to be burned in the burner is preheated by the flue-gases. [224, PL 2023]

The data shown in Figure 1.35 are corrected to a 3 % O₂ reference level (for all EPs from IED and non-IED plants). [169, TWG 2021], [210, TWG 2022]

All data refer to heating/reheating and heat treatment furnaces using natural gas.

Monitoring frequencies of once every year (1/y) and once every 3 years (1/3y) were reported for IED and non-IED plants.

1.3.5.2 Emissions of carbon monoxide (CO)

CO emission data were reported for IED and non-IED plants. The reported data on CO emissions to air from feedstock heating (heating, reheating) using 100 % natural gas are shown in Figure 1.36 (IED and non-IED plants). The data shown in Figure 1.36 are corrected to a 3 % O₂ reference level (for all EPs from IED and non-IED plants).

The data were reported from four plants (two IED plants (ES008, PL009) and two non-IED plants (DE004, DE006)). A total of 7 out of 19 emission points are related to IED plants. CO emission concentrations from IED plants (without correction to the 3 % O₂ level) are in the range 3 mg/Nm³ to 23 mg/Nm³. The reported O₂ reference levels corresponding to the reported CO emissions vary from 8.5 % to 19.78 %. [169, TWG 2021], [210, TWG 2022]

In addition, Figure 1.37 shows a scatter plot for combined NO_x and CO emissions to air (corrected to a 3 % O₂ level).

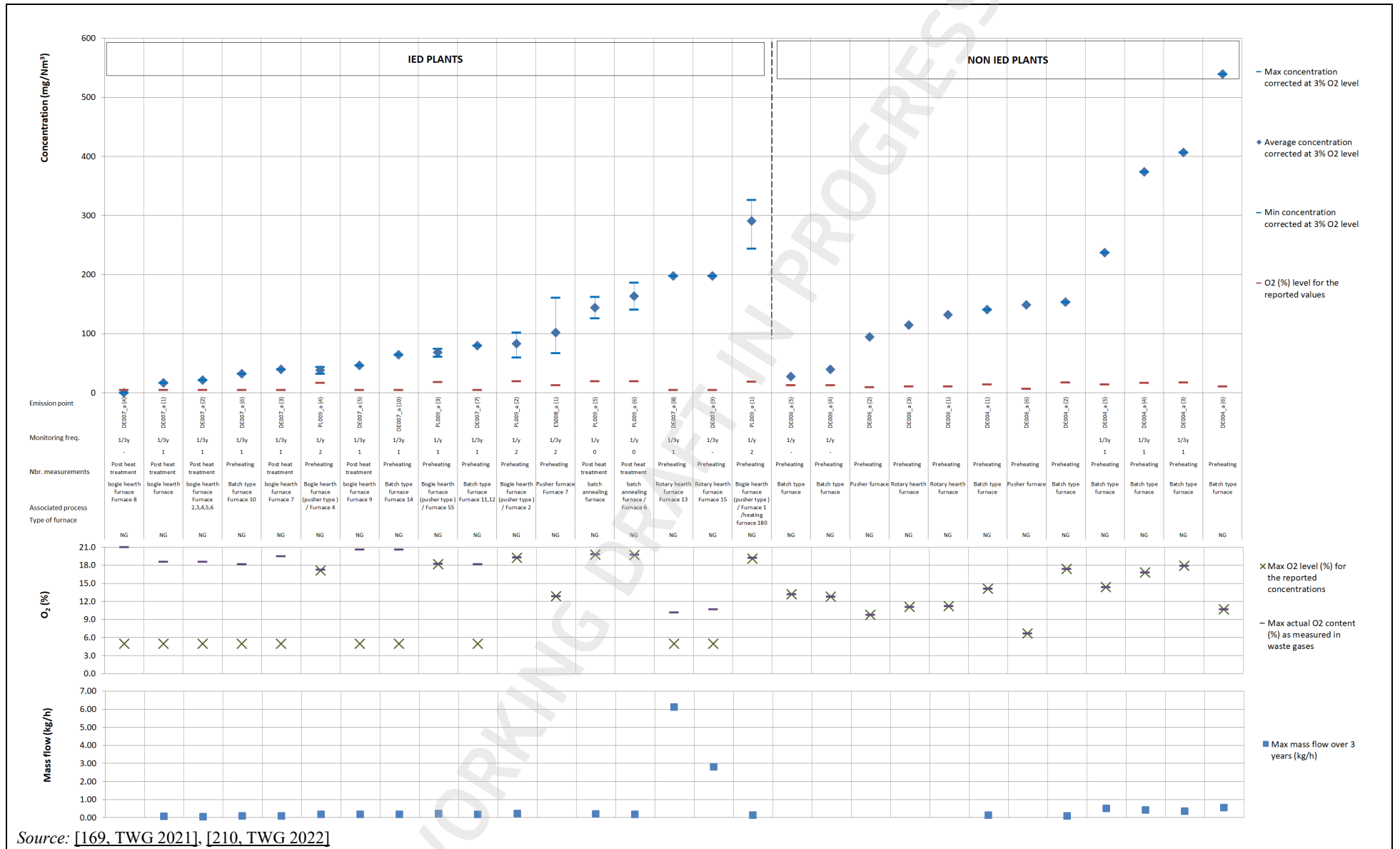


Figure 1.35: Reported NO_x emissions per EP corrected to a 3 % reference O₂ level – IED and non-IED plants

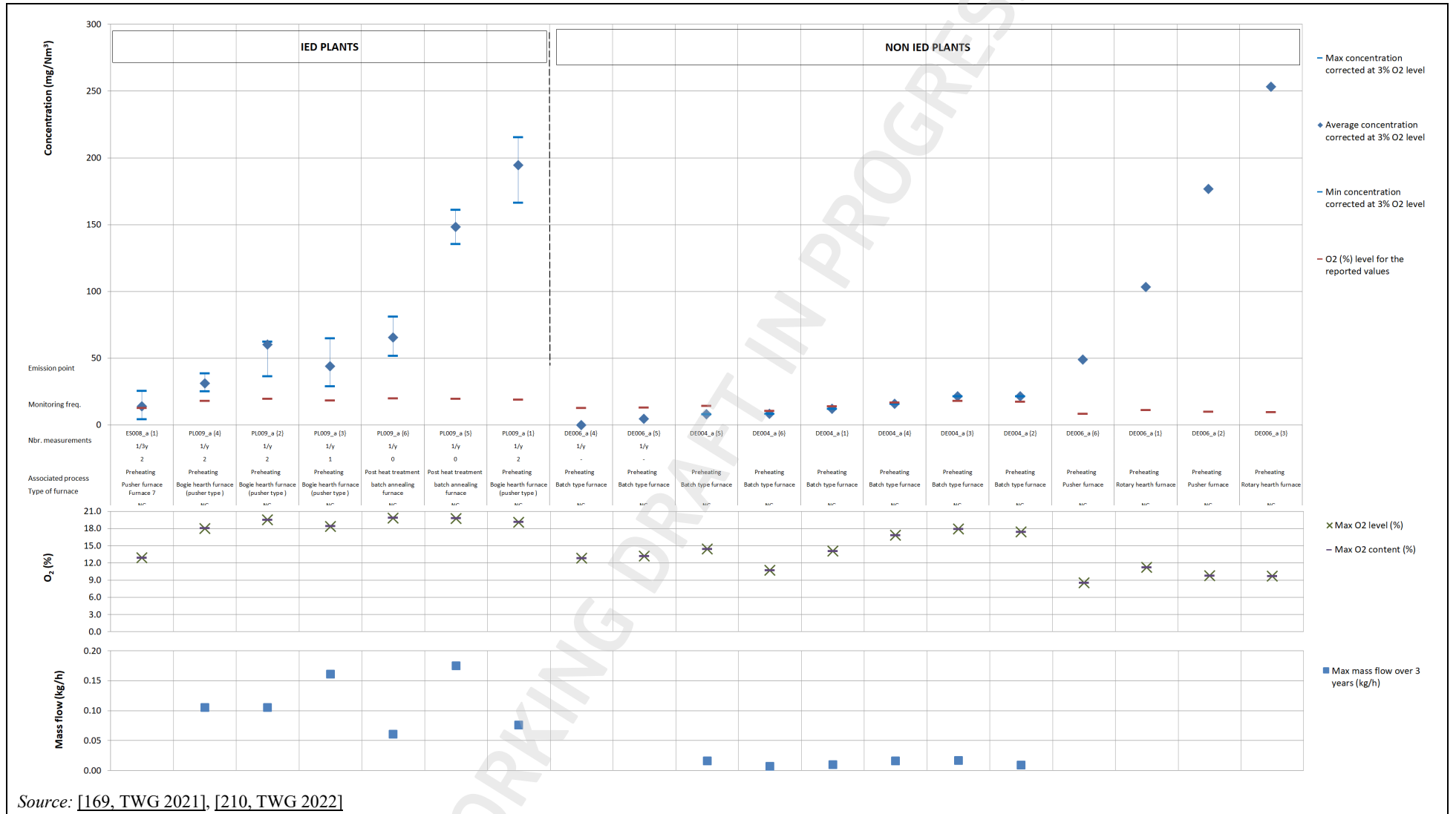
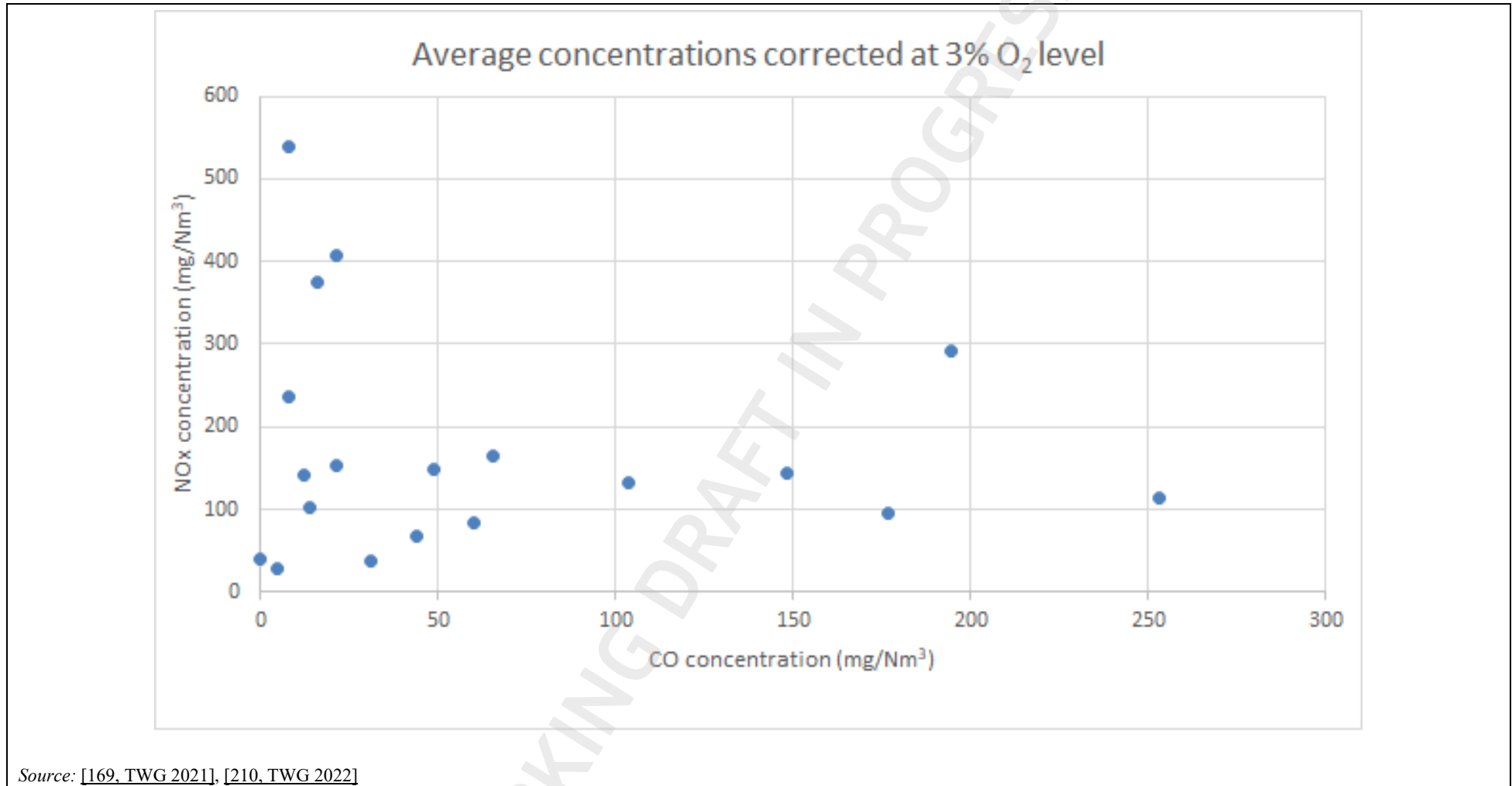


Figure 1.36: Reported CO emissions per EP corrected to a 3 % reference O₂ level – IED and non-IED plants



Source: [169, TWG 2021], [210, TWG 2022]

Figure 1.37: Scatter plot for combined NO_x and CO emissions to air (corrected to a 3 % O₂ level)

1.3.5.3 Diffuse emissions to air

Diffuse emissions (mainly diffuse dust emissions) may arise in smitheries during the following process steps:

- raw materials and chemicals storage and handling (basically caused by moving material around the premises, e.g. from open storage and also from road surfaces because of road transport);
- heating /reheating, heat treatment via furnaces (emissions from combustion);
- hammering;
- cooling;
- finishing, e.g. descaling, grinding, welding, blasting/shot blasting. [210, TWG 2022]

For new and large open-die forging furnaces, waste gas from furnaces is extracted. For smaller and older furnaces, off-gases in general are released through roof openings (as diffuse emissions). Collection and treatment may be applied for some finishing processes, e.g. grinding, welding, shot blasting. [210, TWG 2022]

Since dust emissions and diffuse dust emissions were not identified and concluded to be a key environmental issue (KEI) at the KoM, there are no data on dust emissions to air reported.

However, several techniques for reducing diffuse emissions were reported which are presented in in Table 1.10. [169, TWG 2021]

Table 1.10: Reported techniques for reducing diffuse emissions by plants (IED and non-IED)

Techniques applied	Additional information regarding diffuse emissions
Enclosure of production equipment	<ul style="list-style-type: none"> • Pilot trials for exhaust air collection and cleaning were carried out with the result that the exhaust gas collection might be challenging, e.g. due to construction issues, vibrations, entry of sparks and flammable sawdust used as separating agent. The use of wet scrubber systems would technically only be feasible to a limited extent.
Enclosure of storage areas	No additional information provided.
Paving and cleaning of roads used by lorries or forklifts	<ul style="list-style-type: none"> • Storage areas only partially asphalted or concreted. Therefore, in the summer months low dust development due to dry floor covering. Factory roads are cleaned weekly. • Roads used by lorries or forklifts are paved and cleaned periodically in order to avoid diffuse dust emissions. • Outdoor areas are cleaned periodically (i.e. weekly), such as roads, paths, and squares, especially in dry season.
Capture of off-gases from heating furnaces	<ul style="list-style-type: none"> • Collection of furnace off-gases.
Appropriate material handling	<ul style="list-style-type: none"> • Reduction of diffuse emissions from material handling.
Collection and treatment of waste gases from finishing processes	<ul style="list-style-type: none"> • Collection and filtering of emissions from blasting.
<i>Source:</i> [169, TWG 2021]	

Additional useful information, e.g. regarding definitions of diffuse emissions, EN standards, measurement methods, can be found in the JRC Reference Report on Monitoring of Emissions to Air and Water from IED Installations (ROM). [174, COM 2018]

1.3.6 Emissions to water

For smitheries, water is used in small quantities, e.g. for cooling and quenching processes as well as for cleaning processes. In general, smitheries do not generate significant amounts of waste water effluent.

As reported by Plants DE001, DE002, DE005, DE007, ES008 and PL009, for cooling a closed cooling circuit/system is applied in order to avoid waste water generation. Furthermore, the once-through cooling system is also applied (DE006). [169, TWG 2021]

At Plant DE006, surface water is used as cooling water for compressors and furnaces. After use in cooling, it is cleaned via a sludge trap and an oil separator and then it is directly discharged into a surface water body. Rainwater is also pretreated in this way on the plant premises. Regular monitoring of pH and oils/fats at the outflow of waste water takes place: sampling and analysis of directly discharged waste water are carried out by the operator. Since the installation is located close to a water body, the cooling system of this installation is operated in continuous flow. No water circulation/central cooling is applied. Compared to closed cooling circuits, the once-through cooling system does not require additional energy for cooling tower systems. No conditioning of circuit water is applied. [169, TWG 2021]

As decided at the KoM, emissions to water is not a key environmental issue (KEI) in smitheries operations.

1.3.7 Process losses – residues

Process losses/residues originating from the smitheries manufacturing processes mainly consist of metallic residues like crop ends, burrs from the hammering process, dust arising from the manufacturing processes and collected via cleaning, oil and grease resulting from several stages of the manufacturing process as well as packaging waste.

Recycling and internal reuse of process residues generated from the hammering processes for example is applied in smitheries. [169, TWG 2021] Process residues, e.g. metallic residues from the processes of preparation of raw materials, hammering and finishing as well as used shot blast media, can be recycled and/or reused. [210, TWG 2022]

2 FOUNDRIES

2.1 General information on foundries

2.1.1 Sector overview

2.1.1.1 Foundry industry

Foundries melt ferrous and non-ferrous metals and alloys and reshape them into products at or near their finished shape through the pouring and solidification of the molten metal or alloy into a mould. The foundry industry is a differentiated and diverse industry. It consists of a wide range of installations, from small to very large; each with a combination of technologies and unit operations selected to suit the input, size of series and types of product produced in the specific installation. The organisation within the sector is based on the type of metal input, with the main distinction being made between ferrous and non-ferrous foundries.

The European foundry industry is the third largest in the world for ferrous castings and the second largest for non-ferrous. The total production of castings in various European countries are given in Table 2.1 and Table 2.2.

In 2020, the iron and steel foundries of the European Foundry Association (CAEF) member states³ produced 7.0 million tonnes of castings. The four countries that dominate the industry in terms of weight, namely Germany, France, Spain and Italy, account for 80 % of the production of ferrous metal castings. In 2020, non-ferrous metal foundries installations of the EU Member States recorded a production decrease of 20 % to about 2.7 million tonnes due to the Covid-19 pandemic. The countries that dominate the production of non-ferrous metal castings, namely Germany and Italy, account for 53.5 % of the total volume of non-ferrous metal castings produced in the EU.

In 2020, 88 400 employees worked in iron and steel foundries in the EU, while 84 700 people were employed in non-ferrous foundries. Both sectors experienced a significant reduction in workforce within the last few years.

The share of cast iron with lamellar graphite in the total output of iron and steel castings accounts for almost 50 % among iron and steel casting production. Correspondingly, the share of ductile cast iron logged equals approximately 43 %. The share of the steel sector is 7 %. The production of castings made of non-ferrous metal alloys is still dominated by light metals. The share is up to 85 %. Furthermore, the share of copper alloys is at a level of about 7 %. Therefore, the share of components made of zinc and magnesium alloys is approximately 8 %.

Table 2.1: European production data for ferrous castings, i.e. iron, steel and malleable iron castings (in kilotonnes)

Country	2016	2017	2018	2019	2020	2018:2019	2019:2020
						% change	
Austria	154.8	156.6	164.2	158.5	134.7	-3.4	-15
Belgium	51.5	42.9	85.2	67.6	52.4	-20.7	-22.5
Bulgaria	n.d.	49.8	n.d.	n.d.	n.d.		
Croatia	42.9	n.d.	n.d.	n.d.	n.d.		
Czech Republic	270.8	295.0	295.5	268.5	192.5	-9.1	-28.3
Denmark	72.8	83.5	91.5	86.9	n.d.	-5.0	
Finland	57.9	66.4	64.6	57.8	47.1	-10.5	-18.7

³ Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Finland, France, Germany, Hungary, Italy, Lithuania, Norway, Poland, Portugal, Slovenia, Spain, Sweden, Switzerland, The Netherlands, Turkey, United Kingdom

Country	2016	2017	2018	2019	2020	2018:2019	2019:2020
						% change	
France	1 263.7	1 330.9	1 339.9	1 304.3	1 067.4	-2.7	-18.2
Germany	3 919.0	4 184.9	4 256.2	3 804.9	2 714.8	-10.6	-28.7
Hungary	83.4	82.3	88.3	76.2	76.4	-13.7	0.3
Italy	1 152.4 ⁽²⁾	1 235.0 ⁽²⁾	1 253.1	1 108.9	893.1	-11.5	-19.5
Norway	30.1	29.4	31.2	31.2	n.d.	0.0	
Poland ⁽¹⁾	696.0	690.0	690.0	655.0	524.0	-5.1	-20
Portugal	140.0	144.6	145.4	140.4	106.3	-3.4	-24.3
Slovenia	202.6	195.1	137.4	177.2	116.7	28.9	-34.2
Spain	1 116.9	1 128.7	1 135.7	1 113.3	931.1	-2.0	-16.4
Sweden	230.3	236.7	248.6	240.4	197.2	-3.3	-18.0
Total EU	9 455.6	9 922.4	9 995.8	9 260.0	7 053.6	-7.2	-23.8

(¹) Without steel castings.
(²) Without steel and malleable iron castings.
NB: n.d.: no data.
Source: [209, CAEF 2022]

Table 2.2: European production data for non-ferrous metal castings (in kilotonnes)

Country	2016	2017	2018	2019	2020	2018:2019	2019:2020
						% change	
Austria	147.1	148.3	163.4	144.8	121.4	-11.4	-16.1
Belgium	0.8	n.d.	2.2	1.0	1.7	-52.6	59.9
Bulgaria	n.d.	n.d.	n.d.	n.d.	n.d.		
Croatia	24.8	n.d.	n.d.	n.d.	n.d.		
Czech Republic	119.9	122.0	124.2	116.0	94.5	-6.6	-18.5
Denmark	3.9	4.4	4.0	3.5	n.d.	-11.4	
Finland	4.8	5.9	5.5	5.3	4.1	-3.9	-21.9
France	362.2	367.3	441.3	392.4	330.7	-11.1	-15.7
Germany	1 248.8	1 206.1	1 176.7	1 019.2	769.4	-13.4	-24.5
Hungary	123.3	127.7	139.2	124.0	121.7	-10.9	-1.9
Italy	805.4	860.3	867.5	827.3	659.2	-4.6	-20.3
Poland	348.8	346.5	346.5	356.5	285.2	2.9	-20.0
Portugal	50.5	54.1	56.5	56.5	50.3	0.0	-11.0
Slovenia	52.1	52.1	70.6	75.7	53.1	7.3	-29.9
Spain	163.5	166.7	153.1	153.9	124.6	0.5	-19.1
Sweden	61.5	63.7	67.3	65.1	56.4	-3.2	-13.4
Total EU	3 516.4	3 525.1	3 618.0	3 341.4	2 672.4	-7.6	-20.0

NB: n.d.: no data.
Source: [209, CAEF 2022]

Data on the number of foundries are given in Table 2.3 and Table 2.4. These data show that there has been a general decline in the number of foundries since 2016. This decline is also reflected in the employment numbers, as given in Table 2.5 and Table 2.6.

Table 2.3: Number of foundries (production units) for iron, steel and malleable iron casting

Country	2016	2017	2018	2019	2020	2018:2019	2019:2020
						% change	
Austria	23	23	15	15	15	0.0	0.0
Belgium	15	15	13	13	13	0.0	0.0
Bulgaria	n.d.	80	n.d.	n.d.	n.d.		
Croatia	32	n.d.	n.d.	n.d.	n.d.		

Country	2016	2017	2018	2019	2020	2018:2019	2019:2020
						% change	
Czech Republic	71	71	71	71	70	0.0	-1.4
Denmark	8	8	8	8	n.d.	0.0	
Finland	18	18	16	18	16	12.5	-11.1
France	120	n.d.	n.d.	n.d.	n.d.		
Germany	243	240	239	232	225	-2.9	-3.0
Hungary	35	34	29	30	n.d.	34.5	
Italy	189 ⁽¹⁾	191 ⁽¹⁾	185 ⁽¹⁾	172	172	-7.0	0.0
Poland	216	215	215	215	216	0.0	0.5
Portugal	31	31	31	31	31	0.0	0.0
Slovenia	11	57	13	11	11	-15.4	0.0
Spain	74	75	75	71	74	-5.3	4.2
Sweden	39	38	38	36	36	-5.3	0.0
Total EU	1 125	1 096	948	923	879	-1.0	-2.6

(¹) Including investment casting.
 NB: n.d.: no data.
 Source: [209, CAEF 2022]

Table 2.4: Number of foundries (production units) for non-ferrous metal casting

Country	Total	
	2019	2020
Austria	23	22
Belgium	6	6
Bulgaria	n.d.	n.d.
Croatia	n.d.	n.d.
Czech Republic	37	37
Denmark	7	n.d.
Finland	14	13
France	n.d.	n.d.
Germany	330	327
Hungary	33	31
Italy	864	866
Poland	240	240
Portugal	57	57
Slovenia	47	47
Spain	52	52
Sweden	60	n.d.
Total EU	1 770	1 698

NB: n.d.: no data.
 Source: [209, CAEF 2022] [210, TWG 2022]

Table 2.5: Employment in the foundry industry for iron, steel and malleable iron casting

Country	2016	2017	2018	2019	2020	2018:2019	2019:2020
						% change	
Austria	2 905	2 971	2 257	2 215	2 158	-1.9	-2.6
Belgium	1 066 ⁽²⁾	1 193 ⁽²⁾	1 757	1 766	1 727	0.5	-2.2
Bulgaria	n.d.	4 382	n.d.	n.d.	n.d.	n.d.	n.d.
Croatia	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Czech Republic	11 000	11 000	11 000	10 500	9 500	-4.5	-9.5
Denmark	914	1 095	1 079	1 047	n.d.	-3.0	

Country	2016	2017	2018	2019	2020	2018:2019	2019:2020
						% change	
Finland	1 242	1 318	1 363	1 264	1 170	-7.3	-7.4
France	13 300	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Germany ⁽¹⁾	41 844	41 774	42 019	39 675	35 385	-5.6	-10.8
Hungary	1 980	1 920	3 850	3 720	3 620	-3.4	-2.7
Italy	14 047 ⁽³⁾	9 182	9 248	9 040	9 432	-2.2	4.3
Poland	16 000	16 000	16 000	16 000	11 125	0.0	-30.5
Portugal	2 381	2 640	2 444	2 582	2 181	5.6	-15.5
Slovenia	1 400	1 418	1 135	1 110	1 277	-2.2	15.0
Spain	10 980	11 070	10 928	11 162	10 808	2.1	-3.2
Sweden	4 746	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Total	123 805	105 063	103 080	100 081	88 383	-2.9	-11.7

(¹) Foundries >50 employees.
(²) Only workmen.
(³) Including investment casting.
NB: n.d.: no data.
Source: [209, CAEF 2022]

Table 2.6: Employment in the foundry industry for non-ferrous casting

Country	2016	2017	2018	2019	2020	2018:2019	2019:2020
						% change	
Austria	3 932	4 127	5 029	4 718	4 380	-6.2	-7.2
Belgium	262	266	496	496	494	0.0	-0.4
Bulgaria	n.d.	280	n.d.	n.d.	n.d.	n.d.	n.d.
Croatia	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Czech Republic	4 000	4 000	4 000	4 000	4 000	0.0	0.0
Denmark	409	n.d.	n.d.	372	n.d.	n.d.	n.d.
Finland	330	413	413	381	344	-7.7	-9.7
France	12 000	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Germany ⁽¹⁾	35 229	35 967	36 845	35 552	32 473	-3.6	-8.6
Hungary	5 490	6 076	5 650	5 230	5 250	-7.4	0.4
Italy	15 100	18 836	18 312	18 815	18 813	2.7	0.0
Norway	452	296	287	287	n.d.	0.0	
Poland	8 300	8 300	8 300	8 300	7 387	0.0	-11.0
Portugal	2 399	3 400	3 461	3 365	3 293	-2.8	-2.1
Slovenia	2 500	4 195	4 138	4 032	3 669	-2.6	-9.0
Spain	5 027	5 275	5 321	5 242	4 623	-1.5	-11.8
Sweden	3 157	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Switzerland	1 297	1 274	1 504	1 450	1 450	-3.6	0.0
Turkey	14 000	13 500	13 750	13 750	13 850	0.0	0.7
United Kingdom	14 000	13 000	13 650	13 150	13 000	-3.7	-1.1
Total	127 874	119 205	121 110	126 110	113 026	4.1	-4.6

(¹) Foundries >50 employees.
NB: n.d.: no data.
Source: [209, CAEF 2022]

The relationship between unit size, production and employment is well illustrated in Figure 2.1.

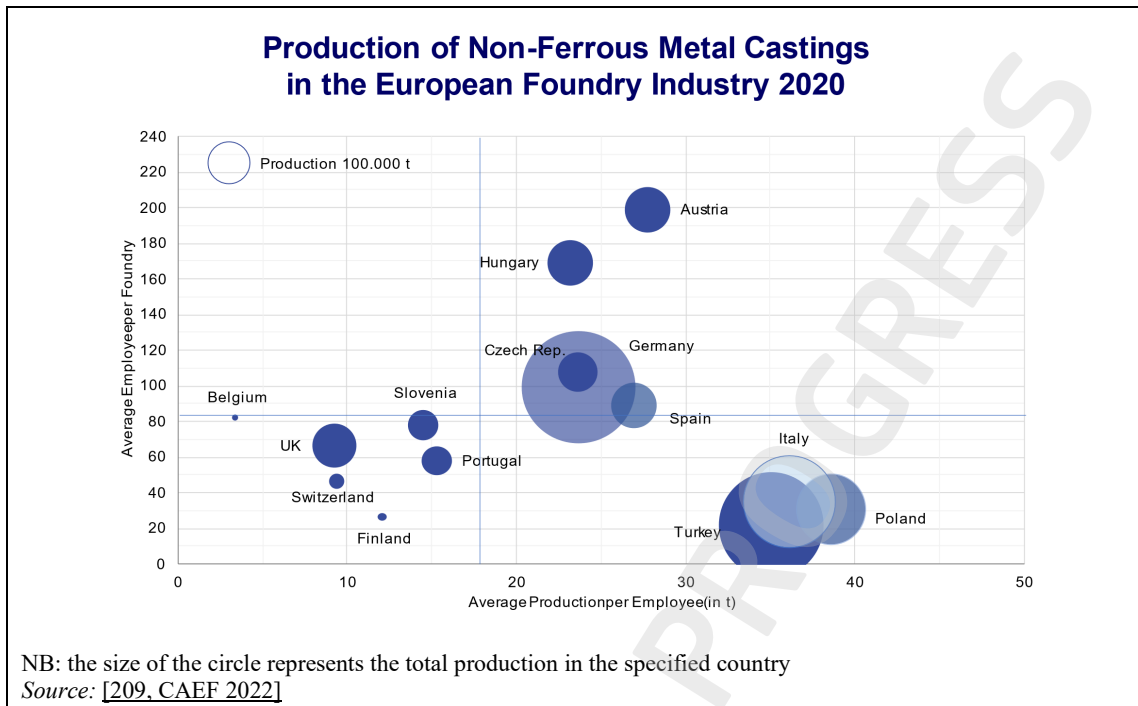


Figure 2.1: Ferrous foundry productivity data for the production of iron, ductile iron and steel castings in the European Foundry Industry in 2020

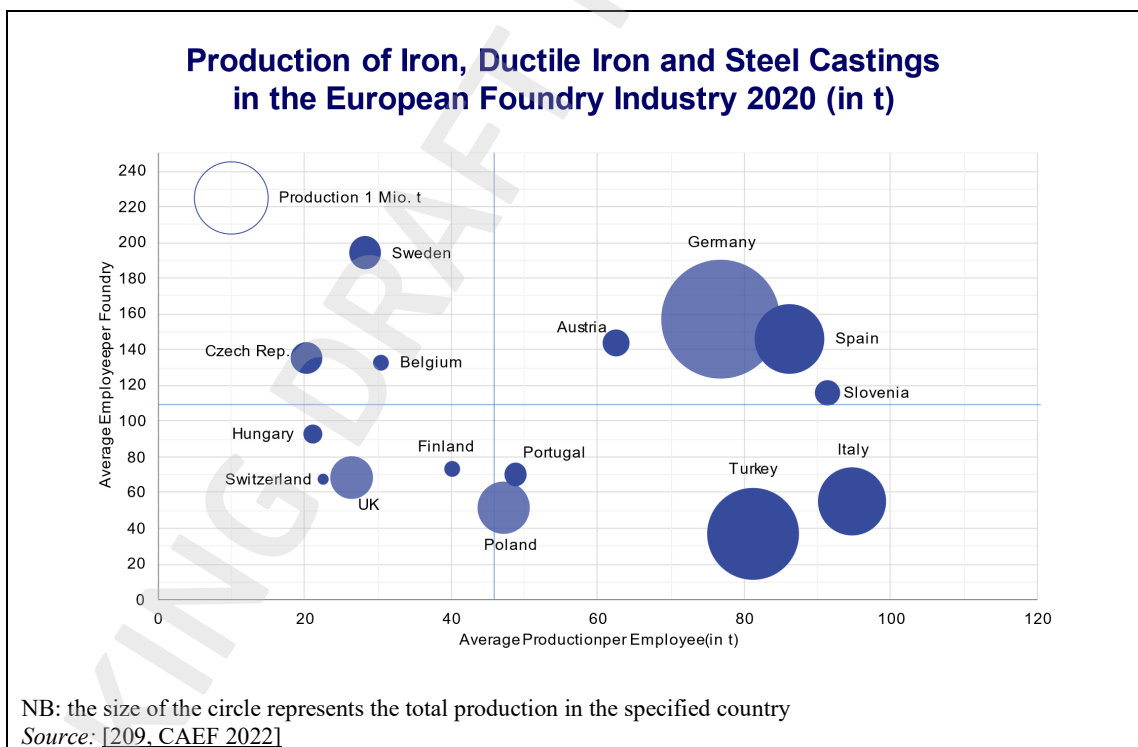


Figure 2.2: Productivity data for the production of non ferrous metal castings in the European Foundry Industry 2020

The development of the European foundry industry is linked with the development of both the metal and the automotive industries. Present foundries often have a history dating back to the beginning of the 20th century. Originally they were usually located on the outskirts of towns, but as villages and cities have grown around them they are now often surrounded by habitation. The foundry industry is basically an SME industry, with 75 % of companies employing less than 250

people. Since castings in general are semi-finished products, foundries are located close to their customers.

2.1.1.2 Foundry markets

The main markets served by the foundry industry are the automotive, general engineering and construction sectors. The high dependence on the automotive sector has a major influence on activities in the foundry sector, and concerns various aspects, such as economy, location, quality standards, environmental standards, new developments, etc. One example of this dependency is that the automotive industry’s shift towards lighter vehicles, is reflected in the foundry industry by an increased demand (and thus market) for aluminium and magnesium casting, thus enabling the growth of these sectors.

Due to the increasing electrification of vehicles in the automotive industry, the sector is facing a radical change. Large series foundries with a focus on the powertrain are particularly affected by this. Elsewhere, this fundamental shift is opening up new market segments. Efficient use of resources means that cast components are becoming increasingly complex. Foundries are turning away from a tonnage-driven market to one that offers complete solutions with post-treatment. While in production tonnes the automotive sector is by far the largest customer segment, castings are essential for almost all other industries too.

The market shares differ according to the type of metal. This is illustrated by data from the German foundry market, as shown in Figure 2.3. The automotive sector takes up more than 50 % of all iron castings from German foundries. Steel castings on the other hand (including low alloyed as well as stainless and other alloys) are used for machine parts and in valve making, and therefore serve a broader range of sectors. Indeed, the largest share of the market for valve making is taken up by stainless castings.

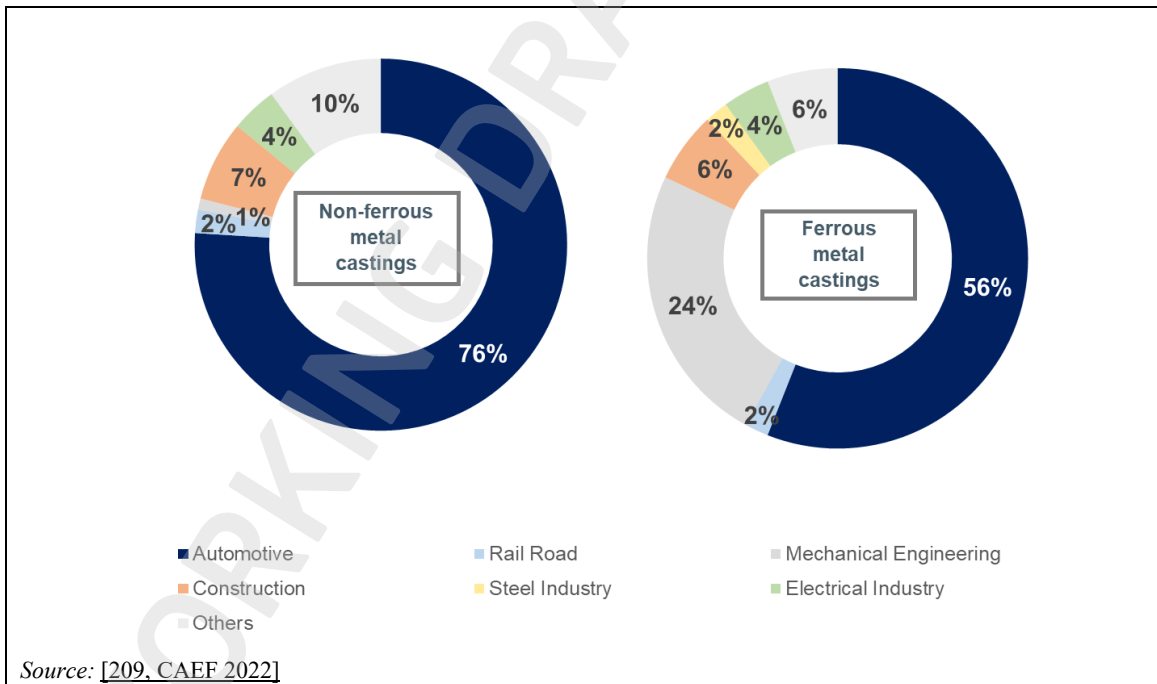


Figure 2.3: Market shares for non-ferrous and ferrous metal castings (data for German market)

The opening of Europe towards the East has led to the big European producers showing a growing interest in the existing foundry activity in countries such as Poland, the Czech Republic and

Hungary. Some of the big European companies have invested in these regions. For the East European countries, the opening of their markets combined with inward foreign investment has allowed the implementation of new techniques, thereby increasing productivity and reducing their effects on the environment. Due to the low labour costs in these countries, their competitive strength lies in jobbing foundries, mainly producing large castings, and in foundries producing a broad range of products. To compete on the world market, West-European foundries now focus on their technological skills, selecting niche markets which require complex castings with high precision, specific quality requirements, or those that require quick or just-in-time delivery.

2.1.1.3 Foundry types

Besides the metal type (i.e. ferrous/non-ferrous) the foundry layout is largely dependent on the size of castings and the series size. There is a large difference between a zinc foundry producing a large series of frames for toy cars and a cast iron foundry producing rotor housings for wind turbines. Foundries apply different degrees of automation according to their series size and the repeatability of the work. Concerning applied techniques, the main distinction is made by the type of melting furnace used (e.g. cupola, electrical, rotary) and the type of mould (e.g. sand moulding, die-casting). These are described and discussed further in Section 2.2.

A classification of the different foundry types has been developed by the industry's foundry sector and consists of different clusters including:

- iron foundries for serial production (including centrifugal casting): these foundries usually employ automatic moulding techniques and manufacture small castings;
- iron foundries for single castings (including continuous casting): these foundries usually employ manual moulding techniques and manufacture large castings;
- steel foundries;
- non-ferrous metal foundries employing sand casting techniques;
- non-ferrous metal foundries employing gravity casting or low-pressure die casting (including continuous or centrifugal casting);
- non-ferrous metal foundries employing high-pressure die casting.

The different foundry types according to the cluster classification and information on their respective operations and specificities are presented in Table 2.7.

Table 2.7: Typical types of foundries – cluster classification

Criteria	Iron foundry, serial production (incl. centrifugal casting)	Iron foundry, single castings (incl. continuous casting)	Steel foundry	Non-ferrous foundry, sand casting	Non-ferrous foundry, gravity casting or low-pressure die casting (incl. continuous and centrifugal casting)	Non-ferrous foundry, high-pressure die casting
Casting material	Grey iron, nodular iron, white iron	Grey iron, nodular iron	Alloyed or non-alloyed steel	Alloys based on aluminium, copper or magnesium	Alloys based on aluminium, copper or lead	Alloys based on aluminium, magnesium, zinc or copper
Typical products	Automotive parts, e.g. brake disc. Parts for mechanical engineering, Wear resistance parts	Machine parts, e.g. wind turbine parts, rolls, engineblocks	High strength or corrosion resistant castings, e.g. pump components, heat resistant parts, wear resistance parts	Automotive or other use, e.g. fittings. Bushings, bearings, marine parts, engineering parts	Automotive parts, e.g. cylinder heads. Counterweights, bushings, bearings, marine parts	Automotive and machine parts, e.g. motor blocks. Handles, enclosures, marine parts, couplings, valves
Melting furnace; raw materials	Cupola or induction furnaces; pig iron and clean scrap	Cupola or induction furnaces; pig iron and clean scrap	Arc furnace or induction furnaces; clean scrap	Induction furnaces, resistance furnaces, gas or oil fired furnaces; refined alloys, clean scrap	Induction furnaces, resistance furnaces, gas or oil fired furnaces; refined alloys, clean scrap	Induction furnaces, resistance furnaces, gas or oil fired furnaces; refined alloys, clean scrap
Foundry tooling (repairing)	Pattern and core box material: metal or plastic	Pattern and core box material: wood or plastic	Pattern and core box material: wood, plastic or metal	Pattern and core box material: wood, plastic or metal	Core box material: metal; die material: steel or plastic	Die material: steel
Sand moulds, sand system or permanent moulds (dies)	Automatic moulding plant, green sands	Hand moulding or mechanised moulding plant, Self curing organic- or in-organic binder	Hand moulding or mechanized moulding plant, self curing organic binder	Automatic moulding plant, green sands, self curing organic- or in-organic binder	Gravity or low-pressure die casting machines	High-pressure die casting machines
Core-making, sand system	Core shooting machines, organic sand binders, gas curing binder	Hand moulding, self curing organic binder or core shooting machines, gas curing organic binder	Hand moulding, self curing organic binder or core shooting machines, gas curing organic binder	Core shooting machines, self curing organic or in-organic binders, gas or heat curing organic binder	Core shooting machines, inorganic or organic binders, gas or heat curing	No core-making
Fettling	Automatic shot blasting and mechanised grinding	Shot blasting and grinding mechanised or by hand	Shot blasting and grinding, mechanised or by hand	Shot blasting, automatic or mechanised grinding, mechanised or by hand	Automatic sawing and mechanised grinding	Automatic cutting

Source: [173, CAEF et al. 2020]

2.1.2 Environmental issues

The foundry industry is a major player in the recycling of metals. Steel, cast iron and aluminium scrap can all be remelted into new products. The possible negative environmental effects of foundries result from the presence of a thermal process and the use of organic and mineral additives. The environmental effects of a foundry process therefore mainly relate to the exhaust and off-gases and to the management (e.g. reuse or disposal) of mineral residues.

2.1.2.1 Air

Noxious emissions from the melting and treatment of metals are generally related to the use of additives and fuels or to impurities in the feed. The use of cokes as fuels or the heating of crucibles with gas or oil-fired burners can cause emissions of combustion products. Also, the application of additives in metal treatment processes generates reaction products. The presence of impurities (e.g. oil, paint) in scrap used for remelting can potentially cause the production of the products of incomplete combustion or recombination and dust. Also any dust generated may contain metal and metal oxides. The evaporation of elements with a high vapour pressure occurs during melting and small particles of metal escape from the bath. Metallic particles are also generated during grinding and finishing operations.

In the making of moulds and cores, a vacuum could be used or various additives are used to bind the sand. In the binding of the sand and pouring of the metal, reaction and decomposition products are generated. These include both inorganic and organic products. The generation of decomposition products further continues during the casting, cooling and de-moulding (shake-out) operations.

Dust and particle releases are a general issue in all stages of the foundry process, and for all processes used. Dust is generated in the production and processing of sand moulds and cores, as well as in the finishing of the castings (both from lost moulds and permanent moulds).

In the foundry process, emissions to air are not limited to one (or several) fixed point(s). The process involves various emission sources (e.g. from hot castings, sand, hot metal). A key issue for a sustainable reduction of emissions are primary measures integrated in the processes, e.g. the usage of clean scrap or of emission-reduced binders in combination with secondary measures, i.e. techniques for capturing and treating the exhaust and off-gas flow.

2.1.2.2 Residues

Sand moulding involves the use of large sand volumes, with sand-to-liquid-metal weight ratios generally ranging from 1:1 up to 20:1. At the end of the moulding process the used sand can be regenerated, reused or disposed of. Modern techniques for sand reconditioning and reclamation lead to reuse rates of more than 90 %. Additional mineral residues such as slag and dross are generated in the melting stage when removing impurities from the melt. These should also be considered for either recycling or disposal.

2.1.2.3 Energy

Since foundries deal with a thermal process, energy efficiency and management of the generated heat are important environmental aspects. There are a lot of techniques applied in foundries for energy saving and heat recovery. However, due to the high amount of transport and handling of the heat carrier (i.e. the metal) and due to its slow cooling, the recovery of heat is not always straightforward.

2.1.2.4 Water

Water is generally used in various processes, e.g. the cooling systems of electric furnaces (induction or arc) and cupola furnaces, wet flue-gas treatment systems, wet sand regeneration, cupola furnace slag granulation, die casting. Waste water streams may also result from surface run-off water from storage areas. In many foundries, water management involves an internal circulation of cooling water, closed-loop cooling systems are considered state-of-the-art. In general, the outgoing waste water stream is therefore very small. For (high-)pressure die-casting, a waste water stream is formed, which needs treatment to remove, among others, organic (phenol, oil) and heavy metal compounds before disposal.

WORKING DRAFT IN PROGRESS

2.2 Applied processes and techniques in foundries

2.2.1 Overview

2.2.1.1 The foundry process

A general flow chart of the foundry process is depicted in Figure 2.4. The process can be divided into the following major activities:

- melting and metal treatment: the melting shop;
- preparation of moulds: the moulding shop;
- casting of the molten metal into the mould, cooling for solidification and removing the casting from the mould: the casting shop;
- finishing of the raw casting: the finishing shop.

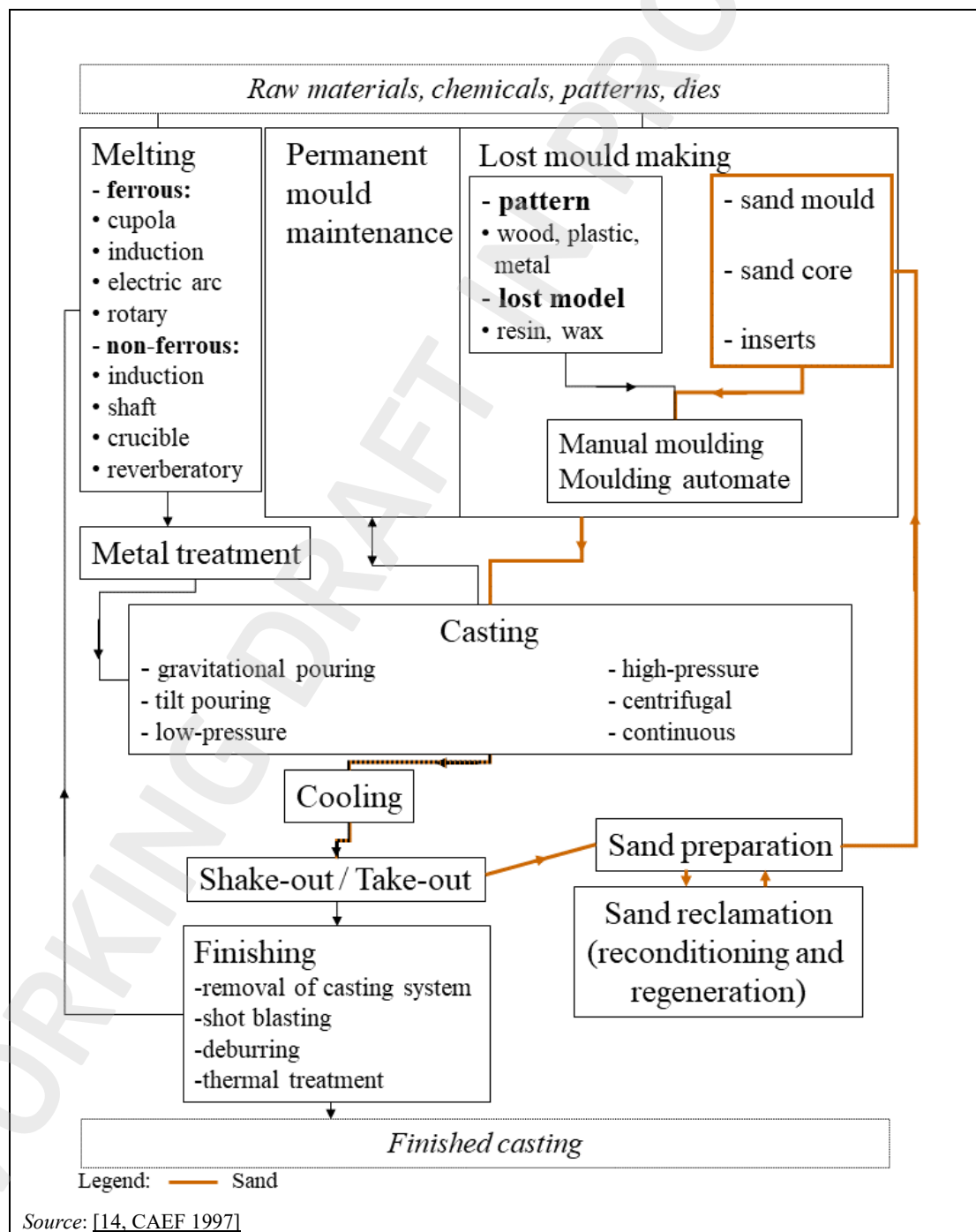


Figure 2.4: The foundry process

Starting from foundry scrap (selected scrap according to a certain chemical composition) or ingots, the foundry produces finished castings. Usually these are components which will require further treatment or assembly to yield a final product.

On the moulding side, a basic distinction is made between permanent and lost moulds. Foundries casting in permanent moulds buy these metal moulds (dies) externally, but typically operate an in-house mould repair and maintenance shop. Foundries casting in lost moulds often buy wooden, metal or plastic patterns (for their mould design) and operate an in-house pattern maintenance and repair shop. Moulds, cores and lost models are generally produced as part of the foundry process.

Traditionally in the foundry sector the main distinction made is between ferrous and non-ferrous foundries. This is mainly because the applied processes in both sectors differ. Non-ferrous foundries often apply die-casting techniques, but permanent dies with sand cores are also common. These die-casting techniques allow a better surface finish, which is important for many of the aluminium and brass applications. Due to the high cooling rate, castings with a high mechanical strength are produced. However, this technique does not allow the production of massive or large pieces, which require sand casting techniques. Sand casting techniques are generally applied in non-ferrous foundries for products that are not produced in large series. However, sand casting techniques such as sand cores in dies and complete core package systems are also applied in non-ferrous metal foundries for production in large series. The non-ferrous metals (and their alloys) discussed in this document are:

- aluminium;
- magnesium;
- copper;
- zinc;
- lead.

Ferrous foundries generally apply the lost mould techniques. Due to their greater stiffness and strength, ferrous alloys are used in different applications to non-ferrous alloys. The size of the products that can be produced is almost unlimited. Ferrous metals have a higher melting point and therefore require different melting techniques. The ferrous metals and alloys discussed in this document are the various types of cast iron (which may be classified according to their properties or by the graphite type) and cast steel.

Superalloys with a high content of alloying elements, such as nickel, will also be discussed (Section 2.2.1.9).

Foundries utilise mechanisation and automation depending on the need for reproductivity and on the series sizes. The most flexible installation is typically the 'single castings' foundry (small series foundry also called 'jobbing foundry' or 'customer foundry'). This produces a variety of products in small numbers (< 100). In general, this type of foundry applies manual or automatic moulding techniques with resin-bonded sand moulds. The melting furnace works batch wise to allow an easy change of alloy. This implies the use of induction or rotary furnaces.

For medium-sized series (< 1 000 parts), mechanised moulding and casting lines are used. Lost mould foundries utilise mould making machines. This implies the use of green sand, which allows fast mould making. The size of the moulding machine (flask size) limits the maximum size of the castings. Casting can be performed manually or by using a pouring machine. Auxiliary side processes, such as sand preparation, are operated in a semi-automated way with remote control. Both continuous furnaces (cupola, shaft) and batch furnaces are used. For non-ferrous alloys, die-casting techniques are applied.

Large series of small castings are often made in flaskless green sand moulding. The main difference for medium-sized series is the further automation of the finishing, the quality control and the mould assembly. For die-casting in non-ferrous alloy facilities, further automation is often applied, this is especially the case in pressure die-casting shops.

Large series from non-ferrous metal castings, especially aluminium alloys, are produced in permanent moulds. The main processes are:

- gravity die casting of aluminium alloys;
- low-pressure die casting;
- high-pressure die casting (HPDC) of aluminium, magnesium and zinc alloys.

These processes use highly sophisticated multiple-part dies with movable parts. The production lines are highly automated.

Complex and precise ferrous castings can also be made by using the core package system (with inner cores and outside mould made from core sand). This results in better accuracy compared to green sand and presents the advantage of being a single-type sand system.

Specific casting techniques, such as lost foam casting, full mould casting, centrifugal casting or continuous casting are applied where the product type requires it.

Regarding emissions to air, various process steps in the foundry have the potential to produce dust, fume and other gases, e.g. material storage, handling and processing. Techniques to reduce emissions to air involve prevention, minimisation and off-gas collection and treatment.

The melting shop, core-making shop, sand plant and post-casting shop are considerable sources of emissions. The emitted air pollutants are mainly dust (possibly with heavy metal particles), sulphur dioxide, carbon monoxide and odorous organic compounds. Table 2.8 gives the results of a survey of the pollutants generated in the different parts of the ferrous foundry process. Both inorganic and organic compounds are listed as individual and group compounds. Dust emissions are of specific importance, since thermal processes can generate considerable amounts of heavy metals.

Table 2.8: Survey of air emissions from different ferrous foundry stages

<div style="text-align: center;"> <p>SOURCE</p> <p>↓</p> <p>RELEASES</p> </div> <div style="text-align: center;"> <p>→</p> </div>	Raw material storage and handling	Furnace operations	Desulphurisation of molten iron	Nodularisation	Preparation of cores and moulds	Casting	Shake-out, reclamation	Fettling, dressing and finishing of castings
Oxides of sulphur		X	X		X	X	X	
Oxides of nitrogen		X			X	X	X	
Carbon dioxide		X	X	X	X	X	X	
Carbon monoxide		X	X	X	X	X	X	
Hydrogen sulphide					X	X	X	
Ammonia					X	X	X	
Oxides of iron		X	X	X		X	X	X
Alkali metal compounds		X	X					
Alkaline-earth metal compounds		X	X	X		X		
Metal oxide particulates		X	X	X		X	X	X
Non-metallic particulates	X	X	X		X	X	X	X
Metallic iron		X						X
Hydrogen cyanide					X			
Sulphur			X					
Amines/amides					X	X		
Dioxins		X						
Volatile organic compounds		X			X	X	X	
Acid vapours		X			X	X		
Noise		X			X		X	X
Substances include their compounds, except where separate reference to the compound is made. Releases to air may also be released to land or water, depending upon the abatement technology employed, e.g. via collected dusts, sludges or liquors. Some releases are specific to a particular binder system <i>Source: [62, UK Environment Agency 2002]</i>								

Techniques to minimise emissions are discussed in Section 3.

2.2.1.2 Iron casting

Cast iron is an iron-carbon-silicon alloy, containing usually between 2.4 % and 4 % carbon. The minimum carbon content is 1.8 %. The chemical composition of basic cast iron grades is not defined in the material standards, only for high-alloy grades. Other alloying elements are also present in various amounts. Special grades of iron are produced which contain various levels of nickel, chrome and other metals. Due to its eutectic composition, cast iron has a low melting point and a good casting ability compared to steel. Castings receive their complex shape and a two-phase microstructure (iron and free graphite) directly when solidifying in the mould (in-situ material, one heat); further processing is not necessary for most grades. This in-situ solidification structure does not have the same toughness as a wrought steel which has undergone recrystallisation and heat treatment (three heats). Their technological properties are achieved by

alloying (adjusting the matrix structure, e.g. ferrite/pearlite) and eventually heat treatment, and by modifying the shape of free graphite (e.g. lamellar, spheroidal, vermicular).

Depending on the concentration and form of the carbon (lamellar, spheroidal or compact), various types of cast iron may be defined:

- lamellar iron: carbon in the form of flakes;
- nodular iron: carbon in spheroidal form;
- compact graphite iron: carbon in bonded form.

The classification of cast iron is often made according to its material properties:

- Grey iron: cast iron with free graphite in a complex three-dimensional shape (lamellar in metallographic sample). It has very good thermal conductivity and machinability.
- Ductile iron (spheroidal graphite cast iron): cast iron with free graphite in a predominantly round shape. This leads to higher fracture elongation and also ductility, especially for unalloyed ferritic grades.
- Malleable iron: cast iron that undergoes subsequent heat treatment called ‘tempering’. This results either in increased ductility or in a graphite-free, weldable structure. Used for smaller parts and fittings.
- Vermicular graphite: cast iron with an intermediate form of free graphite, resulting in better mechanical properties than grey iron and still with good thermal conductivity.
- ADI (Austempered Ductile Iron) / ausferritic spheroidal graphite cast iron: spheroidal graphite cast iron that undergoes subsequent special heat treatment, resulting in a two-phase austenitic-ferritic matrix. This material has excellent tensile properties or excellent wear properties.
- Special grades: grades for special applications are abrasion-resistant (white) cast irons, austenitic heat-resistant cast irons, SiMo ferritic heat-resistant cast irons and continuous cast irons.

Cast iron can be melted in the cupola furnace, induction furnace (generally of coreless type, but very occasionally can be the channel type) or in the rotary furnace. The electric arc furnace is seldom applied for the production of cast irons. It has the potential to melt low-quality steel scrap. Figure 2.5 gives process flow diagrams for the melting and metal treatment of cast iron in the three different furnace types. The process generally consists of melting – tapping – metal treatment – pouring. The various aspects of melting and metal treatment are discussed in the following sections. Metal treatment involves various steps such as desulphurisation, nodularisation, inoculation and deslagging. The desulphurisation step in cupola melting may also be incorporated into the nodularisation, e.g. by using a nodularisation process which simultaneously takes up the sulphur, such as the core wire process.

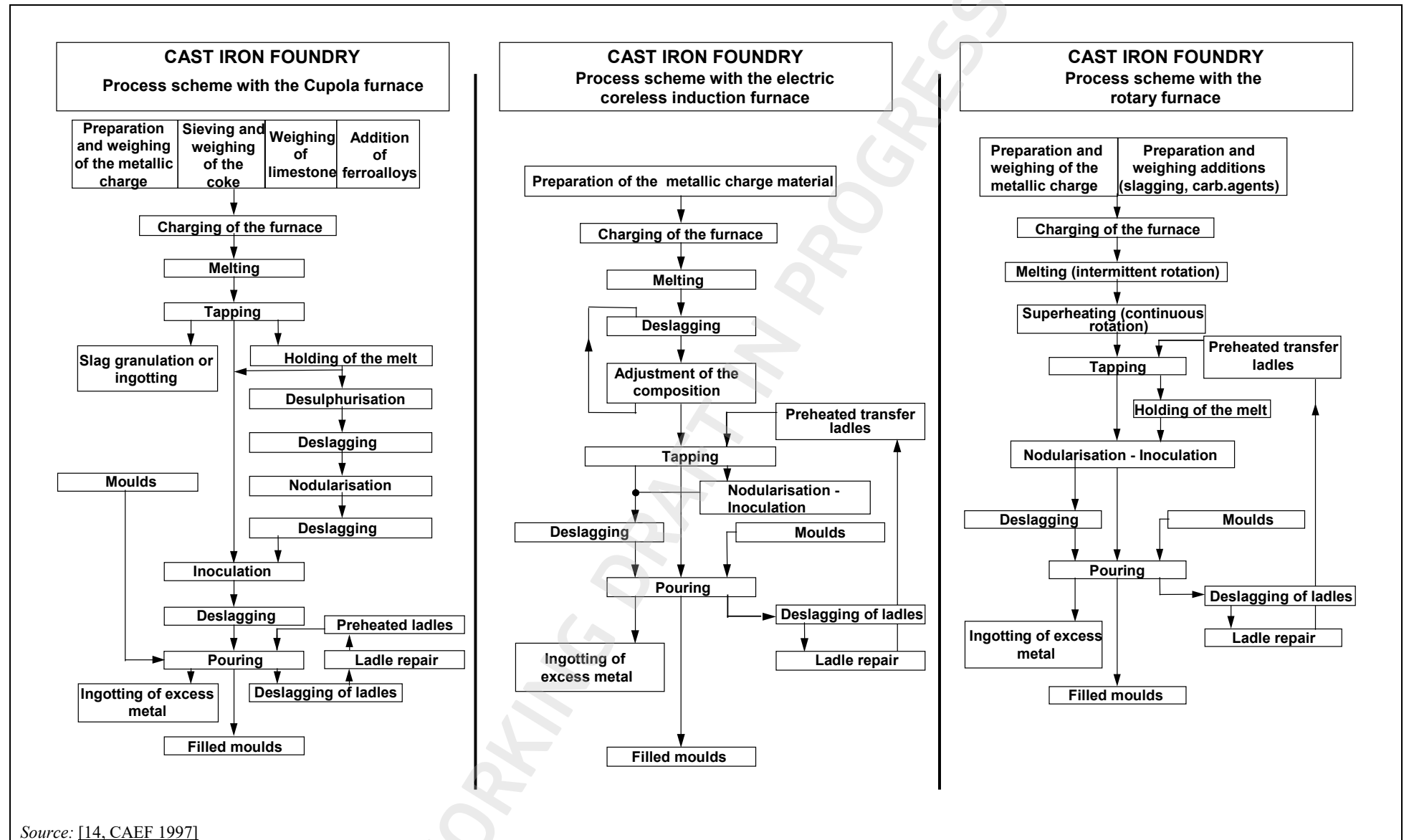


Figure 2.5: Process flow diagrams for the melting and metal treatment of cast iron

The cupola is the leading furnace for remelting iron in Europe. It is responsible for about half of the tonnage of iron castings produced in western Europe. Nowadays, the cupola is increasingly facing major challenges to its market domination. This is partially due to its flue-gas quality, which requires treatment. Faced with the possible financial burden of investing in, and then seeing the depreciation of a stack gas treatment installation, some medium-sized cupola units have been equipped with oxy-fuel combustion. Some smaller furnaces were already replaced by induction furnaces. Thus the number of cupolas used in foundries is falling, but their average size is increasing. There have been major changes in the market for cupolas in Europe, particularly due to the restructuring of the coke industry, leading to a decreased number of suppliers and a need to import coke into Europe. Another major change is the smaller number of cupola manufacturers, with one German firm having a quasi-monopoly in the hot blast type.

The majority of repetitive iron castings are made in green sand moulds with resin-bonded cores. The cold-box amine technique is most widely used. The 'Croning resin shell' moulding process is used where a high precision and good surface finish are needed. The Lost Foam process is used to a limited extent, for repetition castings. Castings made in smaller numbers (e.g. big castings) are made in chemically bonded sand moulds. Special sand processes, such as vacuum moulding and full moulding are used for certain iron castings. There are also a few permanent moulding (die-casting) foundries making iron castings, but the high temperature of the iron melt limits its production capacity to only a few thousand components and therefore has restricted the use of ferrous die-casting.

[59, Godinot 2001], [73, Brown, J. R. 2000], [133, DE UBA 2014]

2.2.1.3 Steel casting

Steel is a material of which the (mass) content of iron is bigger than that of any other element, with a carbon content generally lower than 2%, and which also usually contains other elements. A limited number of chromium steel types may contain over 2 % carbon, but 2 % is the usual cut-off limit used to distinguish steel from cast iron [99, CEN 2000]. One particularly useful aspect of steel is that it can be hot worked. Low alloy cast steel contains elements such as Mn, Cr, Ni, and Mo in amounts less than 5 %. High alloy steel includes more than 5 % of alloying elements, e.g. 12 % Cr and 8 % Ni. Special steel grades are produced with enhanced properties, such as higher strength; higher magnetic permeability; better resistance to corrosion, fatigue or wear; and improved behaviour during welding or at high or low temperatures.

Cast steel is normally melted in electric arc furnaces (EAF) or in coreless induction furnaces (IF). Once melted, the liquid metal can be refined (i.e. removal of carbon, silicon, sulphur and or phosphorus) and deoxidised (i.e. reduction of metallic oxides), depending on the base material and the quality requirement of the finished product . Figure 2.6 gives process flow diagrams for the melting and metal treatment of cast steel in the different furnace types.

[14, CAEF 1997]

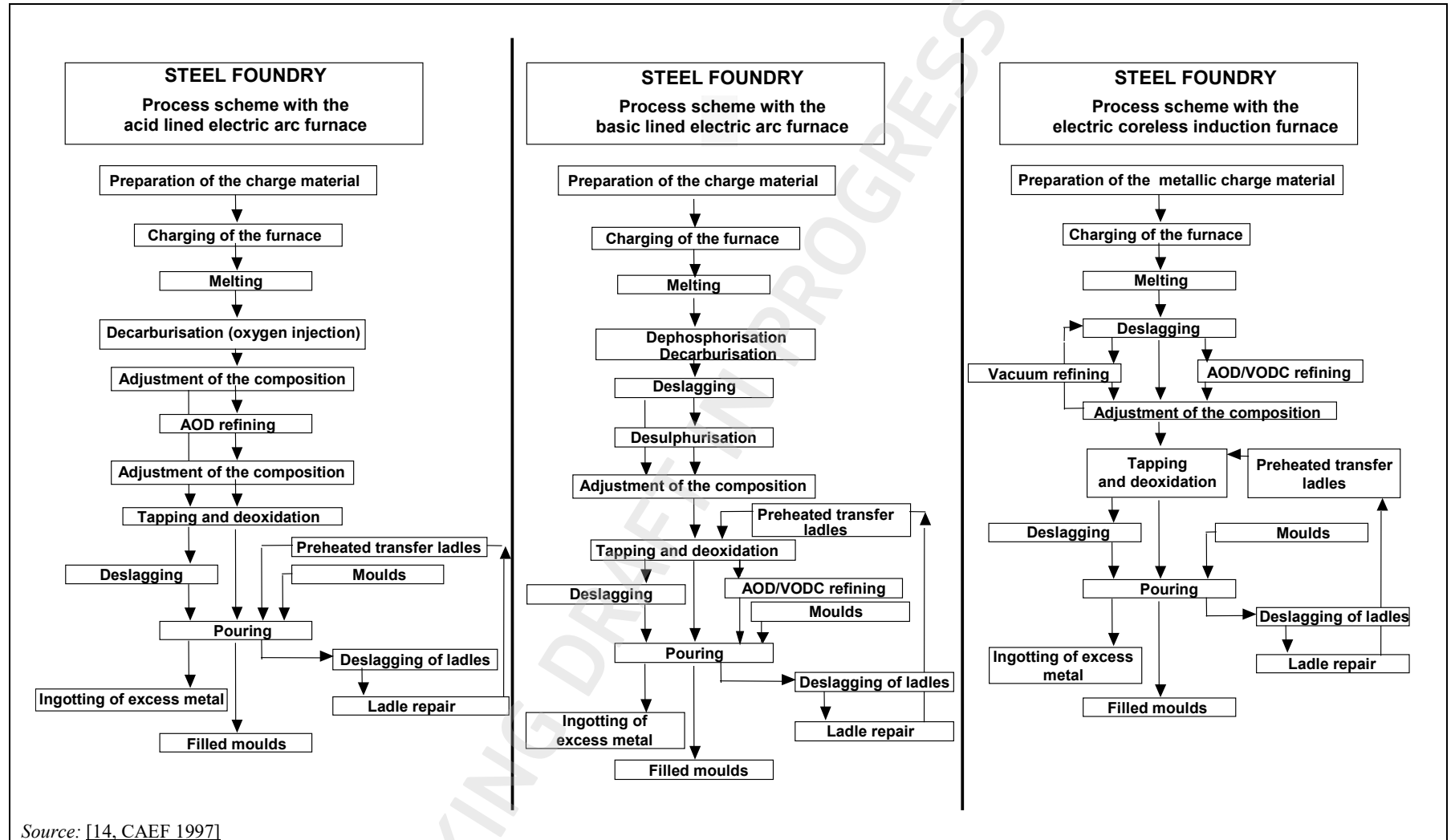


Figure 2.6: Process flow diagrams for the melting and metal treatment of steel

2.2.1.4 Aluminium casting

About two thirds of all aluminium castings are used in the transportation industry, e.g. in cars, buses, lorries, trains and aircraft. The need to reduce vehicle fuel consumption and weight has increased the interest in aluminium. The amount of aluminium used per car produced in Europe almost tripled between 1990 and 2012. The total mass of aluminium in a European car roughly tripled between 1990 and 2012, increasing from 50 kg to 140 kg. Information from industry (European Aluminium, 2019) stated that this amount was predicted to rise to 160 kg by 2020. This growing use of aluminium in its major user sector clearly has an effect on the overall number of castings produced.

Aluminium is mainly cast into permanent moulds. The relative share of applied casting techniques for aluminium are given in Table 2.9.

Table 2.9: Relative shares of applied casting techniques for Al

Casting type	Relative share (%)
Pressure die-casting	59
Low-pressure die-casting & gravity casting	37
Sand casting	3
Others	1
<i>Source: [49, Inasmec and CTIF 2002], [120, TWG 2003], [134, CAEF 2020]</i>	

Many different types of melting furnaces are used in aluminium foundries the choice depending on individual requirements. Directly and indirectly heated furnaces, using fuel and electricity, are applied. The fossil fuels currently used are natural gas, liquid petroleum gas (LPG) and oil. Natural-gas-fired furnaces have been installed over recent decades by most aluminium foundries because of the lower cost. Electrical heating may be provided by either resistance elements or by induction. Capacity is one of the most important parameters for melting and holding furnaces. Today induction furnaces are normally used when a high melting capacity, e.g. above 10 tonnes/hour, is needed. Shaft melting and holding furnaces, as well as crucible furnaces, are often used when the melting capacity is less than five tonnes/hour. Small and medium crucible furnaces are often used when it might be necessary to be able to change the alloy easily or if the production rate is low.

For holding, electric furnaces have the advantage of not producing burner off-gases and being able to sustain a homogeneous temperature over the whole molten volume, at a relatively low energy expense.

Aluminium melting in foundries generally uses alloyed ingots as a starting material, although in some cases the metal is delivered already as a liquid. The secondary melting of aluminium scrap in aluminium smelters is not performed in foundries and falls outside the scope of this document. It is discussed in the BAT reference document for the non-ferrous metals industries (the NFM BREF).

[24, ETSU 1994], [52, Eurofine 2002], [1, COM 2017]

2.2.1.5 Magnesium casting

Magnesium alloy castings are used for aerospace, automotive and electronic applications. The main advantage for using them is their light weight; typically magnesium alloys have a density of 1.8 g/ml compared with 2.7 g/ml for aluminium alloys. Aluminium is the principle alloying constituent of magnesium-based casting alloys, with zinc and manganese also present in small amounts. Pressure die-casting is the most commonly used casting process, due to the low casting temperature (650-700 °C); both hot chamber and cold chamber die-casting machines are used. Sand moulding is applied to a lesser extent. Magnesium die-castings can be made with thinner

walls than aluminium, but their use is limited by stiffness problems. The thinner walls allow the overall weight of the components to be substantially reduced, thus compensating for the higher alloy cost per kilogram. Gravity die-casting and sand casting are also used, particularly for more highly stressed castings. The use of magnesium alloy die-castings in automotive components is growing rapidly, with some vehicles already containing 10 – 20 kg of Mg components. The most popular parts made at present are instrument panel substrates, cross car beams, wheel drives and seat frames.

Molten magnesium alloys attack firebrick and refractory furnace linings, resulting in harmful silicon contamination. Therefore steel crucibles are used. Iron is also slightly soluble in magnesium but it has a much less harmful effect than silicon. Scrap is usually cleaned and if possible shot blasted to remove any adhering sand as a further precaution against silicon pick-up. To eliminate ladling, the molten alloy is, if possible, poured direct from the melting pot.

Due to its very easy oxidation, magnesium alloys are melted under a cover using a cleansing flux or cover gas, to avoid oxidation losses and to prevent inclusions. Inhibitor powders are used to cover any exposed metal during holding and pouring, and are added to moulding-sand to prevent chemical reactions. The fluxless melting of Mg alloys requires another form of melt protection. For this purpose, SO₂ or mixtures of nitrogen and 1,1,1,2-tetrafluoroethane (R134a) or of nitrogen, CO₂ and/or SO₂ or of sulphur and argon is used in magnesium die-casting foundries as inert gas. Magnesium shielding gases usually consist of a reactive and carrier gas. The use of R134a (1,1,1,2-tetrafluoroethane) results in the formation of a MgF₂ protective layer. It is also noted that R134a has a high Global Warming Potential (GWP) of the order of 1 430. The use of SO₂ results in protective MgSO₄, MgS and MgO phases which prevent oxidation. The use of sulphur hexafluoride (SF₆) in magnesium die-casting and in the recycling of magnesium die-casting alloys is prohibited by Regulation (EU) No 517/2014 on fluorinated greenhouse gases as of 1 January 2018.

Magnesium alloys benefit from grain refinement, which is carried out by inoculation with carbonaceous materials. This used to be done with hexachloroethane, but since 1 July 2003 this product is banned in Europe generally to ensure environmental protection and for health and safety reasons. This applies both for magnesium and aluminium alloys.

[74, Brown, J. R. 1999], [120, TWG 2003], [134, CAEF 2020]

2.2.1.6 Copper casting

Copper is cast in the form of various groups of alloys, each having copper as the main element. Short descriptions of some of these are given below:

- *High conductivity coppers*: These are used mainly for their high electrical and thermal conductivities. Applications include tuyères for blast furnaces and hot blast cupolas, water-cooled electrode clamps, switchgear, etc.
- *Brasses*: Cu-Zn alloys, where zinc is the major alloying element. These are easy to cast, with excellent machinability and good resistance to corrosion in air and fresh water. They are widely used for plumbing fittings. High tensile brasses are more highly alloyed and find uses in marine engineering. Brasses are cast both in sand and in permanent moulds.
- *Tin bronzes*: Cu-Sn alloys, where tin is the major alloying element. With tin contents of 10-12 %, tin bronze castings are more expensive than brass. They have high corrosion resistance and are suitable for handling acidic waters, boiler feed-waters, etc. High tin alloys are also used in wear-resistant applications. Their applied casting techniques are sand and centrifugal casting.
- *Phosphor bronzes*: Cu-Sn alloys, with an addition of about 0.4 – 1.0 % P. These are harder than tin bronzes but have lower ductility. They are used for bearings where loads and running speeds are high and for gears such as worm wheels.
- *Lead bronzes*: Cu-Sn-Pb alloys. These are used almost exclusively for bearings, where loads and speeds are moderate.

- *Gunmetals*: Cu-Sn-Zn-Pb alloys. These are the optimal alloys for sand casting. They have a good combination of castability, machinability and strength, and good corrosion resistance. They are used for intricate, pressure-tight castings, such as valves and pumps. They are also used for bearings, where loads and speeds are moderate.
- *Aluminium bronzes*: Cu-Al alloys, where Al is the major alloying element. These combine a high strength with high resistance to corrosion. Their applications range from decorative architectural features to highly stressed engineering components. They have many marine uses, including propellers, pumps, valves. They are also used for the manufacture of non-sparking tools. Al casting techniques are applied.
- *Copper-Nickels*: Cu-Ni alloys, where Ni is the major alloying element. These are used for e.g. pipework for marine applications in severe conditions.
- *Copper-beryllium alloys*: Beryllium is cast as a copper-beryllium alloy for the production of parts that require resistance to corrosion and very high mechanical characteristics. These include plunger tips for die-casting machines, precision parts for the electrical and mechanics industry, in watchmaking, for tooling, and for measurements instruments. Two alloy types are used: a copper-beryllium alloy with 2 % Be, and a copper-cobalt-beryllium alloy with 0.5 % Be. There is a tendency to reduce or exclude beryllium in alloys due to its known carcinogenic character. Casting is done in permanent moulds using pressure or gravity die-casting. For precision parts casting, the investment casting technique is used. [74, Brown, J. R. 1999]

2.2.1.7 Zinc casting

Zinc casting almost exclusively uses the pressure die-casting technique. In the EU, there are mainly two alloys in use; their compositions are given in Table 2.10. They are also referred to as Zamac, which in origin is a trade name. The basis of these alloys is pure zinc.

Table 2.10: Most common zinc alloys, contents in %

Symbol	Alloy number	Al (%)	Cu (%)	Mg (%)
ZnAl ₄ Cu ₁	ZP0410	3.7 – 4.3	0.7 – 1.2	0.025 – 0.06
ZnAl ₄	ZP0400	3.7 – 4.3	0.25	0.025 – 0.06

The zinc alloy is almost exclusively melted in a casting machine, of the hot chamber type. In rare cases, and only when high production capacity is needed, centralised melting may be applied.

Zinc alloys have comparable material properties to aluminium. The main differences are the lower melting point and the higher density of the zinc alloys (6.7 g/cm³ versus 2.6 – 2.7 g/cm³). They are mostly used for small pieces requiring high precision and a low wall thickness. They also allow a higher casting speed to be utilised and result in a 10 times longer die life (800 000 to 1 200 000 shots), which makes them more suitable for large series (of small pieces). The zinc alloys are melted in an electrically or fuel heated cast iron crucible and cast using hot-chamber die-casting machines. The products are used in e.g. automotive and electronics components and in machine construction applications.

2.2.1.8 Lead casting

Lead is a low melting (melting point 327 °C) heavy metal. Lead is relatively soft, corrosion-resistant and has good self-lubricating properties. The uses of lead castings include accumulator sheets, shielding material for X-rays and nuclear applications, and in ballast and counterweight materials. Mainly pressure and gravity die-casting techniques are applied.

2.2.1.9 Casting of superalloys

The superalloys are typically Ni, Ni-Fe, and Co based alloys with Cr, Ti, W, Al additions. They were originally used for high temperature applications (over 810 °C) or in severe corrosive media. Superalloys can be distinguished from high alloyed steels (see definition in Section 2.2.1.3). Since iron is not the major compound (as defined in [99, CEN 2000]), they are considered non-ferrous materials. The casting of superalloys may occur in certain investment casting foundries, as well as partly in foundries which specialise in high alloyed steel qualities.

The nickel base alloys are produced from a group of alloys which have chemical compositions generally over 50 % nickel and less than 10 % iron. They are mainly strengthened by intermetallic precipitation in an austenitic matrix. The cobalt base alloys have a high Co content (40 % to 70 %), high Cr (over 20 %), high W (7 % to 15 %) and they are strengthened by a combination of carbides and solid solution hardeners.

Some superalloys, particularly Ni-Fe and Cobased alloys, are directly melted in electric furnaces by classical methods usually applicable to stainless steels. However for Ni and special Ni-Fe superalloys, vacuum induction melting is required in order to reduce the content of interstitial gases (O, H, N) to a very low level. This enables foundries to achieve high and controlled contents of oxidisable elements such as Ti or Al.

The control of interstitial gases and oxidisable elements is very important for the product's mechanical properties, the corrosion resistance and its reliability. In general, superalloys are cast into complex final shapes where machining is not possible. Therefore, they are mainly produced by investment casting (i.e. using a ceramic mould and even ceramic cores). This casting process produces a product of very precise dimensions with a very smooth surface. Additional processes, such as HIP (hot isostatic pressing), can be used to eliminate the internal porosity that can appear in large castings. In aircraft gas turbine manifolds, directional solidification technology is commonly applied. This technology eliminates the grain boundaries and greatly increases the strength of the material.

Initially superalloys were developed for high temperature applications. However, their field of application continues to expand and now covers areas such as cryogenic temperature appliances and orthopaedic and dental prostheses. In general, superalloys are mainly used in aircraft and industrial gas turbines, in nuclear reactors, in aircraft and spacecraft structures, in petrochemical production and in medical applications.

[100, TWG 2002]

2.2.2 Pattern making**2.2.2.1 General pattern making**

Pattern making, or foundry tooling as it is also called, requires a high level of skill to achieve the close tolerances required of the patterns and core boxes. This step is critical in the casting process since the castings produced can be no better than the patterns used to make them. Patterns are made by means of hand tools, universal machines, or by a CAD/CAM system on computer-numerical-controlled (CNC) machines. In some pattern making shops, computer-aided design (CAD) is used in the design of patterns. Cutter tool paths are designed with computer-aided manufacturing (CAM). The numerical output from these computers is conveyed to CNC machine tools, which then cut the production patterns to shape. Such computer-aided systems have better dimensional accuracy and consistency than manual methods.

Patterns (Figure 2.7) and core box materials (Figure 2.8) are typically metal, plastic, wood or plaster. Wax and polystyrene are used in the investment and Lost Foam casting processes, respectively. Pattern makers have a wide range of tools available to them, including woodworking and metal machining tools. Mechanical connectors and glues are used to join pattern pieces

together. Wax, plastic or polyester putty is used as a filler to fill or round the inside of square corners.

[18, US EPA 1998]



Source: [132, HUT 2003]

Figure 2.7: Wooden pattern



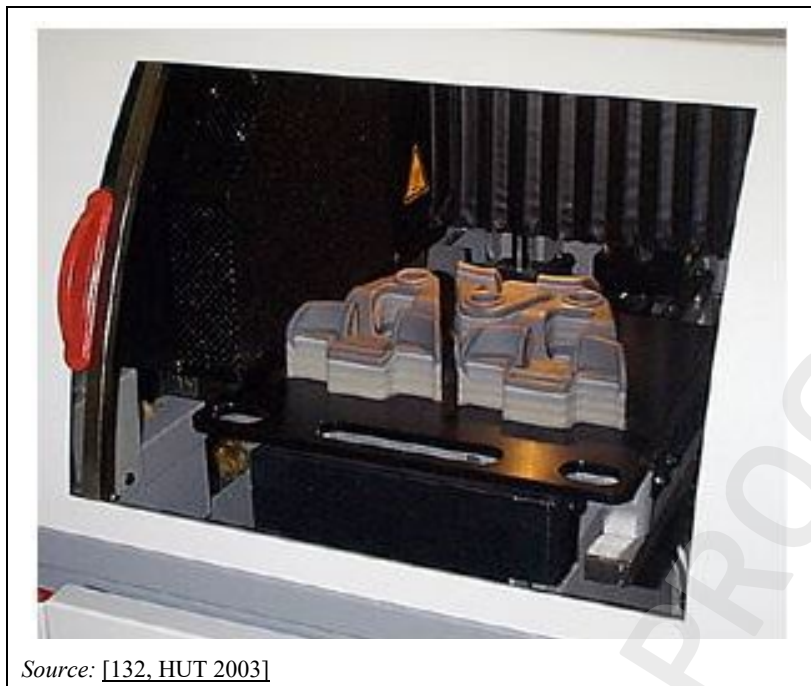
Source: [132, HUT 2003]

Figure 2.8: Core boxes

2.2.2.2 Rapid prototyping (RP)

Rapid prototyping is a technique to pass very quickly from a product concept to a cast prototype. The term 'rapid prototyping' (RP) includes all technical and organisational measures from the formulation of the concept of a product to the manufacture of the product. Rapid prototyping can be used for every stage of product development, i.e. for concept models, geometrical prototypes, functional prototypes or for technical or sales prototypes. All the currently available techniques allow the fabrication of a prototype part from a three-dimensional drawing. Most of the RP processes create a casting, a sand mould or a sand core without a pattern or a core box, e.g. there is direct sintering of sands for the production of moulds or cores.

RP technique consists of building an object to a design pattern by joining particles or layers of raw material such as polymer resin, wax, paper, ceramic powder or sands. In Figure 2.9 an example picture of a wax pattern is given.



Source: [132, HUT 2003]

Figure 2.9: Thermopolymer (wax) patterns in an RP machine

There are four basic steps to rapid prototyping:

1. the creation of a 3D-CAD model;
2. making the interface between the 3D-CAD system and the rapid prototyping system. For example the CAD data may be converted to the STL (Standard transformation format) file format;
3. slicing the STL file into thin cross-sectional layers;
4. realisation of the RP-model.

The advantages of Rapid Prototyping, particularly for complex forms, include:

- shorter development time and the possibility of rapid modifications during the development;
- saving of costs, materials and time;
- early error detection.

[100, TWG 2002], [101, Linxe, D. 2002]

An overview of available techniques is given in Table 2.11.

Table 2.11: Description of rapid prototyping techniques

Process	Principle	Materials	Special features
Liquid – solid	Polymerisation by local UV exposure of a photosensitive resin	Photosensitive resins Acrylates, epoxydes	- shrinkage and deformation - model needs support
Solid – solid	Contours of a layer are cut out from a foil	Paper, metals, polymers	- no supports - consumption of base material
	Deposition of a material showing thermal fusion	ABS, wax, elastomers	- model needs support
	Material jet	Waxes, polymers	- model needs support

Process	Principle	Materials	Special features
Powder – solid	Agglomeration of powder by sintering	Metals, ceramics, sand, polystyrene, nylon, polyamide, wax	- no support - porosity - shrinkage
	Agglomeration of powder by binder projection	Alumina; sand	- no support - porosity

Source: [101, Linxe, D. 2002], [134, CAEF 2020]

At the time of writing of this document (2023), for prototypes or small series, additive manufacturing (AM) of moulds and cores can be applied, without using a pattern.

The process most often applied is called binder jetting. Fine-grained, homogeneously sized sand grains are spread over a building platform. Afterwards, the binder is added via a printhead. The building platform is lowered for the next step. Printed sand moulds or cores use mostly furane resin as binder, but also phenolic resin and inorganic binders.

Other AM techniques include:

- direct metal printing of components from alloy powders (melted in a furnace, sprayed and evenly sized);
- printing of lost ceramic shells for investment casting;
- printing of lost wax patterns for investment casting.

[237, TWG 2023]

2.2.3 Raw materials and raw material/residue handling

The main flows of raw materials entering the foundry are metal ingots, foundry scrap and sand. A distinction can be made between ferrous and non-ferrous foundries. Non-ferrous foundries generally melt only internal return material and alloy ingots (Figure 2.10). The remelting of external scrap is generally considered a separate activity, usually forming part of the secondary metal production. If external scrap is acquired, it is first subjected to a spectroscopy analysis in order to determine the alloy type. Ferrous foundries use pig iron and selected iron and steel scrap as starting materials, besides internal return material. The various qualities of metal feeds are stored in separate areas in order to allow the controlled feeding of the melting furnace.



Figure 2.10: Aluminium scrap (L) and ingots (R)

Raw materials, including fluxes in lump and powder form; foundry cokes for cupola furnaces; deoxidants; and refractories are normally stored under cover. Following delivery, handling is kept to a minimum. Powdered materials may be stored in sealed silos and conveyed pneumatically or kept and handled in sealed bags, as displayed in Figure 2.11.



Figure 2.11: Pneumatic conveyors and silos for powdered materials

Sand is normally delivered in bulk and discharged directly to a silo via a pneumatic conveyor, conveyor belt or grab. Specialist sands may arrive in bags or by silo truck. Used sands are stored in silos for preparation or regeneration and in silos or heaps for transport for external reuse or disposal.

Liquid binders and oil products are delivered in drums, by bulk container or by road tanker. They are stored in their delivery containers or, in the case of rail tankers, discharged direct into a dedicated storage. The containers are connected by pipe directly to the sand/resin/catalyst-mixing unit. Some catalysts and co-reactants are used in a gaseous form, but these are also delivered as liquids and handled in a similar fashion before being vaporised and mixed with a carrier gas. Evaporation is enclosed and may be carried out by a variety of methods.

Release agents and other minor deliveries are stored indoors.

Refractories are delivered in unmoulded (masses) or moulded conditions (bricks and components). Unmoulded refractories have to be kept dry. Extensive moving must be avoided as the material can separate into fines and coarse fractions. Dust will be emitted by the lining operation.

Coarse solid residues, such as used refractories and slags, are stored on separate heaps, in a subdivided storage area or in boxes. They are moved and handled using small lift trucks. Fine solid residues are collected at the filter unit into big bags or containers, which may be stored intermediately before transport for disposal. In order to avoid soil contamination from the various classes of materials, specific measures are taken. Potential impacts are listed in Table 2.12.

The metal charged in the melting furnace is carefully selected and weighed to ensure the correct composition. The charge composition is calculated based on the average chemical composition of each component, the oxidation losses during melting and the required final composition of the casting. The different charge elements are combined into a charging device (e.g. drop bottom skip, vibrating feeder, skip hoist) with a tilting magnet, usually equipped with a weighing system, to allow collection of the correct amount.

Additional alloying elements can be added to the charge as ferro-alloys such as FeSi, FeMn, FeCr, or pure such as Cu, C, Ni. However most alloys are added to the molten metal to prevent metallic losses due to oxidation. Alloying elements are usually present in the foundry in small quantities and are always stored inside the building, preferably close to the melting installation. [14, CAEF 1997].

Table 2.12: Potential soil contamination from ferrous foundry raw materials

Activities	Contaminants of Concern		Potential Impact
Raw materials storage			
Scrap storage – external, often on soil	Loose materials from scrap - metals and coatings		Localised contamination of soil surface
	Oils - may include: - PAH from combustion engine oils - PCBs from capacitors (mainly in shredded scrap, unless PCB phase-out has taken place successfully)		Leaching into groundwater and nearby surface waters
	Cutting fluids - may be chlorinated		
Liquids in underground tanks	Petroleum products, e.g. fuel oil diesel		Leakage into soil with leaching into ground and surface waters
Raw materials handling, transfer and use			
Chemical binder products – accidental spillage or leaks	Phenolic resins	Free phenol content of 0.5 to 5 %	Water-soluble; can leach into groundwater. Rapid degradation if less than 400 ppm. Concentrated larger volume spills will be slower to degrade due to toxicity to bacteria
	Furan resins	Furfuryl alcohol	Water-soluble
	Solvent carriers in resins	e.g. methanol, up to 20 % volume	Mostly water-soluble, can leach into groundwater
	Urethane resins	Aromatic solvents ¹	Solvents could leach into groundwater
	No-bake sand hardeners	e.g. Toluene-, Xylene-, Benzene-sulphonic acids	Could leach into groundwater or alter soil properties, e.g. mobilisation of metals
	Urea-based resins	Ammonia	Can leach into ground and surface waters
	Silicate resins	Alkaline pH	Could leach into groundwater or alter soil properties, e.g. mobilisation of metals
Mould coatings	Isopropyl alcohol (IPA)		Water-soluble, can leach into groundwater
Fuels, maintenance products: - accidental spillage or leaks (particularly around filling points) - deliberate disposal to ground	Fuel oils, diesel, petrol with PAH & SO ₄ ²⁻ post-combustion; Lubrication & hydraulic oils; Quench oils; Transformer oils (potential for PCBs)		Oils can leach into ground and surface waters. Air deposition of PAH and SO ₄ ²⁻ from the combustion of fuel oils. SO ₄ ²⁻ will leach down soil profile. PAH, PCBs will tend to absorb onto soils
¹ Former formulations contained PAH (mainly naphthalene), but naphthalene-depleted formulations have been developed, which have eliminated this contaminant. Source: [47, EU Thematic Network Foundry Wastes 2001], [120, TWG 2003], [134, CAEF 2020]			

2.2.4 Melting and metal treatment

The selection of a melting furnace is an important aspect in the setting up of a foundry process. Each furnace type has its own properties concerning feed requirements and alloying possibilities, which in turn will have repercussions on the full foundry process. On the other hand, the type of metal to be melted determines which furnace may or may not be used. The applicability of the various furnace types is given in Table 2.13.

Table 2.13: Applicability of furnace types, for melting (m) and holding (h)

	Cupola	Electric arc	Channel induction	Coreless induction	Rotary	Hearth type	Shaft	Crucible/Ladle	Other holding furnaces
Iron	m	m*	h	m, h	m*	m		h	
Steel		m		m				h	
Aluminium			m, h	m, h	m	m	m, h	m, h	h**
Magnesium								m, h	
Copper			h	m, h		m		m, h	
Lead				m, h				m, h	
Zinc				m, h				m, h	

* Less common.
 ** Purely holding furnaces either gas-fired or electric (e.g. resistance furnaces).

Iron foundries do not remelt ingots. The metallic charge consists of:

- steel scrap (new scrap or post-consumer) as a low-carbon iron-base material for the charge or pig iron, a kind of simplified cast iron composition high in C and Si;
- internal or external foundry scrap, to be remelted, close to desired composition;
- basic alloying constituents (carbon, silicon, manganese, etc.);
- other alloying constituents like ferroalloys.

Iron foundries melt iron metal of a controlled composition and temperature, supplied at a rate sufficient to match the varying demand of the moulding line. The metallic charge to be melted usually consists of foundry returns, iron and steel foundry scrap and pig iron, with alloying additions such as e.g. ferrosilicon, ferrophosphorus or ferromanganese. The charge is usually melted in a cupola or in an electric induction furnace. Hot-blast cupola furnaces are used to melt large quantities of liquid iron of the same or similar composition in continuous operation for long-series production. Cold-blast cupola furnaces are usually smaller. They allow at least one-shift continuous operation to melt one alloy. Larger cold-blast cupolas are used in continuous operation. Changing the cast iron alloy in a cupola is time-consuming. Induction furnaces are usually operated in batch operation, allowing frequent alloy changes. Each furnace charge is a batch of its own, the next charge can be a different alloy. Most common is the medium-frequency induction furnace. A 'battery' of two or more induction furnaces allows a quasi-continuous operation. The net frequency induction furnace is an older type, operating with a liquid heel. This is used for more or less continuous operation with few changes of the cast iron alloy. Rotary furnaces are usually smaller and melt cast iron in batch operation. Short-term holding, transport and metal treatment are performed in ladles. Induction furnaces are gradually gaining higher market preference compared to the cupola type. Coreless induction furnaces are used for melting. Channel induction furnaces are only used for holding, their main application being in combination with the cupola furnace, in the so-called duplex configuration. Gas-fired and oil-fired rotary furnaces can also be used, although their use is less common. Short-term holding, transport and metal treatment are performed in ladles.

Steel foundries do not remelt ingots. Like iron foundries, they use different charge materials but with low carbon content. Like steelworks, they can perform secondary metallurgy to refine the cast steel composition.

The charge varies largely for unalloyed, low alloyed and high alloyed cast steel grades.

The metallic charge consists either of:

- steel scrap (new scrap or post-consumer) as a low-carbon iron-base material for the charge or internal or external foundry scrap, to be remelted, with about the desired composition; or
- alloying constituents like ferroalloys.

Steel foundries melt steel of a controlled composition and temperature, supplied at a rate sufficient to match the varying demand of the moulding line.

Steel is melted in both electric arc and induction furnaces. Large steel foundries may use electric arc furnaces, but induction furnaces are more commonly used. Arc furnaces are capable of using low cost scrap charges, since refining takes place in the furnace. However, they have the limitation that there is always some carbon pick-up from the graphite electrodes, so very low carbon stainless steels (< 0.03 % content in carbon) cannot be made. In the induction furnace, refining is not possible, so a carefully selected charge must be used. However, any type of steel may be melted. Short-term holding, transport and metal treatment are performed in ladles.

The melting furnace used in non-ferrous melting is dependent on the foundry size. Non-ferrous foundries with low capacity often use a variety of different alloys and/or have a limited melting capacity. In this case, melting is done in small volume furnaces, for which the crucible furnace is most suited. Additionally, die-casting is the major casting technique. In this case, there often is no need for a centralised melting, as the melting (and holding) furnace is integrated into the casting machine. Non-ferrous foundries with a higher capacity and a need (or reason) for centralised melting typically use induction, hearth type or shaft furnaces for melting, and then distribute the molten metal to holding furnaces and casting crucibles.

[73, Brown, J. R. 2000], [120, TWG 2003] (CAEF submission in [237, TWG 2023])

2.2.4.1 Cupola furnaces

2.2.4.1.1 Cold blast cupola furnace

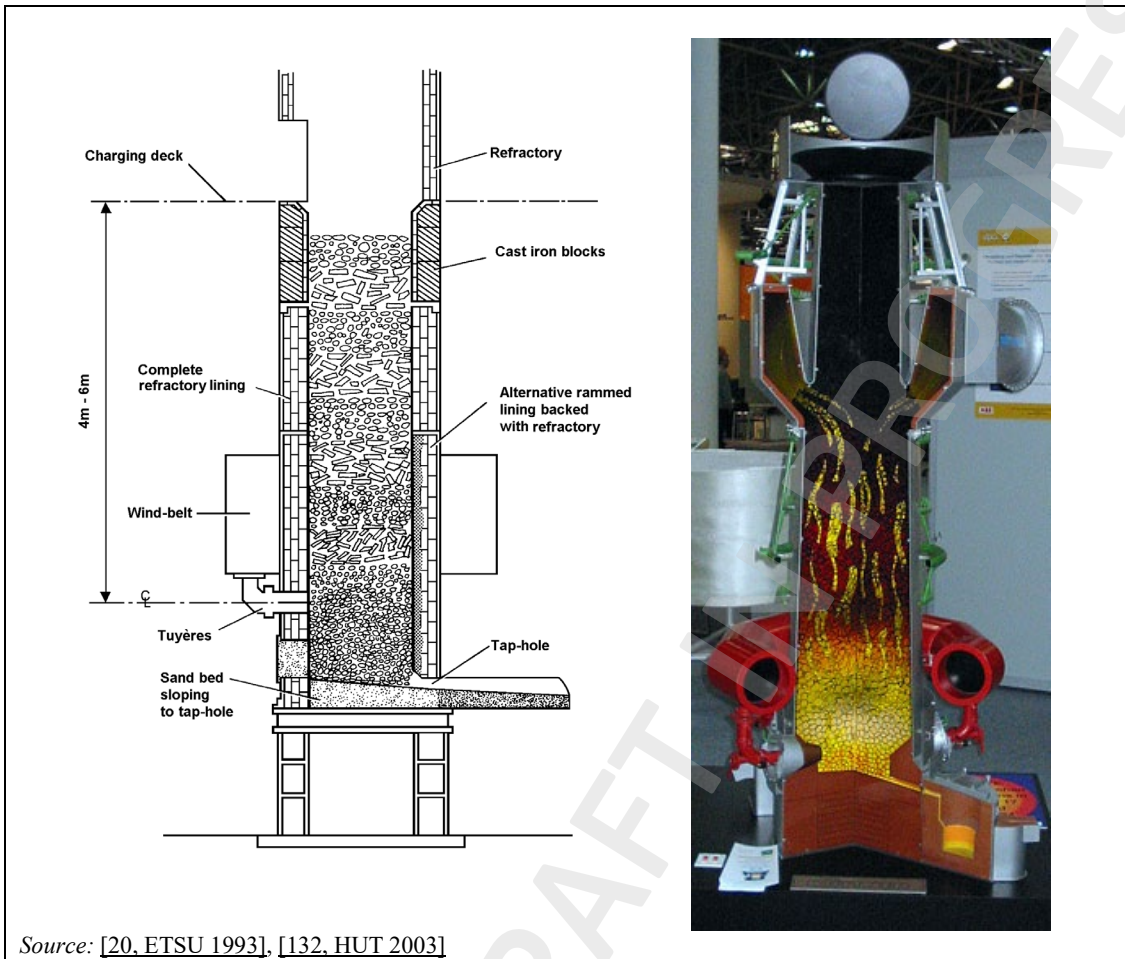
Description

The cupola is a refractory-lined shaft furnace. The metal charge is heated and melted by the combustion of coke, which takes place in the lower part of the shaft (the 'hearth'). Ambient air with ambient pressure is injected in the hearth through a ring with several exhaust nozzles ('tuyères') resulting in an evenly distributed air flow. The charge consists of ferrous metal (pig iron, steel scrap, scrap iron, foundry returns), foundry coke, alloying elements (e.g. FeSi, SiC), slag forming (SiO_2) and fluxing agents (e.g. CaCO_3). The charge is added through a charging door at the upper part of the shaft. Combustion gases rise up from the hearth and heat the charge, before leaving the cupola stack.

Operation

In the combustion zone, the metallic charge melts. A part of coke burns with air oxygen. Molten metal drops through the coke bed, dissolves carbon (carburising effect) and gathers below in the well. The dynamic Boudouard equilibrium $2 \text{CO} = \text{C} + \text{CO}_2$ (exothermal) is the principal cupola reaction. High temperatures shift it to the CO side. Below the tuyères, the iron droplets are protected by the reducing atmosphere. Above, some metal oxides can be oxidised before the tuyères. Limestone prevents SiO_2 formation. Impurities (oxides) are trapped in the slag, consisting of SiO_2 , CaO , Al_2O_3 and FeO . Fluxing agents lower the viscosity of the slag. Due to its lower density, the slag floats on the molten metal in the well. Once the liquid metal in the well has reached a certain level, a tap-hole is opened. The metal flows via a refractory-lined channel into a collection vessel (fore-hearth), a ladle or a holding furnace.

The slag is tapped separately by means of a dam and a slag spout placed at a higher level. It is collected discontinuously in pots, or continuously granulated in a water stream, or granulated dry, for subsequent use, e.g. in road construction.



Source: [20, ETSU 1993], [132, HUT 2003]

Figure 2.12: Schematic outline and miniature model of a (cold blast) cupola furnace

Economy

Larger cold-blast cupolas are operated continuously; smaller cupolas are run for one extended shift.

In order to reduce the CO₂ emission and increase the energy efficiency, the conversion of cold blast furnaces to hot blast furnaces may be considered. However, for medium-sized foundries handling less than 2 000 tonnes/month of good castings, the hot blast cupola will be difficult to consider because of the large investment it requires. The use of a hot blast cupola is also restricted to continuous melting, otherwise the running costs are too high.

[20, ETSU 1993], [59, Godinot 2001], [100, TWG 2002], [134, CAEF 2020]

Maintenance

One specific feature of the cupola furnace is that the lining material (quartz-clay mixture) of the furnace at the melting and heating zone only lasts for one melting campaign. The intense heat and the presence of slag results in a chemical dissolution and mechanical wearing of the lining, which consequently converts it into slag. Cupola furnaces are therefore normally constructed in pairs. While one furnace is melting, the second one is relined with new refractory material. The operation is switched the next day of use.

[38, Vito 2001]

Advantages

- Light shredded steel scrap (economical) can be used, oxidising some trace elements and carburising with coke.
- The thermal efficiency is acceptable if appropriate measures are utilised.
- Option to substitute anthracite coke at least partly with biocoke (see Section 5.2.4).

Disadvantages

- The production regime is not flexible.
 - Difficult production management because of the slowness of the system.
 - Expensive charge with pig iron, and little steel scrap.
 - No quick alloy change possible.
 - Sulphur pick-up/take-up in the cupola.
 - An environmental burden is caused by the foundry, i.e. lots of dust, slag and refractory lining.
 - Big dedusting installations are needed because of the high flue-gas rate.
- [38, Vito 2001], (CAEF submission in [237, TWG 2023])

2.2.4.1.2 Hot blast cupola furnace**Description**

The hot blast cupola is a refractory-lined shaft furnace. The metallic charge is heated and melted by the combustion of coke in the lower part of the shaft (the ‘hearth’). Preheated air with elevated pressure is injected in the hearth through a ring with several exhaust nozzles (tuyères). This increases efficiency, compared to the cold blast cupola.

Hot-blast cupola furnaces are used to melt large quantities of liquid iron of the same or similar composition in continuous operation for long-series production.

Operation

The efficiency of operation can be improved by oxy-fuel burners which can replace a fraction of the charge coke. Special burners allow the injection of fine metallurgical carbon of any kind.

The two methods of heating are the following:

- *Recuperative heating*: This involves the transfer of the residual (‘latent’) heat of the flue-gases to the combustion air. The flue-gases are collected at the top of the furnace, mixed with sufficient air and then burned in a post combustion unit. This provokes the exothermic oxidation of CO. The burnt gases are led through a heat exchanger (recuperator) where the heat is transferred to the combustion air. Typically the blast air is heated at temperatures of 500 °C to 600 °C. Above these temperatures, problems arise with the sintering of furnace dust on the surface of the recuperator.
- *External heating*: Here the combustion air is heated by some external means, e.g. by a gas or fuel burner, by electrical resistance or by a plasma torch.

The combination of these two heating methods, permits the superheating of the blast air up to 1 000 °C. These high temperatures, however, require the use of more expensive refractory materials and heat-resistant steels.

Recuperative systems offer increased energy and thermal efficiencies. The effect of air preheating on thermal efficiency and coke use is depicted in Figure 2.13. It should be noted that the coke quality may affect the overall blast efficiency.

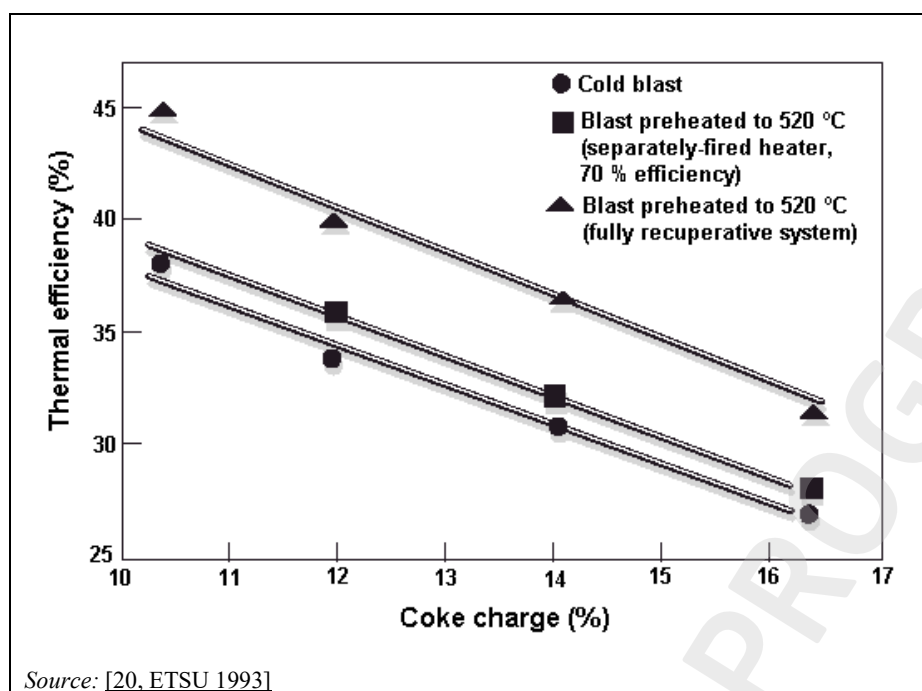


Figure 2.13: Effect of air preheating on blast furnace efficiency

The hot blast cupola remains the most widely applied melting device for mass production foundries, e.g. for parts for the automobile industry, centrifugally casted cast iron pipes, road accessories.

Hot blast cupolas are normally set up for long campaign operation, in order to minimise process switch overs and maintenance time and effort.

[14, CAEF 1997], [20, ETSU 1993], [59, Godinot 2001], [134, CAEF 2020] (CAEF submission in [237, TWG 2023])

Advantages

- Light shredded steel scrap (economical) can be used, oxidising some trace elements and carburising with coke.
- Reduced coke consumption.
- High energy efficiency, heat recovery.
- Heat recovery for internal process heat (core drying, etc.) or external use (sector coupling, district heating).
- High tap temperature.
- High melting capacity.
- Less sulphur pick-up in the cupola.
- Possibility to use different kinds of cheap lower grade ferrous scrap.
- More scrap steel can be used because of the higher pick-up of the carbon by pig iron.
- Option to substitute anthracite coke at least partly with biocoke (See Section 5.2.4).

It should be noted that not all these advantages can be attained at the same time. For example, an increase in the proportion of steel scrap in the furnace charge may require an increase in the proportion of coke for recarburisation; this in turn will reduce the melting rate and increase the sulphur pick-up. Changes in production management are supported by digital furnace steering systems. (CAEF submission in [237, TWG 2023])

Disadvantages

- Production regime is not flexible (designed for supplying one base iron in large quantities).
- Limited to iron alloys only, no quick alloy change possible.
- Big dedusting installations are needed because of the high flue-gas rate.

[38, Vito 2001], [134, CAEF 2020], (CAEF submission in [237, TWG 2023])

2.2.4.1.3 Long campaign cupola

A **long campaign cupola** is usually a water-cooled refractory lined cupola that may be hot blast or cold blast. Such cupolas are operated daily for one, two or three shifts and are very often used only as a single unit. This form has a campaign life of several weeks or months. The liningless cupola allows a much longer campaign life but heat losses through the furnace shell can be significant. Further developments in refractories and operating practices are continually being made which improve the life and cost effectiveness of the long campaign cupola. A schematic representation of a long campaign cupola with an in-shaft afterburner is given in Figure 2.14.

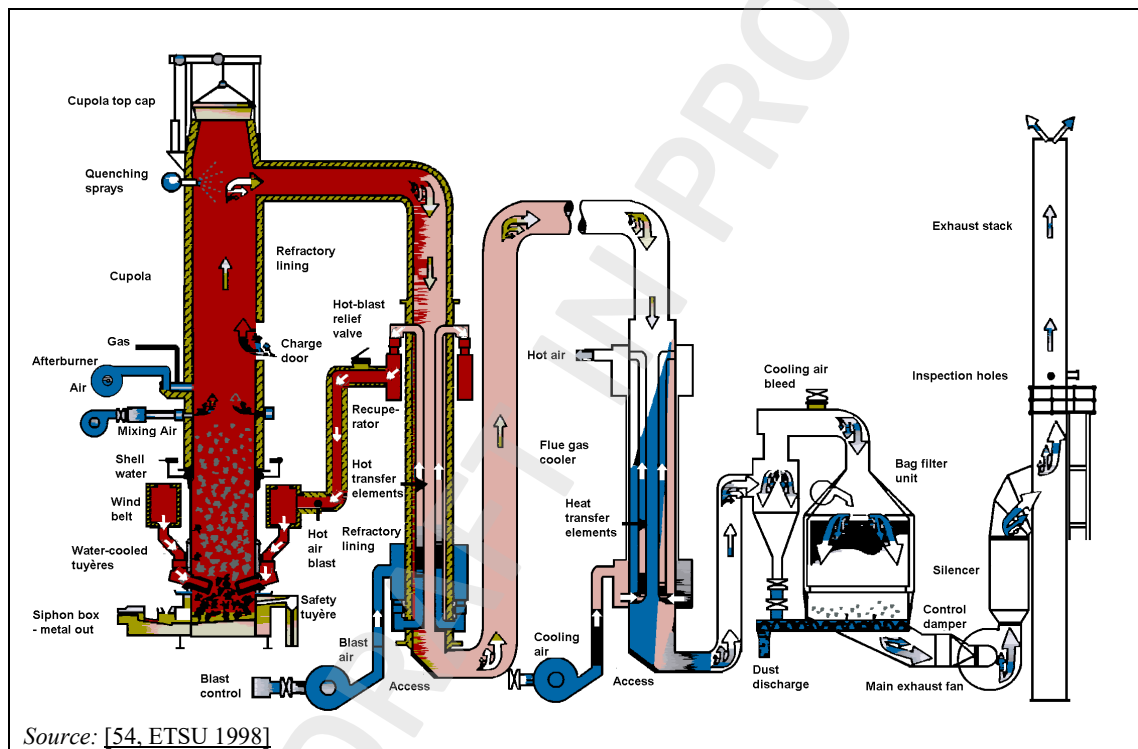


Figure 2.14: Schematic representation of a long campaign cupola

To allow for long campaign operation the following measures need to be taken:

- apply a more persistent refractory lining of the shaft, bottom and the hearth;
- apply water cooling of the furnace wall: this keeps the wall temperature low and thus prevents rapid wearing of the hearth lining;
- use water-cooled blasting pipes that penetrate deeper into the furnace shaft. Here, the combustion zone is not in direct contact with the furnace lining; water-cooling has also been used for reasons other than only reducing the consumption of refractories, such as:
 - to extend the duration of the melt;
 - to enable the internal diameter of the furnace to be increased, thus allowing a higher melting rate.

In the liningless operation, the charge is in direct contact with the water-cooled steel furnace shell. Liningless operation is only used on relatively large capacity cupolas, melting for long campaigns. This results in the following advantages:

- only one cupola is required;

- the cupola only requires internal repairs after one, or several, week's operation;
- daily bed-coke consumption is reduced;
- monitoring is easier throughout the campaign, because of the constant diameter and the more consistent melting conditions.

[14, CAEF 1997], [20, ETSU 1993], [38, Vito 2001], [54, ETSU 1998], [134, CAEF 2020]

2.2.4.1.4 Nature of atmospheric emissions

Cupolas can be charged with a wide range of iron-containing materials. Some of them may contain impurities such as rust, sand and even unseparated non-ferrous materials. The metallurgical coke can break into small pieces, as can the added fluxing materials. Breakage and mechanical abrasion during charge preparation, as well as during charging itself, generate particles, some of which are immediately emitted.

During melting, abrasion of the refractory lining by the charge will also generate dust (as in any melting furnace).

A third source of particulate matter is coke ash, which is not trapped by the slag phase.

Particulate matter of various sources, if light enough, can be entrained in the combustion gases of the cupola. Under certain conditions metallurgical fume may be generated from the melting zone, leading to a visible plume from the cupola stack. The smoke particles consist of submicron agglomerates of spherical soot particles and metallic oxides, such as ZnO, PbO, etc., if the metals are present in the charged steel or iron scrap, such as in galvanised or painted scrap. The smoke emission will increase with the proportion of coke and contaminants in the charge, the blast temperature, and the oxygen injection rate.

Carbonaceous smoke is airborne matter formed by the incomplete combustion of organic matter in the cupola. Scrap contaminants such as oil and grease will form oily vapours in the stack gases. Vapours and partially burnt organic matter may carry unpleasant odour. Again, scrap cleanliness and its nature significantly effect the nature of the emissions. Clean scrap avoids generation and emission of organic substances.

The burning of coke creates gas emissions containing CO₂, CO and SO₂ (odorous). Decreasing the proportion of the coke charge (by oxy-fuel combustion) or (partial or complete) substitution of the anthracite coke by natural gas or by biocoke can help reduce the levels of these substances. (CAEF submission in [237, TWG 2023])

2.2.4.2 Electric arc furnace (EAF)

2.2.4.2.1 Description

The EAF is a batch-melting furnace consisting of a large bowl shaped refractory lined body with a dish shaped hearth. The wide furnace shape allows the handling of bulky charge material and leads to efficient reactions between the slag and metal. Typically the shell diameter is 2 m to 4 m. As shown in Figure 2.15, the furnace is covered by a refractory roof, which has ports for three graphite electrodes. The electrodes are supported by arms, which allow movement up and down. Most furnaces use roof charging: by moving the roof and electrodes aside, the furnace can be charged using a drop bottom charging bucket or a magnet. The metal charge is heated by an electric arc, which is created by a three phase alternate electrical current between the three graphite electrodes. These are positioned above the charge, which itself acts as the neutral.



Source: [132, HUT 2003]

Figure 2.15: EAF

The furnace is tapped by tilting it, forcing the metal to flow out through the spout. Opposite the spout, an operable door allows deslagging and sampling operations to be carried out prior to tapping.

The lining of the furnace may be acidic (SiO_2 -based refractory) or basic (MgO -based refractory). A basic lining allows the use of virtually all kinds of steel scrap. The furnace can also be used for the production of high alloy and manganese steels. If scrap with high phosphor or sulphur content is used, lime and limestone which are usually added for dephosphorisation and desulphurisation. An acidic lining would be attacked by these compounds. Therefore, the acidic type refractory is used for melting scrap with a low sulphur or phosphorus content only.

Electric arc furnaces are almost exclusively used for the melting of cast steel. Only in a few cases are they used for cast iron production, which requires carburisation of the melt. Electric arc furnaces designed for steel foundries' purposes usually range from 2 to 50 tonne capacities. They can be run intermittently and are suitable for a wide range of steel analyses. They can provide steel at high temperatures, with typical meltdown times of about one to two hours, while achieving high thermal efficiencies of up to 80 % (without taking into account the efficiency of electric power generation). Power consumption varies from 500 kWh/tonne to 800 kWh/tonne of molten steel, depending on the furnace capacity, the hot metal consumption, and the refining techniques, tapping temperature and pollution control equipment applied. The total melt time is typically 1 to 4 hours. Newly built EAFs are able to process lower quality post-consumer steel scraps. They require a high voltage supply and special shielding methods. For cast irons, metallurgical measures are required to achieve the desired graphite structure (CAEF submission in [237, TWG 2023]).

2.2.4.2.2 Melting and refining with the acidic-lined EAF

Due to the chemical nature of the acid lining (SiO_2), the refining abilities of this type of furnace are restricted to decarburisation. Consequently considerable care has to be exercised in selecting the charge for acceptable sulphur and phosphorus levels, as these cannot be removed in the acid melting practice. The charge consists of balanced quantities of pig iron, foundry returns and purchased scrap. The carbon in the charge is held at a high enough level so that after melting it is 0.2 % to 0.4 % above the final level.

The decarburisation starts by injecting oxygen into the metal bath. This creates a strong stirring action during which carbon in the melt is burned. At the same time the 'boiling' burns out Si, and

flushes out H₂ and N₂ from the metal bath. All impurities (oxides) are trapped in the slag. During melting, sand (SiO₂) may be added to bring the slag to the proper consistency. When the carbon reaches the proper concentration, oxygen injection is stopped, and silicon and manganese are added to halt the boiling reaction.

After slag removal the metal composition is controlled and adjusted if necessary. Finally the metal is deoxidised by adding aluminium or other agents into the melt stream during tapping, to prevent the formation of CO bubbles during solidification. Additional desulphurisation and or dephosphorisation refining can be done in an AOD or VOD converter (see Sections 2.2.4.9 and 2.2.4.10).

[14, CAEF 1997], [63, UK Environment Agency 2002]

2.2.4.2.3 Melting and refining with the basic-lined EAF

The alkaline MgO-based lining of this EAF makes it possible to refine the metal in the furnace itself. Therefore it is possible to charge the furnace with virtually any combination of scrap and foundry returns. The basic lining practice is used when the purchased scrap contains higher phosphorus and/or sulphur levels than desirable.

Dephosphorisation of the melt is performed by periodic additions of lime during meltdown. Upon the injection of oxygen in the bath, phosphorous oxide is formed and trapped in the slag, together with other metallic oxides and impurities. The lime keeps the slag very basic, which stabilises the phosphorous oxide. At the same time carbon is burnt out. After sufficient reaction time, the oxygen injection is stopped and the slag is fully removed.

Desulphurisation takes place in a second stage, in a similar way but at a higher temperature. Again, lime or limestone is added to the melt, reacting with sulphur to form insoluble CaS, that is trapped by the slag. Periodic additions of carbon, aluminium, or FeSi reduce the metallic oxides (e.g. manganese-, chromium oxides), and thereby minimise losses of these elements from the metal bath. All other impurities (oxides) are trapped in the slag and removed during the final deslagging operation.

After refining the metal composition is controlled and adjusted if necessary. Finally the metal is deoxidised by the addition of aluminium or other agents in the metal bath prior to tapping, to prevent the formation of CO bubbles during solidification. Further metal treatment, using an AOD or VOD converter (see Sections 2.2.4.9 and 2.2.4.10), may be applied if the final alloy composition requires it. [14, CAEF 1997], [63, UK Environment Agency 2002]

2.2.4.2.4 Nature of atmospheric emissions

The emissions from EAFs originate from the charging, melting, and refining operations and during tapping of the furnace.

During charging, dust and particles will be emitted from the open furnace body. When charging a hot furnace (for instance when melting with a molten heel in particular), any combustibles such as grease, paint or oil ignite and give rise to smoke plumes of burned and partially burned organic material and dust particles. The mechanical abrasion of the furnace lining also generates additional dust.

During melting, heating of the scrap generates metal oxide fumes that significantly increase during the decarburisation treatment. The injection of oxygen gas into the molten metal develops significant quantities of iron oxide fumes, which leave the furnace as red clouds. The addition of slag forming materials increases the furnace emission, but only in small quantities and only for a short time.

Minor emissions occur during the transfer of the molten metal into a ladle or holding furnace.

Emissions from the melting operation itself are referred to as primary emissions. Secondary emissions are the fumes and dust originating from the charging and tapping.

In considering the nature and quantities of the emissions, the different sources of dust and fume emissions, as described above, demonstrate that large differences exist between foundries, depending on the cleanliness of the charged material, the applied charging procedure, the composition of the charge, the refining treatments and on the additions to the melt. Since no coal or fuel is burned in the furnace the emissions solely depend on these parameters.

2.2.4.3 Induction furnace (IF)

Induction furnaces are used to melt both ferrous and non-ferrous metals. There are several types of induction furnaces available, but all operate by utilising a strong magnetic field created by passing an electric current through a coil wrapped around the furnace. The magnetic field in turn creates a voltage across, and subsequently an electric current through, the metal to be melted. The electrical resistance of the metal produces heat, which in turn melts the metal. Induction furnaces are made in a wide range of sizes. The induction furnace is suited for the melting of cast steel, cast iron and non-ferrous metals, using suitable refractory lining for each case.

Proper functioning of the water cooling circuits is crucial to prevent the coil from overheating. The water cooling systems are therefore designed to provide the highest level of reliability, and thus incorporate various thermostats and flow-meters. [18, US EPA 1998], [38, Vito 2001]

2.2.4.3.1 Coreless induction furnace

Description

The coreless IF is a batch-melting furnace containing a water-cooled copper coil, the inside of which – the crucible – is internally refractory-lined. The outside is insulated and enclosed in a steel shell. The furnace body is mounted in a frame equipped with a tilting mechanism. A coreless induction furnace is normally a refractory-lined bucket-shape refractory, the top of which is open for charging and deslagging operations (see Figure 2.16).

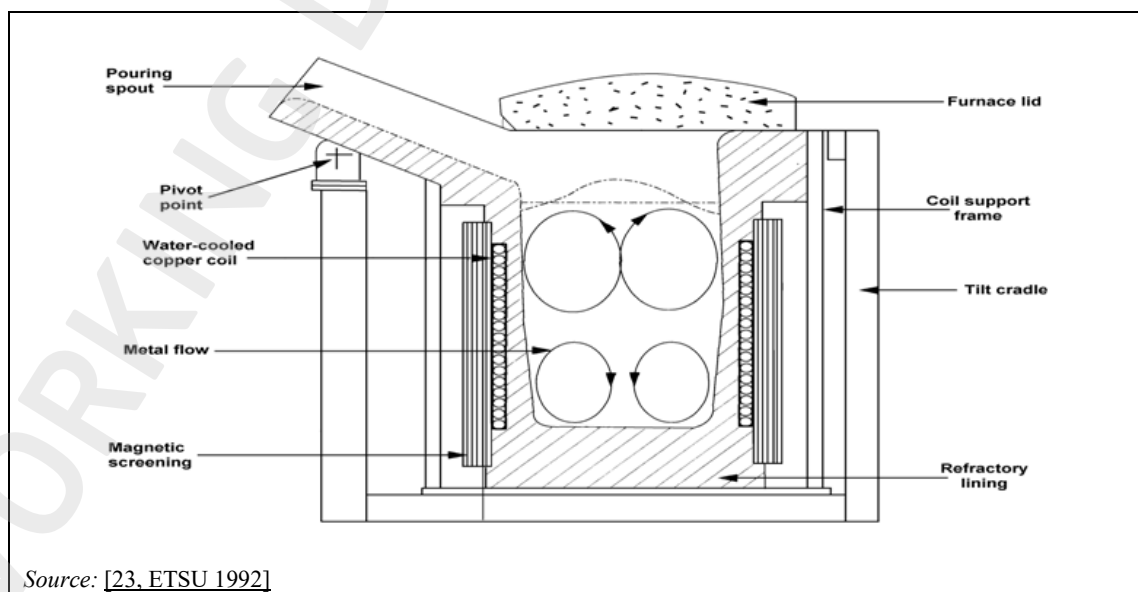


Figure 2.16: General arrangement of a coreless induction furnace

According to the capacity, the furnace is charged by a lifting magnet, bucket skips, a vibrating conveyor or manually. A large number of foundries use induction furnaces for producing relatively small lots or for changing alloy compositions. Typical furnace capacities range from some 100 kg up to 30 tonnes. The core is fed by mains, medium or high frequency alternating current (50 Hz, 250 Hz or 1 000 Hz, respectively).

Depending on the installed power density and the melting practice, the thermal efficiency generally ranges from 60 % to 75 % (see Figure 2.147), without taking into account the efficiency of electric power generation.

The coreless induction furnace can be designed to operate at any frequency usually from 50 Hz upwards, although furnaces operating at a lower frequency of 35 Hz are also used (more seldom). The induction heating of liquid metal causes a stirring effect. The lower the frequency of the primary current, the more intense is the stirring. Therefore, in a mains frequency furnace working at 50 Hz or 60 Hz, the turbulence is greater than in one operating at higher frequency. Because of the high turbulence, the power input to a mains frequency furnace is restricted to around 250 kW per tonne of capacity. With higher frequencies, the power density can be increased to three or four times this level.

The frequency of operation also affects the current penetration. The higher the frequency, the lesser the penetration depth. This affects the minimal charge piece size and the effective furnace size. 50 Hz furnaces are not practicable at capacities below 750 kg. At 10 kHz, charge pieces less than 10 mm in diameter can be heated, so furnaces as small as 5 kg capacity can be used. Frequencies are usually limited to 250 Hz to 350 Hz (in the case of variable frequencies), as at higher frequencies metal homogenisation becomes insufficient. Higher frequencies are only used in special cases, e.g. with very small furnaces or for melting alloys which require a smooth bath surface to avoid oxidation. Figure 2.17 shows coreless induction furnaces of various sizes.

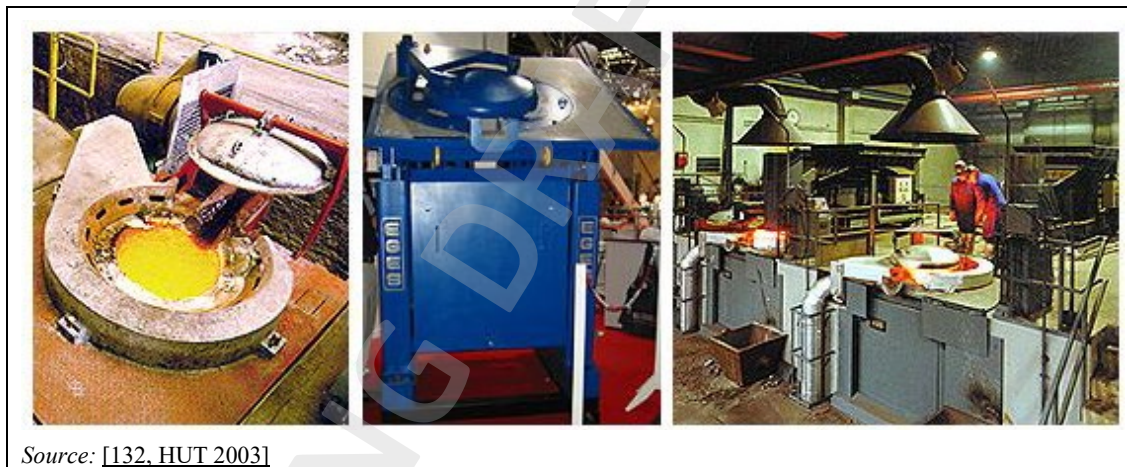


Figure 2.17: Coreless induction furnaces

Water-cooling systems are essential for operation of the coreless induction furnace. Cooling the coil protects both the coil and the insulation from thermal damage, not only during normal operation but also during the cool-down period when the power has been switched off and the furnace emptied. Several types of cooling are available, using closed circuits with heat-exchangers or open evaporative systems. The cooling system can be used for internal energy recovery. Due to the low temperature difference typically about 40 K, it is often used for hall or water heating.

[14, CAEF 1997], [23, ETSU 1992], [38, Vito 2001], [75, ETSU 1998], [100, TWG 2002], (CAEF submission in [237, TWG 2023])

Melting practice

The coreless induction furnace is used for melting but cannot be used for refining. Therefore, in steel foundries the induction furnace has to be charged with raw materials of the ‘correct’ chemical composition, i.e. that corresponding to the required composition of the melt; hence steel scrap is mainly used. If necessary, the metal can be refined after melting in an AOD converter or in special treatment ladles (see Section 2.2.4.12).

High powered furnaces allow melting following the ‘tap and charge’ method. Here the furnace is tapped completely empty and charged with cold material to start the next melting cycle. The method of maintaining a liquid heel in the furnace is used on low powered (mains frequency) furnaces where approximately one third of the melt is tapped before the cold charge material is added. This procedure could be applied when charging DRI/HBI (Direct Reduced Iron/Hot Briquetted Iron), if available, to cope with the large amount of slag. DRI/HBI does not couple to the electromagnetic field. Medium-frequency induction furnaces are applied in most iron and steel foundries because of their high productivity and higher flexibility. This may be affected by the availability of new pre-consumer scraps. Indeed, medium frequency requires lower field penetration depths than mains-frequency furnaces. For this reason, the thermal efficiency for cast iron materials is better because the ferro-magnetic properties of the charge can be taken advantage of. Medium-frequency furnaces are emptied after each charge; the next charge may have a different composition. Mains-frequency induction furnaces are never applied in steel foundries.

Steel grades containing more than 0.2 % of reactive elements such as Al, Ti and Zr cannot be melted in an oxidising environment such as air. They require an inert atmosphere or a vacuum melting and casting method. This is obtained by placing an induction furnace in a vacuum or airtight chamber. The application of a vacuum ensures very good degassing of the melt. Highly oxidisable elements are added in vacuum or after backfilling with an inert gas.

Induction furnaces are excellent melting units and can be used for combined melting and holding. Many types of coreless induction furnaces are available, with fixed or removable crucibles. For aluminium, both channel and coreless induction furnaces are available for melting and holding. However, the channel type is seldom used, due to difficulties in keeping the channel open and due to the need to maintain a molten heel at all times. [14, CAEF 1997], [24, ETSU 1994], [134, CAEF 2020], (CAEF submission in [237, TWG 2023])

Advantages

Due to its multiple advantages, the induction furnace is increasingly being implemented. Its main advantages are:

- higher flexibility in alloys and melting regime; as such, it is an ideal melting technique for jobbing foundries and special alloys;
- short meltdown times;
- little maintenance, depending on the lifetime of the refractory lining;
- good process control: computer support and fully automatic operation is possible, which allows optimal temperature control;
- maximum thermal efficiency is possible, if process parameters are locally calculated and set-up;
- heat recovery from the cooling water is possible, mainly for lower-energy uses as hall or water heating;
- intense stirring in the bath makes the melt homogeneous;
- charging, sampling and deslagging of holding the liquid metal, though typically with low efficiencies, although high holding efficiencies have been reported for copper and aluminium.

Disadvantages

- The operator is fully dependent on the connection conditions of the local electricity grid, the energy costs and any possible extra costs (peak control, etc.)

- The cleaning action of the induction furnace on the melt is limited because of the small amount of slag and the relatively small contact area between the slag and melt. This requires the use of a high quality, and thus, more expensive charge than cupola or EAF.
- It has a low efficiency during holding because of the heat losses in the water-cooled induction coil.
[38, Vito 2001], [134, CAEF 2020], (CAEF submission in [237, TWG 2023])

2.2.4.3.2 Channel induction furnace

Description

This type of furnace is mainly used for holding purposes, though it may also be used as a combined melting and holding aggregate.

The channel induction furnace consists of a crucible with highly insulated refractory lining, equipped with a top-lid. The charge is introduced from the top (Figure 2.18). The bottom is equipped with one or more U-shaped (ferrous) or W-shaped (non ferrous) channels. Around these channels is an air- or a water-cooled induction coil, which heats and circulates the metal. The induction current has the frequency of the local electricity grid. The furnace is generally mounted in an hydraulically tiltable frame for tapping or maintenance operations. Pressurised and non-tilting furnaces are also in use.

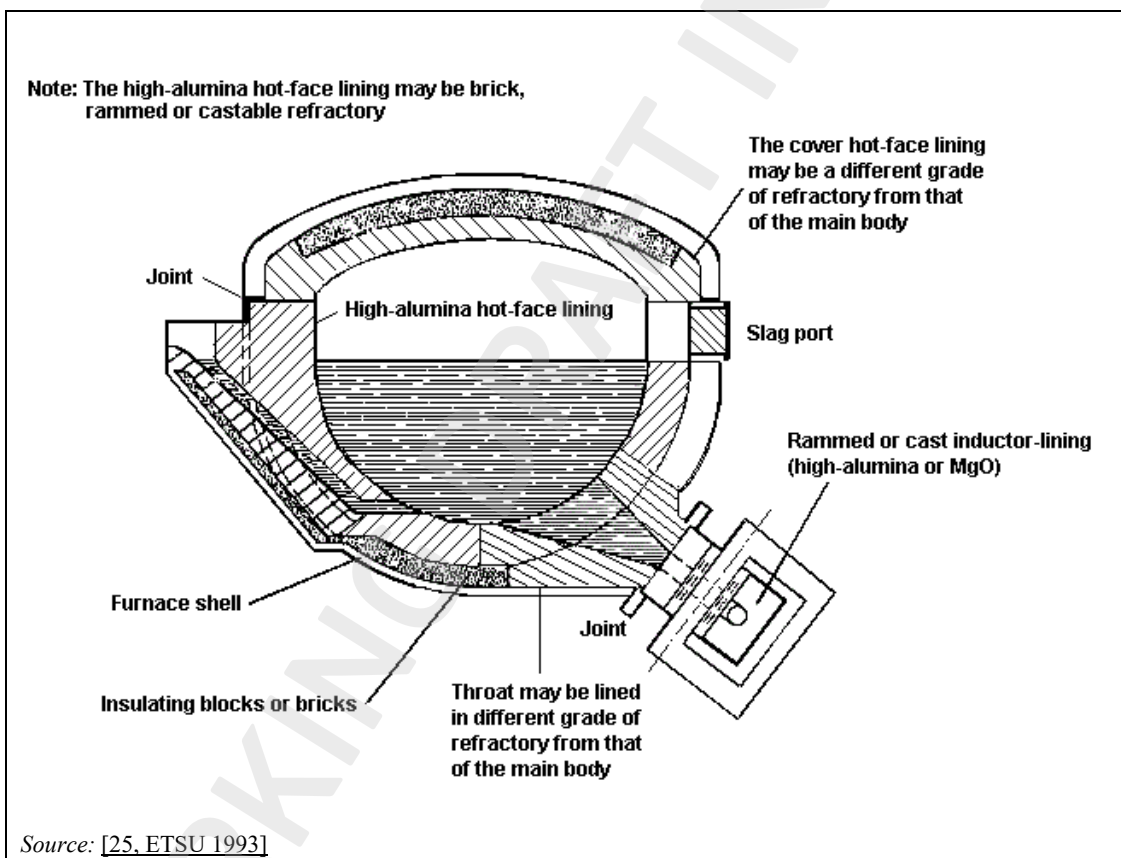


Figure 2.18: Typical construction of a bath channel furnace

In order to allow operation, a minimum amount of molten metal needs to stay inside the crucible and channel. The crucible needs to stay filled up to one third of its capacity. Two values are usually quoted when the capacity of a holding furnace is defined, these are total capacity and useful capacity; for example 60/35 tonnes. The difference between these two values represents the amount of metal that must be retained in the furnace. The amount of liquid metal which needs

to remain in the furnace depends on the vessel design, inductor position in the vessel and others parameters such as power rate, frequency and type of metal.

Thermal losses through the cooling water and the furnace wall are low compared to those in the coreless induction furnace. Equipping the furnace with pouring channels according to the ‘teapot principle’ allows for a reduced oxidation of the melt and wearing of the refractory.

Due to the large content of the crucible, any changes in the melt composition are flattened out. This principle however counteracts the flexibility of the furnace, as changing to another melt composition requires a long transition period. In practice, the melt composition is therefore kept fairly constant.



Source: [132, HUT 2003]

Figure 2.19: Channel induction furnace

The channel induction furnace finds its main application as a holding and pouring furnace in iron foundries. An example picture is given in Figure 2.19. The capacity varies between 5 tonnes and more than 100 tonnes. The holding furnace serves as a buffer between the melting and casting shop. It is important to assess foundry and production requirements fully when considering whether to use a holding furnace. There may be more cost-effective and energy efficient methods of achieving the requirements, and it is advisable to investigate thoroughly all possible solutions before a decision is made. For aluminium, the channel type is seldom used, due to difficulties in keeping the channel open and due to the need to maintain a molten heel at all times.

Output requirements are an important consideration when deciding the size of a channel furnace. [24, ETSU 1994], [25, ETSU 1993], [38, Vito 2001], (CAEF submission in [237, TWG 2023])

Advantages

- High thermal efficiency as a holding furnace.
- Minimal burn-out of the alloy elements.
- Little maintenance.
- Pouring applications are possible.

Disadvantages

- A substantial amount of molten metal has to be kept in the furnace.
- The furnace cannot perform a cold start because of the limited power density that can be achieved in the loop.
- Difficult to monitor the channel wear.
- Potential danger of accidental leaks, because of the induction coil on the bottom.
- Contact between the cooling water and metal is difficult to prevent.

[38, Vito 2001]

2.2.4.3.3 Nature of emissions

Since no coal or fuel is burned in the induction furnace and no refining procedures are executed, the emissions solely depend on the cleanliness and the composition of the charged material. Two major categories of emissions can be distinguished. The first, and major, category relates to the charge cleanliness, e.g. rust, dirt, foundry sand, paint, oil, galvanised metal, which give rise to the emission of dust and fumes. The second category relates to chemical reactions at high temperatures, (e.g. while holding or adjusting the metal composition), which can give rise to metallurgical fume due to oxidation.

Additionally the refractory lining (acid SiO_2 -based, neutral Al_2O_3 -based, or basic MgO -based) may add a small amount of dust particles to the emission.

It is difficult to obtain average emission data since the charge cleanliness, which is the dominant contributor to emissions, varies from foundry to foundry.

2.2.4.4 Radiant-roof furnace (resistance heated)

The radiant-roof furnace is a low-energy holding furnace with a heavily insulated box design with banks of resistance elements in a hinged, insulated roof. They are mainly used in non-ferrous (aluminium) pressure die-casting shops with centralised melting facilities. Typical units have a capacity of 250 – 1 000 kg with a 5 kW to 12 kW connected load. Bale-out and charge wells are separated from the main bath by refractory walls with connectors at the bottom to allow clean metal to pass from one area to another. Figure 2.20 gives a schematic view of the radiant-roof principle.

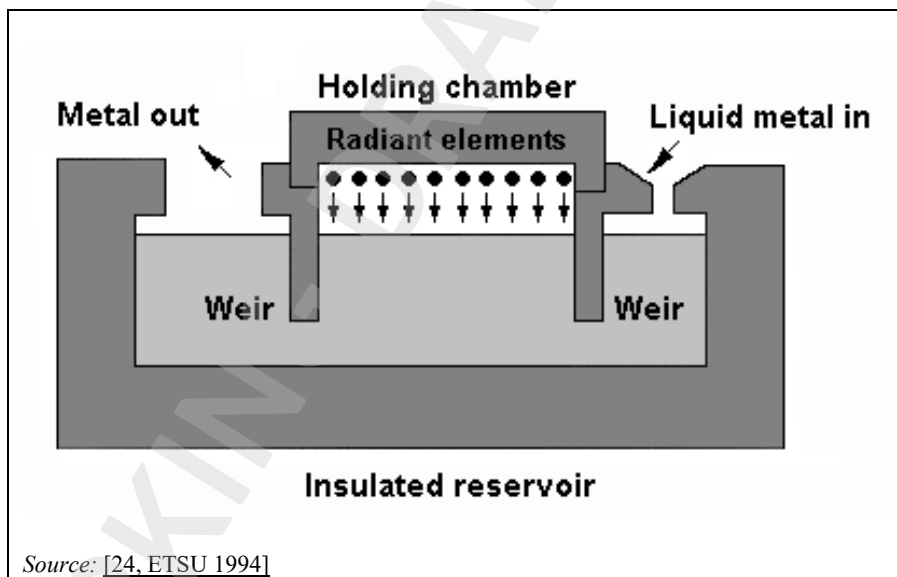


Figure 2.20: Radiant-roof furnace

The advantages of radiant-roof furnaces are:

- no crucible required;
- close temperature control;
- clean, cool, silent working conditions.

Although most low-energy holding furnaces serve individual casting machines, some larger ones are used as buffers between bulk melters and machine furnaces. This latter use allows better use of the melter, which is seldom an efficient holder.

Some foundries use large radiant-roof furnaces with higher power as melters, for example to generate molten metal for low-pressure die-casting. Several manufacturers build versions of radiant-roof furnaces that can be fully sealed and pressurised by gas, in order to function as dosing furnaces. Dosing furnaces provide precise shots of metal for pressure or gravity die-casting and compete, to some extent, with mechanical ladle systems as automatic pouring systems. Provided that they are carefully maintained and used, radiant-roof furnaces can provide a valuable control of both temperature and shot weight and can improve yield. [24, ETSU 1994]

2.2.4.5 Rotary furnace

Description

The rotary furnace consists of a cylindrical vessel rotating around an almost horizontal axis, in which the metallic charge is heated by a burner located at one side of the furnace. The flue-gases leave the furnace through the opposite side. To generate the required heat, fuel or natural gas is used combined with air or pure oxygen.

A tilting mechanism allows the furnace to be lifted to a certain angle or into a vertical position. This position is used for charging of the furnace with a drop bottom bucket or a vibrating chute, and for lining repair or renewal. During heating and melting the furnace is rotated slowly to allow the heat transfer and distribution. The furnace atmosphere is controlled by the air (oxygen)/fuel ratio.

Once the metal is melted, and after a composition check and adjustment, a tap-hole in front of the furnace is opened and the melt in the furnace is discharged into ladles. Because of its lower density, the slag floats on the metal bath in the furnace and is finally collected through the tap-hole into slag pots.

A melting cycle spans 1.5 to several hours. For continuous molten metal production, foundries install two to four rotary furnaces, which are operated consecutively. The thermal efficiency of the rotary furnace is very high, i.e. at 50 % to 65 %⁴, depending on the capacity. This high yield is achieved by using pure oxygen instead of air as the combustion medium. [14, CAEF 1997]

Melting practice

For cast iron melting, the furnace is charged with pig iron, foundry returns, steel scrap, slagging (e.g. sand, lime), and carburisation agents (e.g. graphite). The melting cycle starts with a slightly oxidising and short flame (air factor, $\lambda = 1.03$), which gives the highest energy input. The furnace is rotated stepwise through 90 ° and the direction of the rotation is changed from time to time. This way, the furnace walls can exchange heat with the charge by convection. As soon as the charge is melted, the flame is reduced to prevent excessive oxidation of the alloying elements. During overheating and holding, a long and reducing flame is applied ($\lambda = 0.9$) and the furnace movement is changed to full and continuous rotation. The slag layer provides thermal insulation and prevents the burning-off of the alloying elements. After controlling and adjusting the melt composition and temperature, the tap-hole is opened and the metal is tapped into ladles. The slag floats on the metal bath and is collected separately after the metal is removed.

The lifespan of the refractory is largely dependent on the overheating temperature and the charge composition. In the charging operation, mechanical shocks and cold start-ups need to be prevented. The furnace atmosphere, the holding time, rotational speed and the burner position also affect the refractory life. In normal conditions the refractory life is 100 to 300 melting cycles. [14, CAEF 1997], [38, Vito 2001]

⁴ This thermal efficiency is calculated provided that the energy for oxygen production is not taken into account. With oxygen production, the efficiency will be 10-15 % less.

Metallurgy

The rotary furnace has been used in non-ferrous melting for many years. In this application traditional oil-air burners can provide the relatively low melting temperatures. The development of oxygen-air burners has enabled the introduction of cast iron production, using a higher relative amount of steel scrap and applying graphite for carburisation.

A significant disadvantage of the rotary furnace is that it also burns Fe, C, Si, Mn and S. These losses have to be compensated for by the addition of alloying elements before or after melting. The efficiency of uptake of these elements is usually rather low. Concentration gradients may occur between the front and the back of the metal bath due to the absence of axial motion and due to inhomogeneities in radiation and the atmosphere above the wide bath surface. [38, Vito 2001]

Application

Due to its batch character, the rotary furnace provides a flexibility equal to that of the coreless induction furnace in the cast iron foundry. Rotary furnaces are used for melting volumes of 2 – 20 tonnes, with production capacities of 1 – 6 tonnes per hour. [38, Vito 2001]

Advantages

- Quick change of alloy possible.
- Melting without contamination, e.g. without sulphur pick-up.
- Small dedusting system because of low flue-gas rate.
- Easy to maintain.

Disadvantages

- Easy burn-out of C, Si, Mn.
 - Gas and oxygen use can be high if not operated continuously.
 - The energy consumption increases if more steel is added to the charge.
- [38, Vito 2001], (CAEF submission in [237, TWG 2023])

2.2.4.6 Hearth-type furnace

The hearth-type furnace is also known as a reverberatory or bale-out furnace. It is a static furnace with direct heating. Hot air and combustion gases from oil or gas burners are blown over the metal (melt) and exhausted out of the furnace. The hearth-type furnace finds its main application in non-ferrous metal melting. A typical furnace design is given in Figure 2.21.

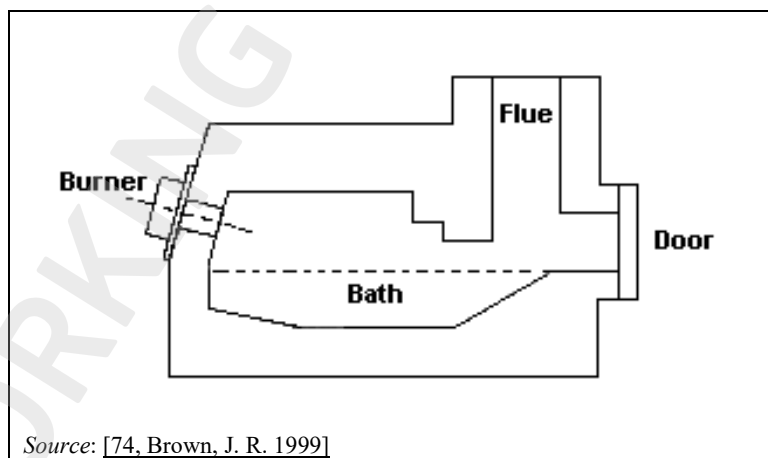


Figure 2.21: Cross-section of a hearth-type furnace

This is a refractory-lined, rectangular or circular bath furnace that is fired by wall or roof-mounted burners. Varieties of fuels are used and additionally oxy-fuel burners can be used to increase the

melting rate. Extraction and treatment of the combustion gases is typically carried out and for this the furnaces are partially sealed. Hoods and covered launders provide extraction during tapping and charging. The furnace can be constructed in a number of configurations depending on the particular metal and application, variations include the provision of sloping hearths and side wells for specific melting purposes, tuyères and lances for the addition of gases. The furnaces can sometimes be tilted to pour or blow metal.

The melting efficiency of a hearth-type furnace is usually not great because of the poor heat transfer from the burner. The efficiency has been improved in practice by the use of oxygen enrichment or by using combinations of gas and solid fuel to extend the flame length. These furnaces are used for batch melting, refining and for holding a variety of metals. Hearth-type furnaces are mainly used to melt large quantities of non-ferrous metals [1, COM 2017].

Large hearth-type furnaces give rapid melting and can handle bulky charge materials, but the direct contact between the flame and charge may lead to high metal losses, gas pick-up and to considerable oxide contamination. Temperature control can also be difficult. These difficulties can be overcome to some extent by good practice. For example, dross can be removed by applying suitable fluxing practice, and applying modern burners reduces problems with the temperature control. After tapping, filtering and degassing, further treatments can be applied as the metal is transferred to holding furnaces.

[18, US EPA 1998], [24, ETSU 1994], [1, COM 2017], [74, Brown, J. R. 1999]

2.2.4.7 Shaft furnace

Description

This is a vertical furnace with a collecting hearth (inside or outside the furnace) and burner system at the lower end and a material charging system at the top. The burners are usually gas-fired. Metal is fed into the top of the furnace and is melted as it passes down the shaft. Independent control of the fuel/air ratio is sometimes provided for each burner. Continuous CO or hydrogen monitoring is also provided for each row of burners and monitor the combustion gases from each burner in turn. Combustion gases are usually extracted and sometimes cleaned. An afterburner is sometimes used to decompose any carbon monoxide, oil, VOCs or dioxins that are produced. The addition of oxygen above the melting zone has been used to provide afterburning in the upper levels of shaft or blast furnaces.

The furnace is used to melt pure metal, but occasionally metal that is contaminated with organic material may be used. If oily metal is fed into the furnace, it passes through a temperature gradient existing between the charging area and the burners. The low temperature can produce a mist of partially burned organic material. The shaft furnace is also used to preheat the charge material before smelting. A typical representation of this furnace is given in Figure 2.22.

This furnace type is only used for non-ferrous metal melting, mainly for aluminium. Due to the complex construction and difficult renewal of the refractory, the furnace is only used for metals with low melting points. Therefore, the maintenance requirements of the furnace lining are rather limited. Typical refractory lifetimes are 4 to 8 years.

Modern furnace types with computer-controlled burner systems reach an energy use of 540 kWh/tonne of melted aluminium (at 720 °C). The theoretical energy needed is approximately 340 kWh/tonne. The thermal efficiency is therefore 63 %.

The shaft furnace is a continuous melting furnace with high capacity, ranging from 0.5 tonnes to 7 tonnes per hour and with a holding capacity of up to 20 tonnes. Change of alloy is possible but can be more difficult when the holding capacity is high. [24, ETSU 1994], [1, COM 2017]

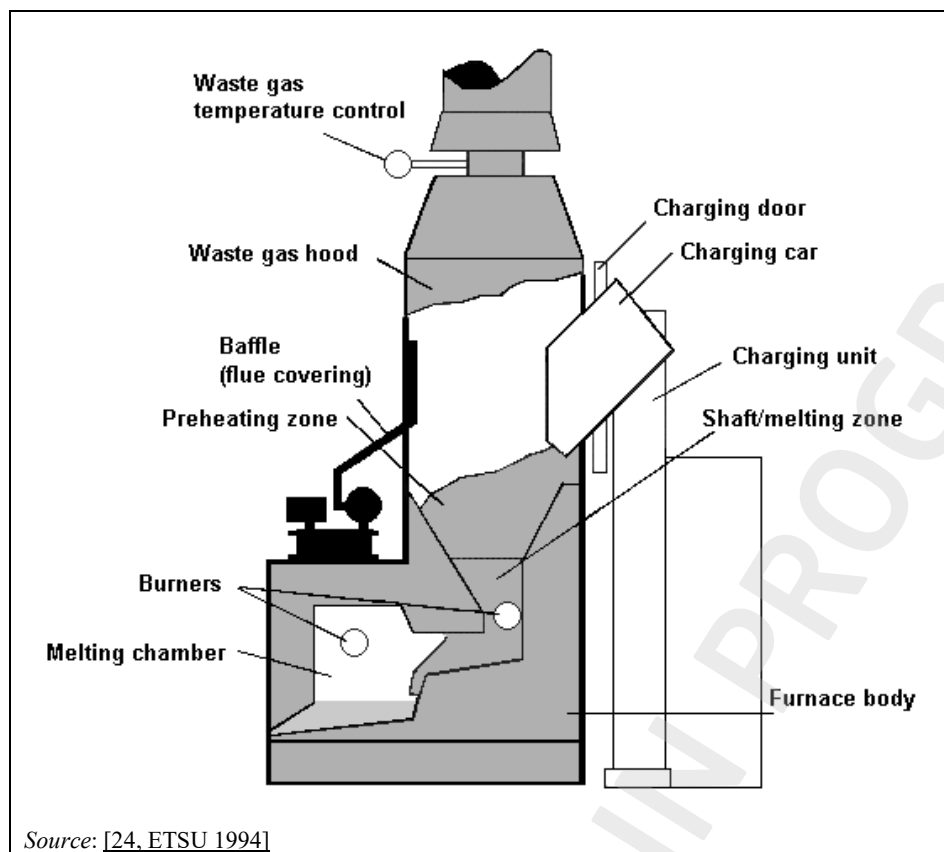


Figure 2.22: Shaft furnace

Advantages

- Due to the long preheating, the charge is very well dried before the melting starts. This makes the furnace well suited for Al, because the risk of explosion when charging liquids into molten aluminium is prevented and the melt quality is improved.
- Due to the charge preheating, internal heat recovery is achieved, which leads to high thermal efficiency.
- Due to the charge preheating, a short residence time of metal in the melting zone is achieved; therefore, the metal loss is greatly reduced.
- Due to the continuous melting process, melt is always available at the required temperature.

Disadvantages

- Depending on the holding capacity (i.e high holding capacity), a change of alloy can become difficult.
- There are possible limitations on the size and weight of the charging materials.

2.2.4.8 Crucible furnace

Description

These are simple crucibles that are heated externally by the combustion gases from gas or oil combustion, by electricity or, for lower temperatures, by thermal fluid. Contact with a direct flame is avoided to prevent there being local hot spots at the base of the crucible and so that good temperature control can be maintained in the melt, to prevent oxidation and vaporisation of the metal.

This furnace type is only used for non-ferrous metal melting. Due to the indirect heating (through the crucible wall) no burn-off or gas take-up can take place. These furnaces are used for the

production of small amounts of molten metal (less than 500 kg per batch) and for low production capacities. Example furnaces are displayed in Figure 2.23.



Figure 2.23: Crucible furnaces

The crucible is tilted manually, with a crane, or automatically to pour the molten metal into the mould. For copper based materials, only graphite or carborundum (silicon carbide) crucibles are used, whereas aluminium can also be melted in cast iron crucibles.

Crucibles used for holding, transport and metal treatment in ferrous foundries are called ladles. [38, Vito 2001], [41, Teknologisk 2000], [120, TWG 2003]

Melting practice

The cold load is brought into the crucible, and heating is started at full power in order to melt the load. At 50 °C to 100 °C below the melting temperature, the power is switched off, and the load is heated further by the thermal inertia of the crucible. Afterwards, the temperature is levelled off using a control system. After deslagging, metal treatment can be performed. This involves oxygen removal, degassing, grain refining and the adjustment of volatile metals such as zinc and magnesium. The slag is then removed once more before casting takes place.

Besides regular renewal of the crucible, no maintenance is needed. The renewal time is primarily dependent on the alloy to be melted. Multiple alloy changes cause a more rapid crucible wear. SiC-crucibles, used for low melting alloys, have a useful life of 130 to 150 charges. For high melting alloys, the useful life is 50 to 80 charges.

Thermal efficiencies are 750-3 000 kWh per tonne of aluminium, i.e. 15 – 30 % efficiency. [15, Binniger, W. 1994], [38, Vito 2001], [41, Teknologisk 2000]

Advantages

- Simple technology.
- Low maintenance.
- Flexibility regarding change of alloy.

Disadvantages

- Low efficiency and production capacity. [38, Vito 2001]

2.2.4.9 Argon Oxygen Decarburisation (AOD) converter for steel refining

The AOD converter is a special vessel for refining steel. The molten metal is transferred directly from the melting furnace (generally electric arc or induction) into the converter. As shown in

Figure 2.24, oxygen (for the removal of carbon, silicon) and argon gas (for the stirring action) can be injected into the converter by means of tuyères positioned in its lower part, to refine the metal. The converter is equipped with a tilting mechanism in order to allow filling and emptying. Steel with a precise chemistry can be produced using AOD, but at a high cost. This system is not widely used in steel foundries outside the US.

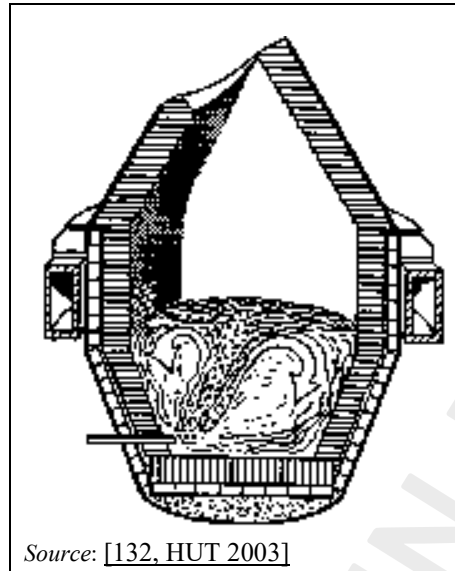


Figure 2.24: AOD converter

The first phase of the refining process consists of a decarburisation, through the injection of oxygen into the converter. This is a refining operation that holds the carbon content of the charge material within a specific range, as required. Decarburisation is initiated by injecting oxygen into the metal bath. This creates a strong stirring action during which carbon in the melt is burned. At the same time the 'boiling' burns out silicon, and flushes out hydrogen and nitrogen from the metal bath. All impurities (oxides) are trapped in the slag. During melting, lime may be added to bring the slag to the proper basicity. When the carbon reaches the required concentration, oxygen injection is stopped and silicon and manganese are added to halt the boiling reaction, especially in the production of stainless steels. A dilution of the oxygen with argon or nitrogen assists the oxidation of carbon in preference to metallic elements such as iron, chromium, etc., leading to very good metallic yields. Consequently Al or Si and limestone are added to the metal and argon is injected in order to remove sulphur. The continuous gas injection causes a violent stirring action and an intimate mixing of slag and metal which can lower sulphur values to below 0.005 %. The residual gas content of the treated metal (hydrogen and nitrogen) is very low. All impurities are trapped in the slag and removed with it. After temperature and alloy adjustment the metal is transferred to ladles for pouring.

[73, Brown, J. R. 2000], [14, CAEF 1997]

2.2.4.10 Vacuum Oxygen Decarburisation converter (VODC) for steel refining

The VODC (Vacuum Oxygen Decarburisation Converter) operates in such a way that molten steel is contained in the converter, which is attached to vacuum pumps, steam ejectors and an argon gas source. Two distinct processes are carried out in the vacuum treatment of stainless steel to obtain a higher quality level.

First, the steel is decarburised by introducing oxygen into the melt. At the same time, some argon is injected from the converter base. The converter uses vacuum pumps to lower the partial pressure of carbon monoxide, to such an extent that effective decarburisation can be carried out

without oxidising too much of the chromium. This first process is similar to AOD decarburisation, but less argon is needed thanks to the lower total gas pressure and the process is much more efficient. The oxidised chromium is reduced back to liquid steel with aluminium.

The second process involves degassing. The converter is brought under deep vacuum (1-5 mbar) using a water ring pump and steam ejectors. Slight argon bubbling is continued in order to maintain an effective steel movement. At the very low pressure, gaseous impurities such as hydrogen and nitrogen are eliminated effectively. At the same time, the total oxygen content and the sulphur content are drastically decreased, which is beneficial for the mechanical properties of the end steel.

Low alloyed steels are normally only degassed.

The VODC process provides specific steel qualities, which cannot be obtained by other methods. The total oxygen content is also lower than what is typical for electric arc melted and AOD-treated steel, because a high level of oxide inclusions are removed from the melt during the VODC process, and most of the dissolved oxygen is further removed during the degassing phase. [100, TWG 2002]

2.2.4.11 Metal treatment of steel

In order to guarantee a good casting quality, cast steel needs further treatment to remove impurities and the possible causes of defects, i.e.:

- *Deoxidation:* Oxygen dissolves in liquid steel, in the form of FeO. During solidification, the oxygen can then combine with C in the steel to form CO. This process can thus change the composition of the steel and generate porosity. Deoxidation is therefore always necessary. Deoxidation is performed with an element that preferentially binds the oxygen. Silicon, calcium silicide, titanium, zirconium and aluminium are possible deoxidants, with aluminium being the most powerful and the one that is most generally used. Aluminium is added in the form of a stick or wire (see Figure 2.25). The treatment is usually performed in the furnace and in the ladle. The produced aluminium oxide is insoluble in the melt and mixes with the slag.

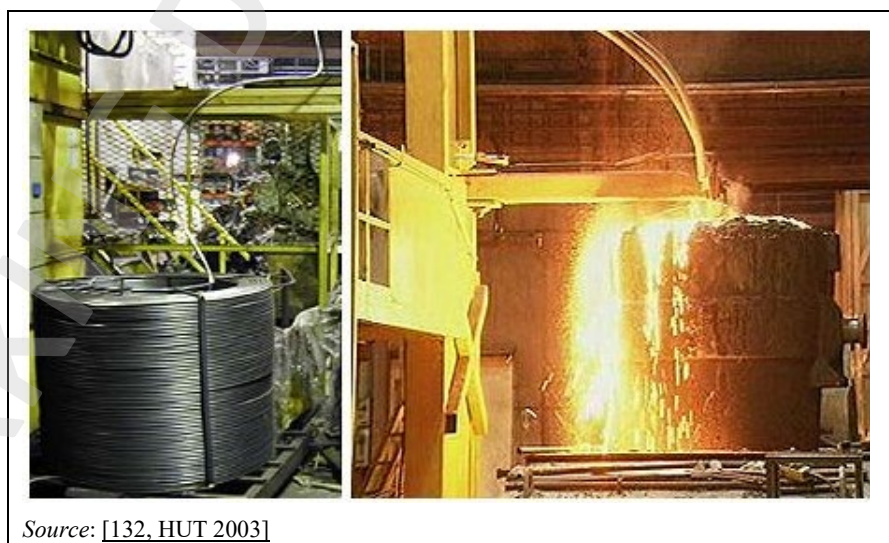


Figure 2.25: Deoxidation, using an aluminium wire

- *Sulphide formation:* As the tensile strength of steel increases, the harmful effect of sulphur increases. Sulphur is soluble in liquid steel, but on solidification it precipitates as MnS.

Precipitates can take various forms and have different effects. The form of the sulphides is related to the residual aluminium content after deoxidation. The residual amount of Al should allow the formation of type III sulphides.

[38, Vito 2001], [73, Brown, J. R. 2000]

2.2.4.12 Cast iron treatment

2.2.4.12.1 Alloying

During melting, some elements in the melt oxidise and are lost to the slag. At the end of the melting period a correction of the composition needs to be performed, in order to guarantee the appropriate final quality. For unalloyed cast iron, the contents of the basic alloying agents (C, Si, Mn) have to be controlled, while trace elements such as S and P must be minimised. For specific purposes, specific alloying elements are applied, usually by adding ferroalloys. In general, these are added as ferrous alloy blocks or grains. The additions are made to the liquid iron, since this reduces the risk of oxidation losses.

The addition is performed in the furnace, in the molten metal flow during pouring, or by putting the additives in the transport ladle before pouring the molten metal into it.

[38, Vito 2001] (CAEF submission in [237, TWG 2023])

2.2.4.12.2 Homogenisation

The addition of alloying elements can introduce impurities. When alloying elements are added to the cast iron melt, homogenisation is needed to evenly distribute the alloying agents. This can be done in the melting or holding furnace. While performing this in an induction furnace, due to the stirring action, oxides may accumulate.

[38, Vito 2001] (CAEF submission in [237, TWG 2023])

2.2.4.12.3 Desulphurisation and recarburisation of cupola melted iron

Sulphur can originate from anthracite coke. As it usually weakens the properties, its content is lowered by desulphurisation.

When producing spheroidal graphite cast iron, the sulphur content must be kept especially low to avoid consumption of magnesium (which is used for nodularisation).

Desulphurisation is achieved by slag reaction, e.g. with soda.

(CAEF submission in [237, TWG 2023])

2.2.4.12.4 Nodularisation treatment of the melt

When producing spheroidal graphite cast iron, the free graphite in the structure shall have a predominantly round shape in order to adjust its mechanical properties. This is done by Mg treatment with different alloying agents – ranging from pure magnesium to magnesium-containing alloys. Several methods are applied, all resulting in a fierce reaction and producing various amounts of magnesium oxide dust.

There are several techniques that can be applied to introduce Mg into the liquid metal:

- *The pour over technique*: This is the simplest method, whereby the liquid metal is poured over the Mg alloy in the bottom of the ladle.

- *The sandwich method:* Here Mg alloy is placed at the bottom of a specially designed ladle and covered with steel sheets or FeSi, as shown in Figure 2.26. The metal is poured into the ladle and after melting of the cover the Mg reaction takes place.
- *The Tundish Cover:* This is an improved sandwich technique, whereby the ladle is covered by a lid after the Mg alloy has been placed at the bottom of the ladle. The metal is poured in the concave lid and flows through a hole in the ladle, where the reaction takes place.
- *The plunging method:* Using a plunger bell, the Mg alloy is submerged in the liquid metal until the reaction is finished. During the treatment the ladle lid is closed, to prevent MgO fume emissions.
- *The G Fischer converter:* This process uses a special ladle that is closed tightly with a lid after the metal is poured into the converter in the horizontal position. The converter is then tilted into a vertical position, allowing the Mg alloy to react with the metal. Once the reaction is finished the converter is turned back into the horizontal position and is tapped after opening the lid.
- *The core wire injection:* Here very fine powdered Mg alloy is rolled in tin steel sheet, forming a filled wire. This wire is then injected, by a controlled mechanism, into a slender shaped ladle, where the Mg is released.
- *The flow through treatment:* Here the metal is poured into a special designed reaction chamber in which the Mg alloy was put earlier.
- *The ductilator:* In this method the metal is poured into a reaction chamber where the flow is forced to form a vortex. The Mg alloy is injected into the vortex with an inert carrier gas. The treatment can be performed on large quantities of metal or during mould filling.
- *The in mold process:* In this process the Mg alloy, shaped as a tablet, is put directly into the mould cavity (gating system). The reaction takes place during mould filling, ensuring a high yield.



Figure 2.26: The sandwich method for nodularisation

After treatment, the metal has to be poured into the mould within a specific time, as the Mg effect tends to fade quickly, necessitating a new treatment if a certain time limit (10 – 15 minutes) is exceeded.

The efficiency, the qualitative assessment of flue-gas production and the complexity of the various nodularisation methods are compared in Table 2.14.

The choice of the Mg treatment process depends on the foundry's equipment, adapted to the foundry process, part size and lot size (CAEF submission in [237, TWG 2023]).

Table 2.14: Comparison of various nodularisation procedures

	Sandwich	Tundish cover	Plunging	Flow through	Wire injection	Inmold	Ductilator
Mg- take-up efficiency (%)	35 – 50	45 – 60	40 – 60	40 – 50	20 – 50	70 – 90	60 – 75
Flue-gas production	High	Low	Low	Low	Low	No	High
Comment	Easy operation	Optimised sandwich but more maintenance	High maintenance	High maintenance	Expensive installation	Different design of pouring system	High maintenance

Source: [110, Zalensas, D. L. 1993], [120, TWG 2003]

2.2.4.12.5 Inoculation of the melt

The cast iron melt needs a treatment to support the growth of eutectic grains from the melt, minimising undercooling and thus the formation of hard carbides. This process is called inoculation. It creates evenly sized eutectic grains and free graphite, altogether a so-called ‘grey’ solidification. Inoculation is performed at a late stage of melting (CAEF submission in [237, TWG 2023]).

Again, several techniques can be used to inoculate the molten metal:

- *Injection during tapping*: Here the inoculant is injected directly into the metal flow during tapping.
- *Injection during pouring*: Here the inoculant is injected directly into the metal flow during pouring of the mould (see Figure 2.27).
- *Filled wire injection in the melt* (see Section 2.2.4.12.4).
- *Inmold process* (see Section 2.2.4.12.4).



Figure 2.27: Inoculation during pouring

2.2.4.13 Non-ferrous metal treatment

There are three main metal treatment (or refining) operations carried out in **aluminium** melting processes. These are as follows:

- *Degassing*: Molten aluminium dissolves hydrogen, which is then expelled upon cooling and can thus lead to porosity in the finished casting. Hydrogen therefore needs to be removed.

This is done by bubbling an inert gas through the melt. Good degassing methods provide bubbles with high residence time and high surface area. The degassing of aluminium is mostly performed using an impeller station. This treatment uses a rapid-spinning mixer and nitrogen injection into the melt. Degassing is often combined with a cleaning of the melt. Cleaning is performed to remove alkali or alkaline earth metals, such as Ca. Cleaning can be done by Cl₂ gas. The use of HCE for this purpose has been banned in the EU (*Dir. 97/16/EC*). A mixture of nitrogen with 3 % Cl₂ is generally used, for simultaneous degassing and cleaning. Alternative degassing methods use tablets, a lance with a porous head, or a porous stone in the holding furnace.

- *Modification and grain refining*: For aluminium alloys this usually involves the addition of small amounts of metal to the melt. These additions control the grain size and modify the microstructure of the solidifying metal and thus enhance the casting mechanical properties. Sodium or strontium are used for the modification, while grain refinement is achieved with titanium, titanium boride, zircon or carbon. This treatment is mostly performed in combination with degassing in a dedicated metal treatment station.
- *Fluxing*: This usually involves the addition of solid fluoride-based fluxes to the melt, to remove solid contaminants.
- *Filtering*: For aluminium alloys and in order to keep the metal clean before the solidification process, a frequently used process is the filtration of the metal in liquid form using ceramic foam filters of different porosity. Ceramic foam filters retain oxides and non-metal particles generated in the furnaces during the casting and also the slag generated in the degassing process. [227, ES 2021]

[65, UK Environment Agency 2002], [74, Brown, J. R. 1999], [77, Wenk, L. 1995], [227, ES 2021]

There are four main metal treatment (or refining) operations carried out in **magnesium** melting processes. These are as follows:

- *Grain modification*: Grain modifiers for magnesium alloy processes are usually in the form of zirconium or formerly hexachloroethane (HCE). The use of HCE for this purpose has been banned in the EU (*Dir. 97/16/EC*).
- *Fluxing*: This usually involves the addition of alkali, earth alkali, chloride and fluoride proprietary fluxes to the melt to remove solid contaminants.
- *Degassing*: For magnesium processes, nitrogen or argon gas sparging may take place for degassing and oxide removal. The degassing of magnesium alloys may also be effected by a mixture of argon and chlorine gases, when argon is used as a carrier gas.
- *Oxidation control*: The presence of beryllium within the melt grain modifies and stops oxidation. Finished magnesium alloys may contain up to 15 ppm beryllium by weight. A master alloy of aluminium/beryllium, containing up to a nominal 5 % beryllium, may be added to the molten magnesium alloy to give it this beryllium loading. Oxidation control may also be achieved by blanketing the surface of the metal with an inert gas, such as SO₂ or mixtures of nitrogen and R134a or of nitrogen and CO₂ and/or SO₂ or of sulphur and argon. Occasionally oxidation control may be achieved by sprinkling sulphur powder on the surface of the melt.

There are three main metal treatment (or refining) operations carried out in **copper** melting processes. Molten copper dissolves oxygen and hydrogen, which may recombine to form water vapour. This in turn will generate porosity in the casting. Degassing and deoxidation are thus applied to remove hydrogen and oxygen, respectively. The applicable metal treatment operations are as follows:

- *Deoxidation*: Deoxidation is performed by adding a reagent which binds the oxygen and forms a fluid slag. Care must be taken to prevent the deoxidation products from being entrained in the solidified casting and the residual deoxidant from adversely affecting the alloy properties. Phosphorus is the most commonly used deoxidation reagent. Alternatives are magnesium, manganese, calcium, silicon and boron.

- *Degassing*: Hydrogen is removed from the melt by bubbling an inert gas through it. Both argon and nitrogen may be used. The technique is comparable to aluminium degassing.
- *Fluxing*: Aluminium in alloys can oxidise and generate oxide skins. These can cause problems upon casting. In non-aluminium alloys, traces of aluminium can cause defects. Therefore they need to be removed, using fluxing agents. Fluxes are also used to cover the surface in order to prevent oxidation, zinc loss and hydrogen pick-up during melting. Specific fluxing agents exist for each type of treatment.

[66, UK Environment Agency 2002], [81, Closset, B 2002], [134, CAEF 2020]

2.2.5 Mould and core production

Moulding consists of making a mould in which the molten metal will be poured.

Just as the mould defines the outer shape of the casting, the core defines the inner one, or at least the parts not directly attainable by moulding.

Moulds may be classified in two large families:

- **Lost moulds** (single use moulds): These are specially made for each casting and are destroyed after pouring. The moulds are generally made of sand, and are chemically bonded, clay-bonded, or even unbonded. Investment casting can also be included in this family.
- **Permanent moulds** (multi use moulds): These are used for gravity and low-pressure casting, high-pressure die-casting, and centrifugal casting. Typically the moulds are metallic.

The cores used for ferrous castings are practically always made of sand. The choice of binder technology used depends on factors such as the size of the casting, the production rate, the metal poured, the shake-out properties, etc.

For sand moulding, the mould may be produced by manual or mechanical ramming actions, such as by jolt, squeeze, air impact, vibration, etc.. When the mould has sufficient strength it is released from the model, which can then be used to produce a new mould.

Generally, cores are produced by the same techniques as moulds, but small or medium sized cores are often blown or shot into wooden, plastic or metallic core boxes.

For non-ferrous casting, about 30 % of copper alloys are cast in sand moulds. Only about 10 % of light non-ferrous metals are cast in single use moulds.

The production of patterns and dies is generally carried out by specialised external suppliers. These activities are found in the metal and plastics treatment sectors.

[2, Hoffmeister et al. 1997], [14, CAEF 1997], [38, Vito 2001]

2.2.5.1 Moulding techniques used in different types of foundries

Table 2.15 provides an overview of the various moulding methods that can be employed (e.g. lost moulds or permanent moulds) in different types of foundries.

Table 2.15: Moulding methods used in different types of foundries

	Lost moulds				Permanent moulds				
	Moulding methods				Casting technique				
	Green sand moulding	Shell sand	Pheno/Furan	Pep set/water glass	Low-pressure die-casting	Pressure die-casting (hot)	Pressure die-casting (cold)	Centrifugal casting	Continuous casting
Cast Iron									
Grey cast iron	X	X	X	X	O			X	X
Nodular cast iron	X	X	X	X				X	X
Malleable cast iron	X	O	X	O					
White cast iron	X	X	X						
Steel									
Unalloyed	X	X	X	X				X	
Low alloy steel	X	X	X	X				X	
Highly alloyed manganese steel	X	X	X	X				X	
Stainless and heat resistant	X	X	X	X			O	X	
Heavy Metals									
Brass	X	X	X	X	X				
Bronze	X	X	X	X					
Copper	X	X	X	X	X		X	X	X
Zinc alloys					O		X	X	
Light Alloys									
Aluminium alloys	X	X	X	X	X		X		X
Magnesium alloys	X	O	X	X	X	X	X		
Titanium	O	O	X	X	O				
X: The method can be used O: The method is possible but not often employed Source: [41, Teknologisk 2000]									

2.2.5.2 Moulding materials

2.2.5.2.1 Moulding sands

Independently of the type of binder applied, the physical and chemical properties of the moulding sands used to make the moulds or cores affects their characteristics and their behaviour during pouring. This is not surprising as these materials make up 95 % to 99 % of the produced moulds and cores.

The purchase price of each sand type has four main components – extraction, preparation, packaging and transportation. Transportation costs will vary for different regions. The main factor however in the price is the sand type. The average purchase price for the various types varies widely.

[29, ETSU 1995], [120, TWG 2003], [134, CAEF 2020]

The different types of refractory sands used for foundry purposes are described in the following sections.

2.2.5.2.1.1 Silica sand

This type of sand is the most commonly used, mostly because of its wide availability and its relatively low cost. Silica sand is composed of the mineral ‘quartz’ (SiO₂), which is more or less pure and clean, depending on its origin. Its dry piece specific weight fluctuates between 2.5 kg/dm³ and 2.8 kg/dm³. The dry bulk density (or loose volume weight) of silica sand is 1.4 kg/dm³ to 1.6 kg/dm³.

The thermal expansion of silica sand generates a mould movement upon pouring and cooling. Specific additives are therefore used, especially when producing cores, in order to prevent casting errors. These may be wood fluff, iron oxide or synthetic additives. Sand containing feldspar has a lower thermal expansion than pure quartz sand and a lower sintering point, but it is widely used in order to minimise expansion defects in castings.

Silica sand is neutral and is compatible with all binders and normal cast alloys. Also, blending of silica sand with chromite sand is relatively common.

The respirable particulate matter (RPM) fraction of quartz is classified by IARC as carcinogenic [128, IARC 1997]. Respirable crystalline silica (SiO₂) dust generated by a process is not subject to classification in accordance with Regulation (EC) No 1272/2008. On the other hand, work involving exposure to respirable crystalline silica dust generated by a work process is included in Annex I to Directive 2004/37/EC and a limit value for respirable crystalline silica dust (‘respirable fraction’) is established. This is mainly an occupational health issue. In the SF data collection, SiO₂ emission data were reported by six plants (16 emission points) with concentrations ranging from 0.02 mg/Nm³ to 3.1 mg/Nm³; in total 15 out of the 16 emission points reported concentrations lower than 0.27 mg/Nm³. [169, TWG 2021]

In both green sand moulding and core sand technology, control of the grain size distribution is very important. The grain shape also needs to be taken into account: the rounder a grain shape is, the better it is for surface quality, gas permeability and for preventing casting defects. Figure 2.28 shows a typical grain size distribution for silica sand. The grain size distribution is used to calculate the AFS number (AFS: American Foundry Society). This gives the overall fineness of the sand. The higher the AFS number, the finer the sand. An alternative classification system is the middle grain number or MK.

A finer sand grade will have more grains per gram, and thus a higher surface area. This requires more binder addition for an equal mould strength. Operators therefore try to use the coarsest sand, but one that still gives a good surface finishing aspect. Standard AFS numbers are 50 – 60. For very smooth surfaces a fine sand is needed, typically one with an AFS of 90 – 110 is used. Fine sands are also used in some instances to replace mould coatings.

[38, Vito 2001], [100, TWG 2002], [120, TWG 2003], [134, CAEF 2020]

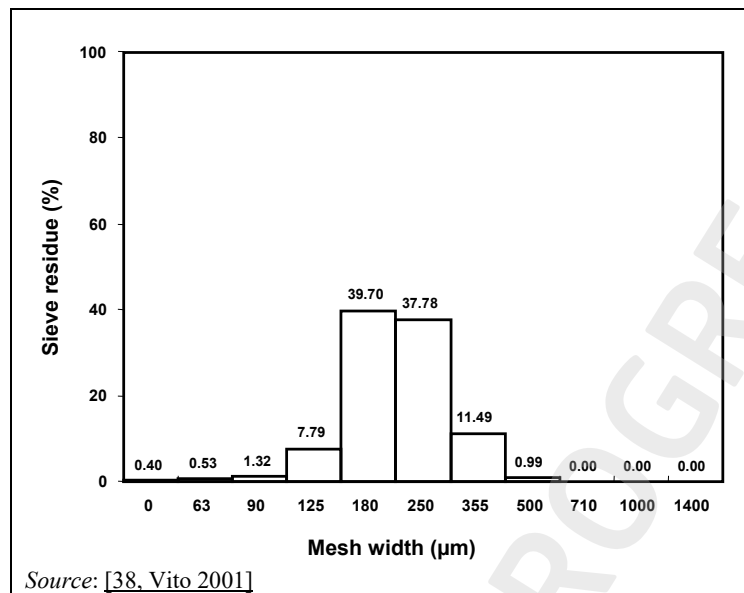


Figure 2.28: Typical grain size distribution for silica foundry sand

2.2.5.2.1.2 Chromite sand

Chromite is a chrome ore, with the theoretical formula $\text{FeO} \cdot \text{Cr}_2\text{O}_3$, which contains other components such as magnesium and aluminium oxides. For its use in foundries, its silica content must be lower than 2 % in order to prevent sintering at low temperatures. Its characteristics are as follows:

- density: 4.3 to 4.6, compared to 2.65 for silica sand;
- theoretical melting point: 2 180 °C, but the presence of impurities can lower this to 1 800 °C;
- thermal diffusivity: more than 25 % higher than that of silica sand;
- thermal expansion: regular, without a transition point, and lower than that of silica sand;
- pH: rather basic, from 7 to 10.

Chromite sand is more refractory than silica. It is more thermally stable and has a greater chilling power. Chromite sand provides a better surface finish on large castings. It is therefore used for the production of large castings and in areas of the mould where chilling is required.

[14, CAEF 1997]

2.2.5.2.1.3 Zircon sand

Zircon is a zirconium silicate, ZrSiO_4 . Zircon is the most widespread zirconium ore. Its characteristics are as follows.

- density: 4.4 to 4.7, compared to 2.65 for silica sand;
- melting point: higher than 2 000 °C;
- thermal diffusivity: more than 30 % higher than that of silica sand;
- thermal expansion: regular, without a transition point, and lower than that of silica sand.

The general characteristics of zircon sand are similar to that of chromite, but zircon sand produces a better finish as a finer grade is used. These physical and thermal properties account for its use for moulding or core-making in difficult cases, in spite of its very high price.

[14, CAEF 1997], [29, ETSU 1995]

2.2.5.2.1.4 Olivine sand

Olivine sands are a mineral group which includes forsterite, fayalite and others. The characteristics of olivine sands are as follows:

- melting point: forsterite: 1 890 °C, fayalite: 1 205 °C;
- density: 3.2 to 3.6;
- pH: around 9.

The basic pH makes this type of sand not suitable for use with acid-catalysed binder systems (e.g. furan acid).

Olivine sand is produced by crushing natural rocks, which explains its diverse characteristics. It is usually used for moulding and core-making in manganese steel casting. The presence of manganese prohibits the presence of silica as these two components react to give a very fusible compound.

[14, CAEF 1997], [108, Martínez de Morentin Ronda, J. 2002]

Since it is a crushed product, olivine sand requires more binders than silica sand. In Sweden, olivine sand is commonly used because it does not generate significant amounts of crystalline silica dust which can give rise to problems of silicosis. However, in the case of furan acid binding systems, olivine sand cannot be used.

2.2.5.2.2 Binders and other chemicals

2.2.5.2.2.1 Bentonite

Bentonite is a clay mineral (montmorillonite, which is a sheet silicate). The grains have a flaky structure. It has a varying composition depending on the different bonded alkali metal ions. By adding water, the clay structure swells due to the adsorption of water molecules. The clay then becomes workable and can be spread to coat the sand grains during mixing.

Natural calcium bentonites do not swell or gel when mixed with water. They are rarely used at present, being used only for very special castings. Alternatively, these materials may be 'activated' by treatment with soda ash to give 'soda activated bentonites'. These are used extensively in ferrous foundries throughout Europe; their properties approach those of natural sodium bentonites.

Natural sodium bentonites greatly swell when mixed with water. The main features in green sand are their high dry strength, good tolerance to water content variation, high resistance to burn-out and their improved high temperature durability. As they are imported from the US, where they are in common use, their price generally limits their use to high value steel casting or in blends with activated calcium bentonites.

Pouring molten metal into a green sand mould subjects the moulding-sand to considerable heat. This heat removes moisture from the sand and destroys the clay-bonded structure. These grains are 'dead burnt' and cannot be activated any more. If during pouring and cooling bentonite stays below the deactivation temperature, the lamellar structure is maintained as well its ability to swell and develop cohesion. The deactivation temperature varies with the bentonite type.

[14, CAEF 1997], [30, ETSU 1995], [100, TWG 2002], [120, TWG 2003]

2.2.5.2.2.2 Resins

Over the past few decades a range of chemical binders have been developed. These are single- or multi-component systems which are mixed with the foundry sand until all the grains are coated with a thin film. After mixing, a hardening reaction starts, binding the sand grains together and developing mould strength. Resins can be classified according to the hardening method:

- cold-setting (also called no-bake) resins;
- gas-hardened resins;
- hot-curing resins.

The various resin types will be discussed under Section 2.2.5.7. In Table 2.16, Table 2.17 and Table 2.18, an overview of the applicability and the distribution of the various sand systems are given.

Table 2.16: Overview of various resin types and their applicability

Curing	Resin type	Mould production	Core production	Curing temperature	Hardening time (*)	Metal types
Cold-setting	Furan resin, acid curing	Medium to large	Some	10 – 30 °C	10 – 120 min	Ferrous + non-ferrous
	Phenolic	Large	Some	10 – 30 °C	10 – 180 min	Ferrous
	Polyurethane (phenolic isocyanate)	Small to medium	Some	10 – 30 °C	5 – 60 min	Ferrous + non-ferrous
	Resol-ester	Small to Large	Some	10 – 30 °C	5 – 400 min	Ferrous + non-ferrous
	Alkyd oil	Large	Some	10 – 30 °C	50 min	steel
	Silicate - ester	Medium to large	No	10 – 30 °C	1 – 60 min	Ferrous + non-ferrous
Gas-hardening	Polyurethane Coldbox, Amine catalyst ("Cold-box")	Small	Yes	10 – 30 °C	<60 s	Ferrous + non-ferrous
	Resol, Methyl formate curing	Small	Yes	10 – 30 °C	<60 s	Ferrous + non-ferrous
	Epoxy/ acrylic SO ₂ curing	Yes	Yes	10 – 30 °C	<60 s	Ferrous + non-ferrous
	Silicate, CO ₂ curing	Small	Yes	10 – 30 °C	<60 s	Ferrous + non-ferrous
	Resol, CO ₂ curing	No	Yes	10-30 ° C	< 60 s	Ferrous
Thermosetting	Oil	Small	Yes	180 – 240 °C	10 – 60 min	Ferrous
	"Warm-box"	Seldom	Yes	150 – 220 °C	<60 s	Ferrous + non-ferrous
	"Hot-box"	Seldom	Yes	220 – 250 °C	<60 s	Ferrous + non-ferrous
	Shell moulding, "Croning"	Yes	Yes	250 – 270 °C	120 – 180 s	Ferrous + non-ferrous
	Silicate; Inorganic binder	No	Yes	150 – 180 ° C	<60 s	Al

Table 2.17: Share of no-bake sands in German ferrous and non-ferrous metal foundries in 2012

System	Share [%]
Furan resin	80
Phenolic resin	15
Polyurethane resin	< 3
Resol resin, ester cured	< 3
Silicate	< 3
<i>Source: [133, DE UBA 2014]</i>	

Table 2.18: Share of core sands for serial production in German ferrous and non-ferrous metal foundries in 2012

System	Share [%]
Polyurethane Coldbox, Amine	78
Warm-box, Hot-box	7
Water glass system	5
Epoxy/acrylic, SO ₂ curing	4
Resol CO ₂	3
Shell moulding/Croning	1
Methyl formate curing	1
<i>Source: [133, DE UBA 2014]</i>	

2.2.5.2.2.3 Coal dust

Coal dust is usually added to green sand for cast iron moulding. It is used to a limited extent in some non-ferrous foundries. Coal dust may be mixed with small amounts of resins and oil products. During casting, the thermal degradation produces ‘lustrous carbon’, which improves the casting surface finish and shake-out properties. Coal dust is added for three reasons:

- to create an inert atmosphere in the mould cavity during pouring, through the combustion of organic compounds, which in turn slows down the oxidation of metal (slag formation);
- to reduce the penetration of metal in-between the quartz grains, through deposition of a graphite film, which also creates a flat casting surface;
- to reduce the amount of sand remaining on the casting surface upon shake-out.

In addition to the black and sticky dust caused by handling, coal dust may contain or generate polycyclic aromatic hydrocarbons (PAH) during pouring.

For steel castings, coal dust is not used because of carbon pick-up. In this case, it is usually replaced by cereal binders such as starch or dextrin.

Various types of coal dust or coal dust replacements exist. These consist of lustrous carbon generating materials blended with clays.

[73, Brown, J. R. 2000], [120, TWG 2003], [134, CAEF 2020]

2.2.5.2.2.4 Cereal binders

Cereal binders are used mainly in steel foundries to increase the strength and toughness of the green sand. There are two main types of cereal binder: starch and dextrin. Starch is the basic material and is produced from a number of plant materials, with maize starch being the most commonly used for foundry purposes. Dextrin is a repolymerised form of starch, produced through a subsequent acid and thermal treatment of starch.

Starches can help to reduce expansion defects, since as they burn out, they allow the sand grains to deform without deforming the mould. Cereals increase the green strength, dry strength and

toughness but can reduce the flowability. Dextrines improve the flowability and moisture retention, preventing moulds from drying out and edges becoming friable.

Cereal additions do not improve the erosion resistance of the sand or its resistance to metal penetration.

[73, Brown, J. R. 2000], [120, TWG 2003]

2.2.5.2.2.5 Iron oxide

Iron oxide reacts with quartz at high temperature and forms a low melting compound, fayalite. This glassy plastic product sinters the grains together. It is mainly used in the production of core sand, in order to reduce the formation of veins. [38, Vito 2001]

In the production of steel castings, iron oxide can be added to shell sand at levels ranging from 5 % to 10 % for quality purposes.

2.2.5.2.3 Running, gating, feeding and filtration

The different parts of the running and gating system are shown in Figure 2.29. The system carries out the following functions:

- controls the flow of the metal into the mould cavity at the rate needed to avoid cold metal defects in the casting;
- avoids turbulence of metal entering the mould;
- prevents slag and dross present in the melt from entering into the mould;
- avoids high velocity impingement of the metal stream onto cores or mould surfaces;
- encourages thermal gradients within the casting, which help to produce sound castings;
- enables the casting to be separated from the running/gating system easily.

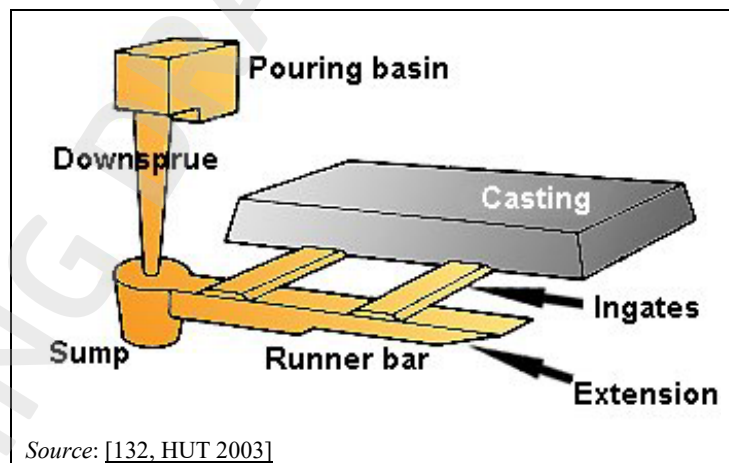


Figure 2.29: Components of the running and gating system

The design of the running system needs to take account of the varying slag and dross forming properties of the metal to be poured, e.g.:

- in lamellar iron, some furnace slag may be present but the melt is not subject to inclusions due to oxidation;
- nodular iron contains magnesium silicate and sulphide dross, arising from the nodularisation treatment;
- steel is susceptible to oxidation and slag formation;

- aluminium alloys (and aluminium bronzes) are all subject to dross formation, whereby a film of oxide forms immediately on any metal surface exposed to air.

Inclusions in steel can arise from slag entrapment, the erosion of furnace or ladle linings or refractories, or from deoxidation. Filtration is now widely used to reduce the presence of inclusions. The introduction of ceramic filters has even enabled simplifications to be made in the design of running and gating systems. Various types of filters are shown in Figure 2.30.

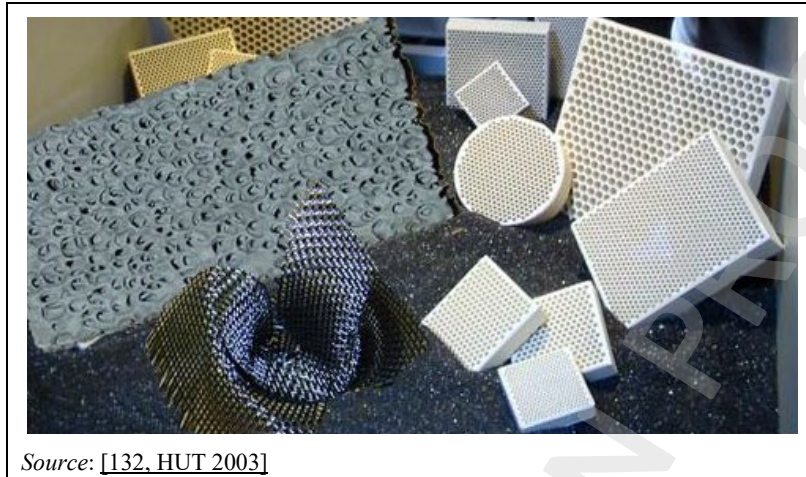


Figure 2.30: Various types of filters

Risers/feeders

During the cooling and solidification of most metals, a reduction in the metal volume takes place; this is known as shrinkage. This can lead to the obtaining of a solidified casting which will exhibit gross shrinkage porosity and will not meet the required product specifications.

To avoid shrinkage porosity, it is very important to ensure a sufficient supply of additional molten metal, while the casting is solidifying, in order to fill any cavities that could otherwise form. This is known as feeding the casting and the reservoir supplying the molten metal is known as the feeder or riser. The design of feeders/risers is crucial to minimise the number of defects in castings. In particular, the feeder must be designed so that it freezes later than the casting itself. The feeder must contain a sufficient volume of molten metal to fill in any cavities that may form due to shrinkage. Also, usually one feeder may only be capable of feeding part of the whole casting; therefore, the feeding distance must be calculated to determine the number of feeders required to feed a given casting [73, Brown, J. R. 2000].

By optimising the design of feeders, a number of benefits can be obtained, e.g.:

- a greater number of castings are produced for a given quantity of molten metal;
- smaller moulds can be used reducing the sand consumption;
- less metal is melted;
- less time is required to remove the feeders from the casting.

2.2.5.3 Sand preparation (transport, sieving, cooling, mixing)

2.2.5.3.1 Sand conditioning (preparation) for green sand moulding

One of the major advantages in using green sand moulding is that the sand from the moulds can be reconditioned for multiple re-use. The layout of a typical green sand plant is depicted in Figure 2.31, and some examples of sand mixers are shown in Figure 2.32.

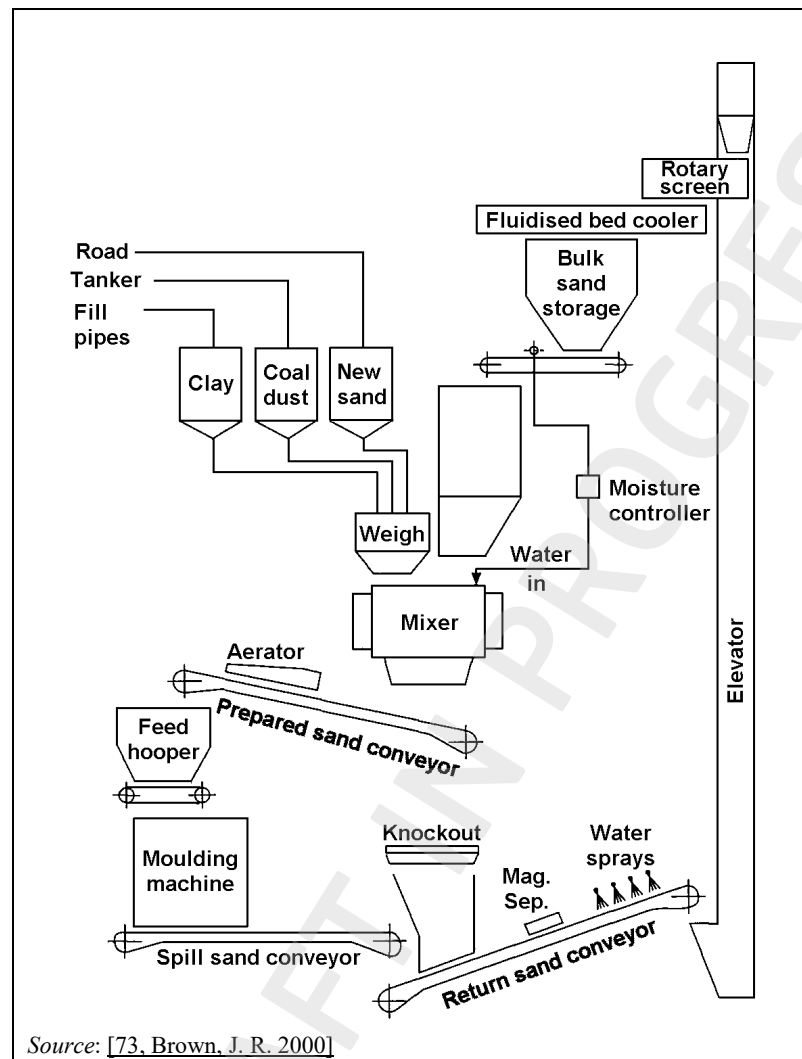


Figure 2.31: Flow diagram for a typical green sand plant



Figure 2.32: Various types of sand mixers

As the sand usually contains metallic elements such as flashes, pouring drops, pieces of sprue or even small parts of casting, all these have to be removed, at first by means of magnetic iron separators. If separation of the magnetic iron castings is not achieved or not possible, separation may be carried out by Eddy current separators. The residual sand lumps are then broken up. It is important not to crush the sand, in order to prevent the demixing of the sand and bentonite.

Usually, the sand has to be cooled in order to keep the moisture level of the prepared sand as constant as possible and to avoid any loss by evaporation. Cooling is often performed in a fluidised bed, which also allows the sand to be dedusted by removing excessive amounts of fines.

The sand is then screened to remove the remaining lumps and stored before mixing with the required amounts of additives, say clay, water, etc. to prepare the green sand for reuse. [14, CAEF 1997], [73, Brown, J. R. 2000]

2.2.5.4 Moulding with natural sand

Some foundries use naturally bonded sand. This is sand which contains a natural percentage of clay. Only water needs to be added in order to activate the binding capacity. If needed, some additives may be mixed as well. The approximate composition of natural sand is given in the following table.

Table 2.19: Composition of natural sand

Compounds	Approximate %
Quartz sand	80
Clay	15
Water	5
<i>Source: [41, Teknologisk 2000]</i>	

Natural sand, which is found ready-mixed in nature, does not have the same high demands for mixing equipment as synthetic sand. It is mainly used in small-sized non-ferrous (e.g. copper) foundries and is seldom used in foundries casting iron and steel.

2.2.5.5 Moulding with clay-bonded sand (green sand moulding)

Green sand moulding is the most common moulding process. Green sand is generally not used to make cores. Cores are formed using a chemical binding system. Green sand is the only process that uses a moist sand mix. The mixture is made up of about 85 % to 95 % silica sand; 5 % to 10 % bentonite clay; 3 to 9 % carbonaceous materials such as powdered coal, and 2 % to 5 % water. The clay and water act as the binder, holding the sand grains together. The carbonaceous materials burn off when the molten metal is poured into the mould, creating a reducing atmosphere which prevents the metal from oxidising as it solidifies. Table 2.20 gives a survey of the additives used for various types of metal castings.

Table 2.20: Composition of additive mix for green sand preparation (excluding water)

Metal	Additives for green sand preparation
Nodular cast iron casting	Bentonite
Lamellar iron casting	Cereal binder*
Malleable iron casting	Coal dust
Steel casting	Bentonite Cereal binder*
Light metal and aluminium casting	Bentonite Cereal binder*
Magnesium-alloyed-aluminium casting	Bentonite

Metal	Additives for green sand preparation
	Boric acid
Magnesium casting	Bentonite Powdered sulphur Boric acid
Heavy metal casting (copper alloys)	Bentonite Cereal binder* coal dust
* Optional additive. Source: [16, Winterhalter et al. 1992]	

Green sand, as demonstrated by its widespread use, has a number of advantages over other casting methods. The process can be used for both ferrous and non-ferrous metal casting and it can handle a more diverse range of products than any other casting method. For example, green sand is used to produce the total range of castings, from small precision castings up to large castings of up to a tonne. If uniform sand compaction and accurate control of sand properties are maintained, very close tolerances can be obtained. The process also has the advantage of requiring only a relatively short time to produce a mould compared to many other processes. In addition, the relative simplicity of the process makes it ideally suited to a mechanised process.

Although manual moulding is still in use, machine moulding is currently the most widespread. Two sequential operations must be performed by a moulding machine: the first is ramming the sand, followed by separating the pattern from the compacted sand. The most commonly used processes proceed from the working principles described hereafter.

Squeeze moulding machines use pressure to pack the sand, which is applied through a squeeze head or by a multiple-piston squeeze head. Moulding by squeezing alone becomes less effective as the depth of the half mould increases. In these cases, jolting the work table greatly increases the compaction of the sand.

In impact moulding, sand is fed under gravity into the flask and compacted by the instantaneous release of compressed air through a rapid acting valve. This process gives a high and uniform densification, particularly in the sand surrounding the pattern.

Flaskless moulding, with both vertical and horizontal parting, achieves impressive production efficiencies. High mould accuracies can be achieved, but this process requires an effective set-up and high quality patterns to achieve the desired objective.

[14, CAEF 1997], [18, US EPA 1998]

2.2.5.6 Moulding with unbonded sand (V-process)

This process uses dry sand, rammed by vibration without any binder addition, with the sand held between two polyethylene sheets by partial vacuum.

The production of a half mould is illustrated in Figure 2.33. The successive steps of the process are as follows:

- The pattern is fixed to an airtight chamber which is connected to a vacuum pump. The pattern is vented by small diameter holes connecting through the airtight chamber.
- A thin film of polyethylene vinyl acetate (PEVA), 75 to 100 microns thick, is heated up to 85 °C.
- This film, which is expanded under heat, is applied on the pattern and fixed by vacuum applied through the airtight chamber.
- A moulding box, in which a vacuum can be created, is placed on the pattern, and filled with dry sand.

- This sand is compacted by vibration, made even, and then a second film of PEVA is applied to the sand.
- Air is extracted from the moulding box and at the same time, the vacuum is released in the airtight chamber; the vacuum stiffens the sand and the half mould can then be stripped off.
- The second half mould is made in the same way and both are assembled and closed, with the vacuum still being applied.
- The metal can now be poured, the two moulding boxes remaining under vacuum until the casting is cool enough to be shaken out.
- Shake-out occurs simply by shutting off the vacuum: the sand flows out from the box through the grid and may be recycled after dedusting and separation of the unburned plastic sheets.

[73, Brown, J. R. 2000]

The V-process may not be applicable to moulding boxes with large dimensions. Typically, vacuum moulding is only possible with moulding boxes up to 1.5 x 1.5 m.

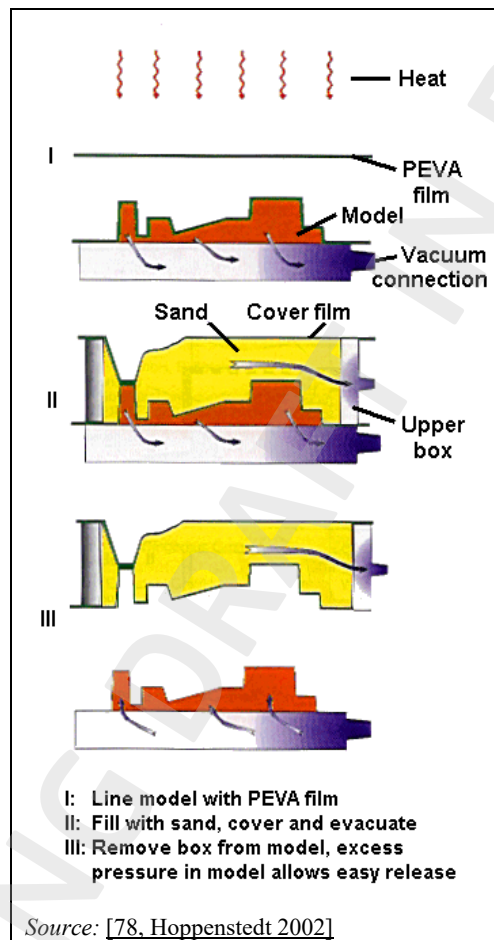


Figure 2.33: Vacuum moulding

2.2.5.7 Moulding and core-making with chemically bonded sand

For core-making, chemical binding systems are primarily used. Cores require different physical characteristics than moulds; therefore, the binding systems used to make cores may be different from those used for moulds. Cores must be able to withstand the strong forces which can occur when molten metal fills the mould, and often must be later removed from small passages in the solidified casting. This means that the binding system used must produce strong, hard cores that will collapse to allow removal after the casting has hardened. Therefore, cores are typically formed from silica sand (and occasionally olivine, zircon or chromite sand or blendings of these materials with silica sand), and strong chemical binders. The sand and binder mix is placed in a

core box where it hardens into the desired shape and is removed. Hardening, or curing, is accomplished with a chemical or catalytic reaction or by heat.

Table 2.18 (in Section 2.2.5.2.2.2) gives the relative share of the various core-making processes in German foundries in 2012. This shows that the amine cold-box and warm-box/hot-box systems dominate the market. Since the 2010s, the share of inorganic silica systems in aluminium foundries producing automotive parts has been increasing. The other processes are mainly used for supplementary use, i.e. making cores with specific requirements (size, thickness, etc.) [18, US EPA 1998], [73, Brown, J. R. 2000], [134, CAEF 2020]

2.2.5.7.1 Cold-setting processes (no-bake)

The curing of cold-setting sands is effective at ambient temperature. The process begins when the last component of the formulation has been introduced into the mix. It then continues for a few minutes to several hours, depending on the process, the amount of binder and the hardening agent strength.

These processes are more often used to make moulds and cores, especially for medium or large sized castings.

2.2.5.7.1.1 Phenolic acid curing

This process has been in use since 1958. As the components are relatively cheap, it is mainly used for the production of large parts. It is applicable for all alloy types.

The resins are either phenol-formaldehyde (PF), or urea-formaldehyde/phenol-formaldehyde copolymers (UF/PF), both being 'resols', with a formaldehyde/phenol ratio higher than one.

The catalysts are strong sulphonic acids, such as paratoluene, xylene or benzene-sulphonic, with sometimes an addition of sulphuric acid, usually used in a diluted form.

2.2.5.7.1.2 Furan acid curing

These binders, firstly introduced in foundries in 1958, are commonly used for the moulding and core-making of medium and large sized parts, for small and medium batch production and for all alloy types. Only certain types are used for steel casting, as cracks, fins or pinholes may occur. The process allows good flexibility in application and properties. Furfuryl alcohol (FA) has the disadvantage of being a (strategic) basic product, which leaves it subject to market price variations. Furan binders are comparable to phenolic binders in that their setting mechanism and the acid catalysts used are the same for both processes. Some examples of furan cores are shown in Figure 2.34.



Figure 2.34: Furan cores

The addition of an acid to a furan resin causes an exothermic polycondensation, which cures the binder. Furan resins are available with different formulations, all of which are based on furfuryl alcohol:

- furan resin FA;
- urea – formaldehyde – furfuryl alcohol UF – FA;
- phenol – formaldehyde – furfuryl alcohol PF – FA;
- urea – formaldehyde – phenol – furfuryl alcohol UF – PF – FA;
- resorcinol – furfuryl alcohol R – FA.

A silane is nearly always added to enhance the resin-sand bond. The acids for curing are strong sulphonic acids, such as paratoluene, xylene or benzene-sulphonic, sometimes with an addition of sulphuric or phosphoric acid, usually used in a diluted form.

[38, Vito 2001]

2.2.5.7.1.3 Polyurethane (phenolic isocyanate)

This process is used to a minor extent for moulding and core-making, with restrictions for steel casting, as cracks or pinholes may occur. These can be prevented however, by the addition of iron oxide.

This process is based on a polyaddition reaction between a phenolic resin and an isocyanate (mostly MDI), catalysed by a pyridine derivative; with the result being a polyurethane structure. All the components are in solution in aromatic and/or polar solvent (i.e. aliphatic solvent) with a high boiling point. Contamination by water must be strictly avoided since water reacts strongly with the isocyanate.

2.2.5.7.1.4 Resol-ester (alkaline phenolic ester curing)

This process is used for small or medium batch production. It may be used for all alloy types but is of special interest for lighter alloys, because of the ease of shake-out. The absence of nitrogen in the compounding reagents is a benefit for steel casting.

The resin is an alkaline phenolic resol solution, which reacts with a liquid ester. The resin and the ester produce an unstable complex, causing gelification. The complex disintegrates and causes cross-polymerisation of the resin, producing a salt and an alcohol.

In this process, the curing speed is not adjusted by the addition rate of the hardener, but by using different grades. The curing time may vary from a few minutes to more than one hour. Mechanical properties immediately after curing are rather poor, but improve upon storage.

2.2.5.7.1.5 Alkyd oil, unbaked

This process is mostly used for single castings or for small batch production in steel foundries. It provides the benefit of a good surface finish and good stripping properties. However, it is expensive.

An oil modified polyester resin is mixed with isocyanate, producing a polyurethane resin, which hardens slowly. The curing of the mould is accelerated by a catalyst and completed by heating to 150 °C.

2.2.5.7.1.6 Ester silicate

This process is used mostly in steel foundries, for medium and large sized castings in medium and small series. It is similar to the unbaked alkyd oil process. However, it has poor shake-out properties and lower mechanical resistance than organic resin-bonded systems.

The curing of a silicate - ester sand proceeds through an intermediate step, which consists of the hydrolysis of the ester by the alkaline silicate solution. This hydrolysis produces glycerol and acetic acid, which precipitates a silicate gel to form the initial bond. Further strength develops as the residual silicate dries.

2.2.5.7.1.7 Cement

This process is only used for very large sized castings. Its application is relevant for public works applications. It does not generate any emission problems during moulding or core-making.

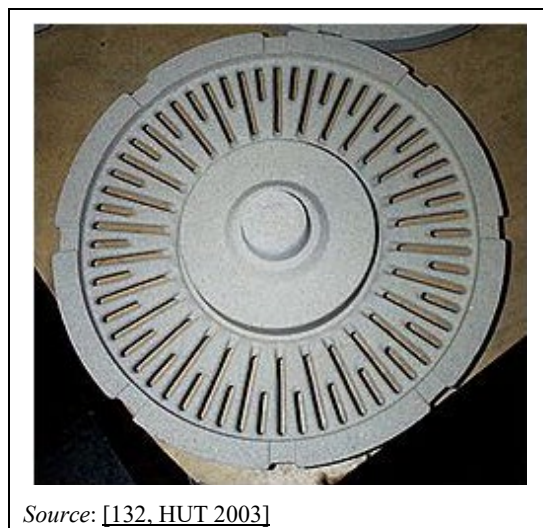
2.2.5.7.2 Gas curing processes

In these processes, curing takes place by injecting a catalyst or a hardener in a gaseous form. The curing speed can be very high, which allows high production rates to be achieved. They are suitable for moulds and cores of limited size, in medium batch or mass production. Their use has been constantly expanding over the last decades.

The chemistry behind many of these gas curing processes is similar to the cold-setting processes. Because of the gaseous form of the catalysts, it is sometimes necessary to collect and treat their emissions.

2.2.5.7.2.1 Cold-box (amine-catalysed phenolic urethane binder)

This process is commonly used to make cores of up to 100 kg and more, and small moulds. It provides a very smooth surface finish, and the dimensional accuracy is very high. The core removal properties are excellent and the sand can easily be reclaimed. This process is the most commonly used in core-making. An example cold-box core is shown in Figure 2.35.



Source: [132, HUT 2003]

Figure 2.35: Cold-box core

The chemistry of this polyurethane based process is very similar to the polyurethane cold-setting one, e.g. it involves a phenolic resin and an isocyanate (MDI). Only the catalyst is different; here a tertiary amine is used, such as triethylamine (TEA), dimethylethylamine (DMEA), dimethylisopropylamine (DMIPA) or dimethylpropylamine (DMPA). The amine is applied as a vapour, using compressed air, nitrogen or CO₂ as a carrier gas. Both resin and isocyanate are in solution in aromatic and/or polar solvents that have high boiling points. Contamination by water must be strictly avoided as it reacts strongly with isocyanate and weakens the binder.

The amine is delivered either by a generator, in which a supporting gas, preferably inert, is saturated with amine vapours, or by an injector, which measures out just the right amount of amine required for the operation, this latter being carried to the sand by compressed air or gaseous nitrogen. The addition rate for the binder varies from 1.0 % to 2.0 % based on the sand weight, with resin and isocyanate in a 50:50 ratio.

The amine is just a catalyst and is not consumed in the reaction. After curing, it remains in the sand of the mould or core and has to be purged. The purging period currently lasts 10 to 15 times longer than the injection of the amine. The amount of amine required for curing is about 0.05 % based on the sand weight, but typically 0.10 % to 0.15 % is used.

[38, Vito 2001]

2.2.5.7.2.2 Resol-methyl formate (alkaline phenolic methyl formate curing)

This process is mostly used for core-making. Even though difficulties in recycling used sand have been reported, this process is used, mainly because of its shake-out properties; the ability to prevent cracking, veining and pinholes; and because of its low odour emissions. The process can be used for all types of series and alloys.

The resin is an alkaline phenolic resol, which reacts with methyl formate to produce methanol and an alkaline formate. The phenolic resin is precipitated as a gel that binds all compounds together. Further cross-linking leads to even higher strength on storage.

Methyl formate is liquid at ambient temperature, the boiling point being 32 °C, but it is gasified by air typically heated up to 80 °C; which also acts as the carrier in the process. The gassing period is always followed by an air purge, the purpose of which is to evenly distribute the methyl formate throughout the mass of sand.

2.2.5.7.2.3 Epoxy/acrylic resin, SO₂ curing (free radical curing)

This process offers many advantages: good compaction ability; long bench lifetime of the prepared sand (the mixers or shooting heads do not need to be cleaned); good mechanical properties; no nitrogen, phenol or formaldehyde; good shake-out performance; and no crack formation. However, the higher cost of binder constituents is one major disadvantage though.

This process is characterised not by the type of resin, but by the principle of its cross-linking, which occurs through free radicals. The resin must contain carbon double bonds: polyester – acrylic, polyester – urethane or polyester – epoxy resins may be used. These resins generally have a low molecular weight and are diluted with organic solvents at nearly 50 % by weight, though solvent free types are also available. They are mixed with an organic peroxide, which acts as a reaction initiator. For curing, sulphur dioxide is carried by gas through the sand. The gas could be inert such as carbon dioxide or nitrogen, or air or a mixture of air with an inert gas.

The gassing period is always followed by purging typically using a gas or a gas mixture with the same composition that was used for curing, the purpose of which is to remove the unreacted excess sulphuric dioxide from the sand mass.

2.2.5.7.2.4 CO₂-hardened sodium silicate (water glass)

This process presents advantages: it is cheap, easy to handle and environmentally clean as well as for workers' health and for reliability of operation. These are advantages over organic binders. Its use however, has declined in popularity due to technical reasons, such as poor compaction ability and problems with collapsibility, poor mechanical strength, sensitivity to crumbling, moisture pick-up and poor reclaimability. Furthermore, the use of water glass can lead to increased cleaning costs. The cores reach their full strength only after a drying period. This reduces their applicability in automated processes. The technique therefore finds its main application in small scale foundries.

The silicate generally used is sodium silicate, defined by its concentration (dry solid content) and modulus (silica soda ratio SiO₂/Na₂O). This modulus ranges from 2.0 to 2.8, the most common being 2.0 to 2.3. This silicate is mixed with the sand at a concentration of between 2 % and 4 %. Shake-out and decoring additives are commonly used and are usually pre-mixed with the silicate.

Curing occurs by gassing with carbon dioxide, due to its slightly acidic character. The CO₂ ratio should not exceed 1 to 2 % of the mass of sand, with a gassing time in the range of 10 to 60 seconds. The cured moulds and cores do not require purging.

[41, Teknologisk 2000], [56, Notzon et al. 1998]

2.2.5.7.2.5 Resole, CO₂ curing

This process was introduced for the first time in 1989 and has been undergoing improvements ever since. It is commercially available but its use is not widespread.

The resin is an alkaline phenolic one, containing a linking substance stabilised at a high pH, approximately 14. Curing occurs by gassing with carbon dioxide, which dissolves in the water solvent of the resin, so lowering its pH and activating the linking substance.

2.2.5.8 Hot curing processes

In these processes, curing takes place by heating the sand-resin mix or, more often, by allowing it to come into contact with the heated pattern or core-box equipment. They all provide a high dimensional accuracy, which can only be achieved by means of using high quality (metal) patterns, which can be very expensive. For this reason, hot curing processes are used for the production of cores of limited size, mostly in mass production processes. Their use, very

widespread for years, is now on the decline, as they are being replaced by gas cured processes or, in aluminum foundries producing automotive parts, by processes using inorganic binders rather than the warm-box or hot-box systems.

Organic hot curing processes are characterised by major emission problems: when heated, the resins and catalysts emit noxious chemicals including ammonia and formaldehyde that can be the source of odour nuisance. More information on the associated emission levels is given in Section 2.3.

2.2.5.8.1.1 Hot-box, phenolic- and/or furan-based

This process can produce cores of a high dimensional accuracy and good mechanical strength. It is currently used in the manufacturing of small or medium-sized cores in mass production. In addition, using special machines, hollow cores can be produced for saving sand and for better degassing and decorating.

A resin binder and a heat activated catalyst are pre-mixed with sand and the mixture is blown into a heated core box or pattern, where it is cured for approximately 5 to 60 seconds.

A wide range of resins may be employed, such as:

- urea – formaldehyde UF;
- urea – formaldehyde – furfuryl alcohol UF – FA;
- phenol – formaldehyde PF;
- phenol – formaldehyde – furfuryl alcohol PF – FA;
- urea – formaldehyde – phenol – formaldehyde UF – PF;
- urea – formaldehyde – phenol – formaldehyde – furfuryl alcohol UF – PF – FA.

The catalysts are ammonium salts of mineral acids, sometimes with urea additions to reduce free formaldehyde. Additionally, other additives are used, such as silanes, iron oxides, preservatives and silicon oil.

The addition ratio for the resin varies from 1.2 % to 3.0 % based on sand weight, with an average of about 1.8 %. The addition ratio for the hardener varies from 10 % to 25 % based on resin weight, with most formulations being optimised at 20 %. The temperature mostly used for the pattern ranges from 230 °C to 290 °C, with the optimum range being 220 °C to 250 °C. If excessive heat is used in an attempt to accelerate the curing time, the core surface can be burnt, producing brittleness during pouring.

2.2.5.8.1.2 Warm-box

This process is very similar to the hot-box process and uses the same production techniques. Only the type of resin differs, allowing curing at a lower temperature. Although the warm-box process presents some advantages over the hot-box process, its use is not widespread.

The binder is furfuryl alcohol-based, with a typical composition containing around 70 % furfuryl alcohol or a low polymer of furfuryl alcohol. The catalysts are copper salts derived from aromatic sulphonic acids, in water or an alcohol solution. The distinctive feature of these catalysts is their excellent stability at ambient temperature and their relatively low dissociation temperature, which is 150 – 170 °C. Accordingly, the tool temperature can be held at around 180 °C, which leads to major energy savings of about 15 % to 25 % compared to the hot-box.

2.2.5.8.1.3 Shell moulding (Croning)

This process is the only one among all moulding and core-making processes using pre-coated sand, directly available from suppliers and ready for use, although pre-coating of the sand may also be performed at the foundry.

For steel grades, normally silica sand with a high silica level $> 90\%$ is used with an addition of $5 - 10\%$ iron oxide.

The sand is cured by heating it in a metallic pattern, producing a hardened surface layer. The unheated or uncured sand may be discarded by turning the pattern upside down and then reused. The cured sand forms a 'shell', which has given its name to the process. With special machines, hollow cores can also be produced to save sand and for better degassing and decoring.

This process gives high dimensional accuracy and a good surface finish to the castings, good shake-out and decoring properties and allows a nearly unlimited storage time for the pre-coated sand. The process limits are the high investment and high operating costs (energy costs). Its use is restricted to the production of small or medium sized moulds and cores in mass production. Example cores and moulds are shown in Figure 2.36.



Figure 2.36: Croning cores (top) and moulds (bottom)

The resin used for pre-coating is a phenolic 'novolac', with a formaldehyde/phenol ratio lower than 1. Hexamethylenetetramine is added to the resin as a hardener and decomposes at $160\text{ }^{\circ}\text{C}$ into its two basic components: formaldehyde and ammonia. When pre-coated sand contacts the heated pattern, the hexamethylenetetramine decomposes and the formaldehyde cross-links the resin binder to form the characteristic strong bond.

2.2.5.8.1.4 Linseed oil

This ancient process is probably the oldest one processing chemically bonded sands. It is very easy to use, does not need sophisticated patterns and has a good resistance to veining and cracking. It is still in widespread use for specialised small cores.

These sands are bonded with a mixture of drying oils, these usually being to a great extent linseed oil, often with an addition of dextrin and a few per cent water. The addition rate of oil varies from 0.8 % to 4 %, based on sand weight. Drying agents may also be added. Curing occurs by cross-linking of the unsaturated fatty acids contained in the drying oils, induced by atmospheric oxygen and accelerated by heating in a drying-oven at a temperature between 190 °C and 260 °C for 1 to 2 hours.

2.2.5.8.1.5 Alkyd oil, baked

This process is similar to the previously described unbaked alkyd oil process, the only difference being in this case heat treatment of the parts in order to accelerate the curing.

2.2.5.8.2 Coating of chemically bonded sand moulds and cores

The skill of the founder is to produce high quality castings, without defects, and requiring only minimal finishing and repair. To achieve this, the ideal is to minimise all the interactions that may occur between mould, core and metal during pouring. These effects may be generated by different causes, such as sand expansion, ramming defects, abrasion of sand, metal penetration, chemical decomposition or by interaction between the binders, etc.

For these reasons, it is often beneficial to coat the mould or the core with a refractory lining, in order to give a smooth surface finish to the casting and to reduce fettling cost.

2.2.5.8.2.1 Composition of coatings

Coatings are available as ready-to-use products or as a mass to dilute with water or alcohol. They usually contain the following components:

- one or more refractory fillings, such as talc, pyrophyllite, mica, zircon, magnesite, quartz, etc., or blacking;
- a make-up liquid, which may be an alcohol (e.g. isopropanol, ethanol) or water;
- high temperature bonding agents, such as bentonites, resins, boric acid;
- rheological agents, such as bentonites or synthetic polymers;
- additives, such as surfactants, foam breakers, fungicides, etc.

2.2.5.8.2.2 Coating process

The coating may be applied on the mould or on the core by different means:

- by brushing, for small cores or for localised application;
- by dipping, for complex shaped cores; this process often being automated;
- by spraying, usually airless;
- by flow-coating, for large or medium-sized moulds or cores.

If alcohol-based coatings are applied, the working area needs to be ventilated in order to prevent the danger of fire or explosion. The coated moulds and cores are mostly burnt out, which limits the emissions. If they are not burnt out then drying is carried out under exhaust with the VOC

emissions maintained under control. Flow coating with alcohol-based coatings and subsequent firing or drying is presented in Figure 2.37.



Source: [132, HUT 2003]

Figure 2.37: Flow coating with alcohol-based coating, followed by firing or drying

The drying of water-based coatings occurs by heating in a drying furnace using hot air, infrared or microwaves. The dip-coating of cores and subsequent hot air drying is presented in Figure 2.38. Water-based coatings do not generate emission problems, neither during coating nor during drying. For these reasons, water coatings are now increasingly replacing alcohol-based ones. However, their application faces technical constraints in terms of the coating quality continuity and drying constraints. A full discussion of water-based versus alcohol-based coatings is provided in Section 3.2.1.5.5. [49, Inasmet and CTIF 2002]



Source: [132, HUT 2003]

Figure 2.38: Dip-coating with water-based coatings, followed by drying in a hot-air furnace

2.2.5.9 Expendable pattern casting

In expendable pattern casting, the pattern is not removed from the mould before pouring. The pattern, which is made of expanded material, is a single-use one, which is destroyed when poured. These expendable patterns may be embedded either in chemically bonded sands or in binderless sand, condensed by vibration.

This process with binderless sand, commonly called ‘Lost Foam casting’, was developed some decades ago and its application is limited. However, during the last 10 to 15 years, it has become more commonly used, primarily for the mass production of automotive parts or similar products, in spite of significant set-up difficulties.

2.2.5.9.1 Unbonded sand – Lost Foam process

The Lost Foam process (Figure 2.39) starts with the 3D-CAD design and production of a precision moulded foam pattern, made from expanded polystyrene (EPS) or PMMA, produced by automated injection moulding machines. These patterns can be made from one piece or by assembling a number of parts by adhesives. Here usually, a number of patterns, dependent on size, are fixed to a runner-down gating system, made from the same material as the pattern, thereby generating a cluster.

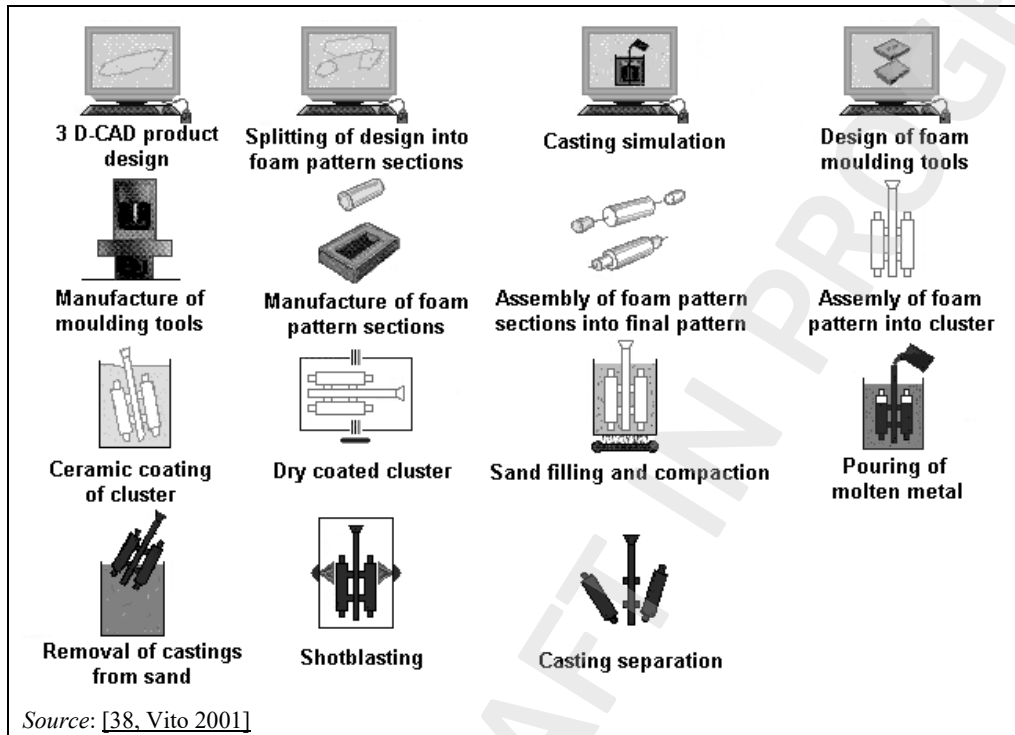


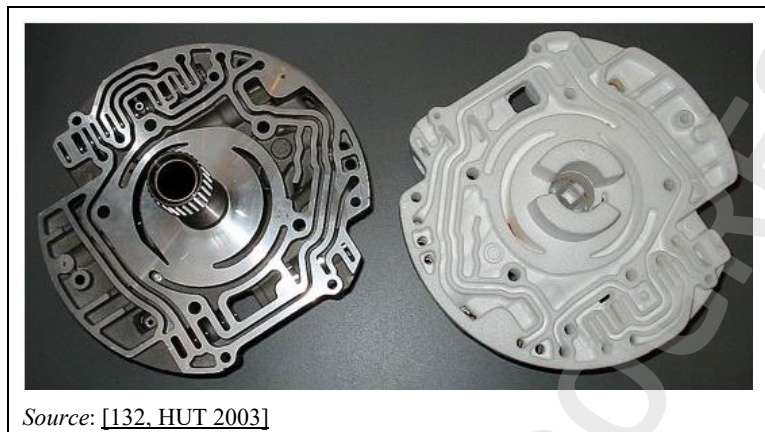
Figure 2.39: The Lost Foam process

The clusters are dipped in a water-based refractory-type coating, which creates a barrier between the molten metal and the sand during pouring. After drying, the cluster is positioned in a moulding flask, which is filled with unbonded sand. A low-viscosity resin may be added to the sand, in order to prevent deformation during compaction. The sand is compacted by triaxial vibration around the patterns, penetrating the holes and reproducing exactly all the details, thus making the core and core-making equipment unnecessary. Upon pouring, the molten metal causes a pyrolysis of the polystyrene and fills the emptied space.

The sand, mostly quartz, needs to be very permeable, in order to ensure the evacuation of the pyrolysis gases. Sand with an AFS-number of 35 – 50 is used. Interruption of the pouring may cause a collapse of the sand mould. Therefore an automatic casting system is often used.

The cast pieces are characterised by a very good dimensional precision, as shown in Figure 2.40. The technique can be used for any type of alloy and is used for medium to large sized series production. The process is environmentally friendly during the moulding but produces gaseous emissions during pouring and shake-out, due to the vaporisation of the expendable patterns. Lost Foam casting enables metal casters to produce complex parts which would often not be possible using other methods. The process allows designers to develop more complex shapes, to reduce machining need and to minimise assembly operations. Proper controls must be exercised in each step of the process to ensure consistent high quality castings. A lack of in-depth industry-wide knowledge on how to set up proper control measures has slowed adoption of the Lost Foam casting process.

[14, CAEF 1997], [38, Vito 2001], [50, US Dept. of Energy 1998]



Source: [132, HUT 2003]

Figure 2.40: Expendable polystyrene pattern (R) for the Lost Foam process and an example of a casting produced by the Lost Foam method (L)

2.2.5.9.2 Chemically bonded sand – Full mould process

Expendable patterns can also be used to produce single-piece prototypes, thereby permitting a shortening of the delivery time. Furthermore the technique can be applied for the production of very big pieces, such as bases for metal processing machines, or presses, etc. in cast iron, steel or non-ferrous alloys. The wall thickness may range from 5 mm up to 1000 mm. Pieces of up to 50 tonnes have been cast using this technique. For the production of these bigger pieces, the application of a (furan) binder is needed in order to attain the necessary mould strength.

This process with chemically bonded sand called the ‘full mould process’, is mostly used for producing medium or large sized castings, in single production or in small batch series.

The patterns are made from low-density expanded materials, such as:

- white, foamed polystyrene, with a density of 16 – 20 g/dm³;
- blue, foamed polystyrene, also called ‘poresta-blue’, with a density of 18 – 22 g/dm³;
- foamed polymethylmetacrylate, also called PMMA, with a density of 25 g/dm³.

These materials are cut out as various parts, which are then assembled and stuck together with hot melt glue, thus creating the final shape of the casting, also taking into consideration any possible shrinkage of the metal.

The assembled pattern, with its gating and feeding system, has to be coated, mostly with a water-based coating system, and thoroughly dried before being embedded in the sand. The binding process of the sand has to be specially selected in order to avoid any moisture pick-up by the pattern before pouring.

This process, as far as moulding is concerned, is very environmentally friendly, but produces gaseous emissions during pouring and shake-out, due to the vaporisation of the expendable patterns and destruction of the sand binder.

The full mould process has the following advantages:

- high size precision;
- production of complex geometries, especially internal cavities;
- integration of several parts into one casted piece;
- reduction or exclusion of release edges;

- possibility of sand regeneration.

Despite the fact that the Lost Foam and full mould techniques have been known for a long time, they are not widely applied in Europe. This is primarily because their optimisation requires a lot of research and development. The main difficulties are:

- definition of the product range: determining which pieces can be made more easily as compared to traditional methods;
- selection of the compaction technique: application of the sand in order to perfectly fill all cavities;
- choice of coating and sand type: these should have a sufficient gas permeability to allow the combustion gases to escape.

[38, Vito 2001]

2.2.5.10 Permanent (metal) moulds preparation

Permanent moulds are made from metallic elements adapted to the shape of the casting, whose assembly allows the moulding, pouring and stripping of the casting. These metal moulds are used for gravitational casting, high pressure die-casting, centrifugal casting, continuous casting and for low-pressure casting. Unlike sand moulds, they can be reused many times and for this reason, they are called permanent moulds.

If the shape of the casting cannot be easily made by the use of metallic core pins, sand cores may be used. For instance, sand cores are used to form the widening-out of centrifugal cast pipes.

Permanent moulds are generally coated with a 'white or black wash'; these water-based release agents are refractory based in the case of the white one and graphite based for the black one. Their function is to provide protection of the die, to regulate die cooling by water evaporation, and to provide lubrication. They also act as parting compounds.

In a few cases, blackening is provided by burning acetylene in the absence of air, producing acetylene black that partially sticks to the die. The non-adhesive black then has to be collected and filtered before emission.

Permanent moulds (or dies) are generally not made in the foundry, although die-casting foundries do have a workshop for die assembly, maintenance and repair. This type of operation, however, does not generate any environmental effects.

2.2.5.11 Investment casting and ceramic shell

This process is used to produce intricate, thin section parts with high dimensional accuracy, fine details, and very smooth surfaces.

The process steps are depicted in Figure 2.41. They begin with the manufacture of expendable wax patterns, by injecting molten wax into an aluminium or epoxy die to form a pattern that is virtually an exact replica of the desired casting. The wax may contain fillers. For smaller castings, several wax patterns are attached to a wax gating system. Water soluble die release agents are used to facilitate the wax model take-out.

The wax patterns are cleaned with water or organic solvent and coated with a wetting agent, which helps the ceramic slurry to adhere to the wax. The cluster is then dipped in a liquid ceramic slurry, stuccoed with granular silica, zircon or alumina/silica refractories and then dried before the application of the next coat. The coating process is continued until a sufficiently thick shell is established.

The dried mould is then de-waxed by inserting it into a steam autoclave in which the wax patterns are melted out, or into a 'flash furnace', in which the wax may be partially burnt out. After this, the shell is fired in a furnace at a high temperature. This burns out the residual wax and hardens the ceramic, leaving a one piece ceramic shell mould, into which the molten metal is poured to form the casting.

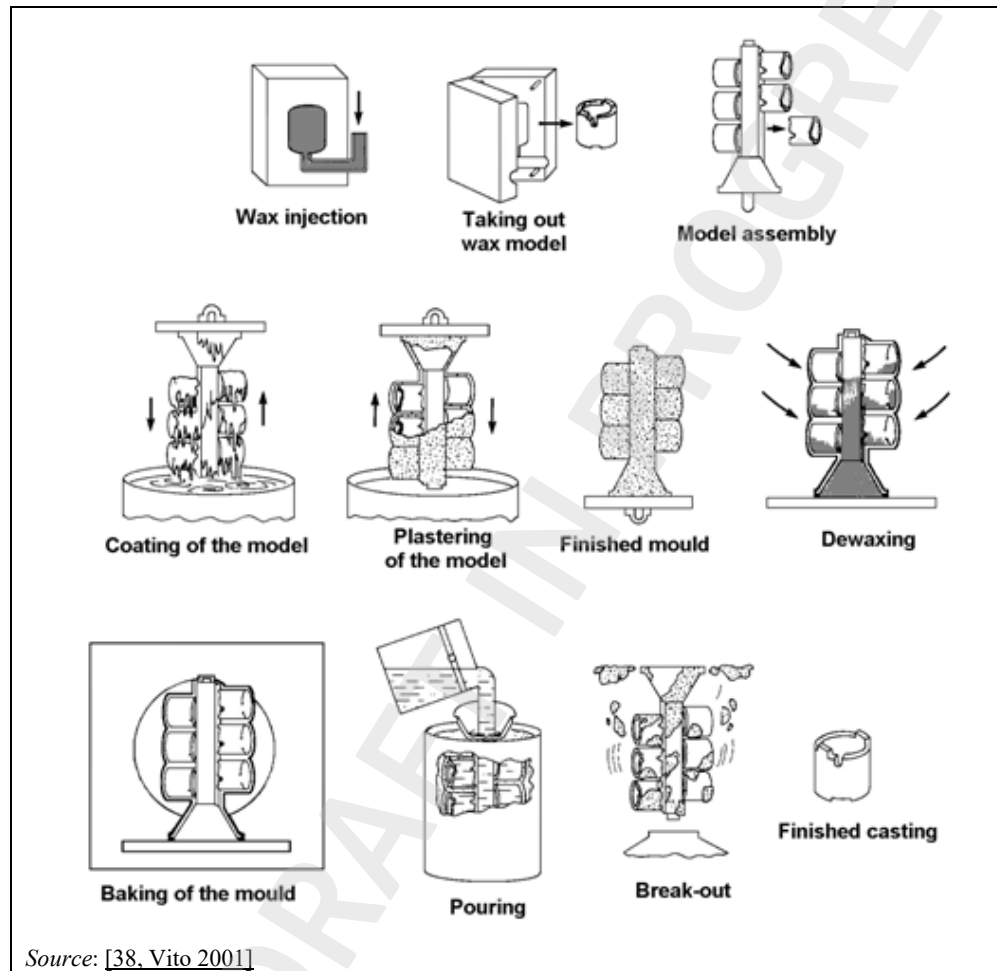


Figure 2.41: Investment casting process

In this process, air pollution may occur during two operations: investing and de-waxing.

Investing

The liquid ceramic slurry consists of a binder and a very fine refractory powder, reduced to slime by permanent mixing. The binder may be colloidal silica, hydrolysed ethyl silicate or hydrolysed sodium silicate, the choice of the technology applied being determined by technical reasons. When using ethyl silicate, drying is faster, which allows a higher cycle rate, but ethyl alcohol vapours are emitted. These vapours, if present in too large an amount, have to be collected and treated before emission.

De-waxing and firing

De-waxing by means of a steam autoclave does not produce any significant impact on air. However, this is not the case if the de-waxing is conducted in a firing oven, and during the firing of the shell, where wax residues are burned.

This burning occurs often in a lack of air, which results in the formation of carbon black particles. These particles have to be collected and either destroyed by afterburning or removed. Ceramic

filters have been successfully used for this purpose, as they suit the high temperature of the exhaust gases, but this very recent technology has not yet become widespread.

This technique is used e.g. for precision casting and art casting. It is generally not applied in large-scale foundries (> 20 tonnes/day capacity), and therefore is mentioned here only for informative reasons.

The ceramic shell process (patented as Replicast[®]) extends the quality and precision of investment casting to larger components, using a combination of Lost Foam and investment casting principles. The technique uses an inert, fired ceramic mould. To create the mould, an expanded polystyrene replica of the required component is produced, which is dimensionally precise and of a high surface finish. No parting lines or cores are required, nor draft angles, and polystyrene replicas can be glued together to create complex geometries. The polystyrene is burnt out before casting, allowing a wide range of alloys to be cast in the mould - from ultra low carbon stainless steel to nickel based alloys. This is in contrast to the Lost Foam process where liquid metal consumes and replaces the polystyrene pattern, making it unsuitable for the vast majority of steel components (polystyrene is comprised of 92 % by weight carbon).

[117, Castings Technology International 2003]

2.2.6 Casting

Pouring is the central activity in casting production. The finished mould is filled with the liquid metal under the effects of gravitational or centrifugal forces or pressure. After pouring the casting is cooled to allow solidification and is then removed from the mould for further cooling and treatment.

[14, CAEF 1997]

2.2.6.1 Casting in lost moulds

2.2.6.1.1 Pouring

There are two types of ladle generally used in pouring liquid metal: lip and teapot ladles. A third type (i.e. the bottom ladle) is more specific to steel.

- *Lip pour*: In this type of ladle (Figure 2.42) the metal is charged over the lip, with the flow controlled by tilting the ladle using a geared handwheel. Since the metal flows from the top of the ladle, the metal surface must be slag-free or a skimmer must be used to prevent slag entering the mould. Lip pour ladles are used for pouring small steel castings.

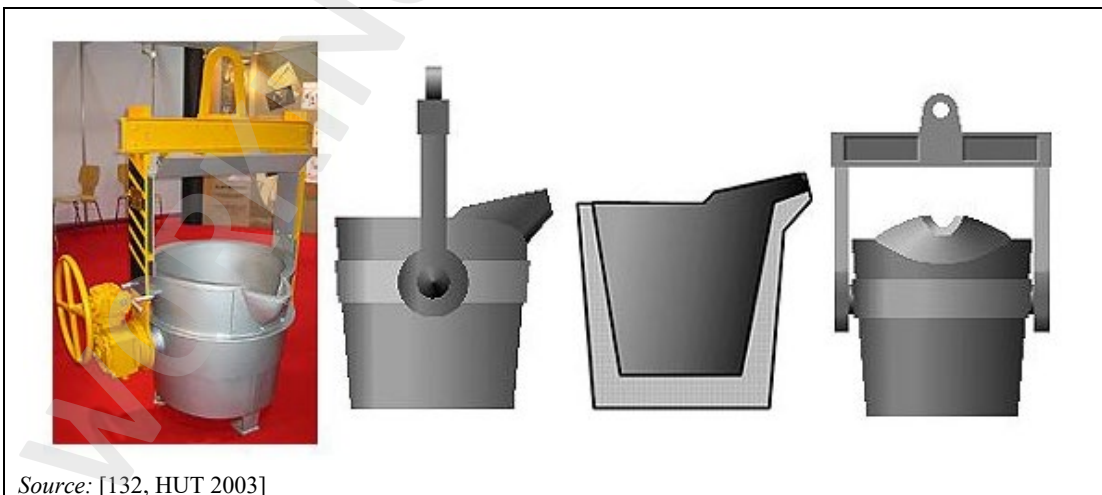


Figure 2.42: Lip pour ladle for molten metal pouring

- *Teapot ladles:* As depicted in Figure 2.43, a refractory dam before the ladle lip ensures that the metal is drawn from the bottom of the ladle, so that the stream is slag free. The molten metal is generally cleaner than from a lip pour ladle. One disadvantage is that the narrow spout may occasionally permit the liquid steel to freeze if the heat is tapped cold or if pouring is prolonged.

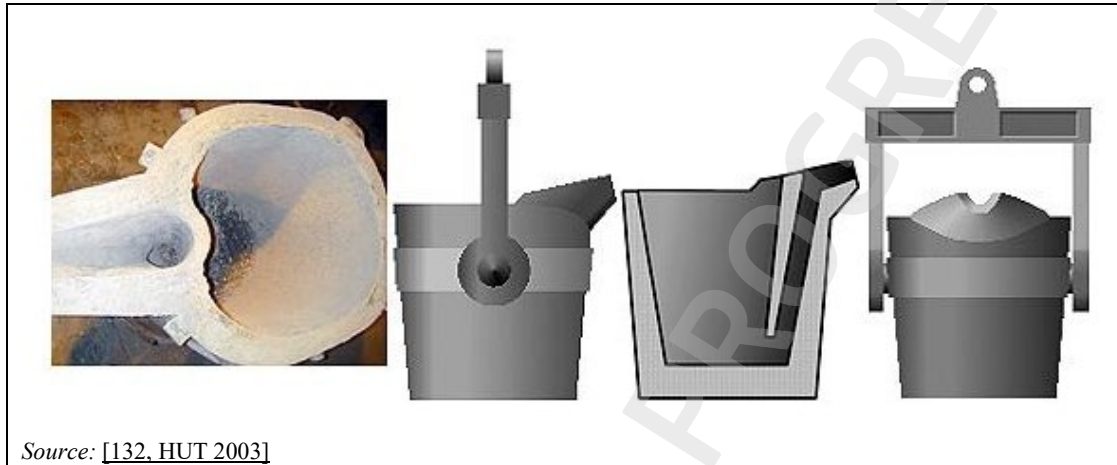


Figure 2.43: Teapot ladle for molten metal pouring

- *Bottom pour ladles:* The ladle is fitted with a pouring nozzle in its base, closed by a refractory stopper rod. The metal is drawn from the bottom and is therefore slag-free and non-metallics, such as deoxidation products, are able to float out of the melt. The metal stream flows downwards, so that there is no movement of the stream during pouring. The disadvantage is that the velocity and the rate of flow change during pouring as the ferrostatic head changes.

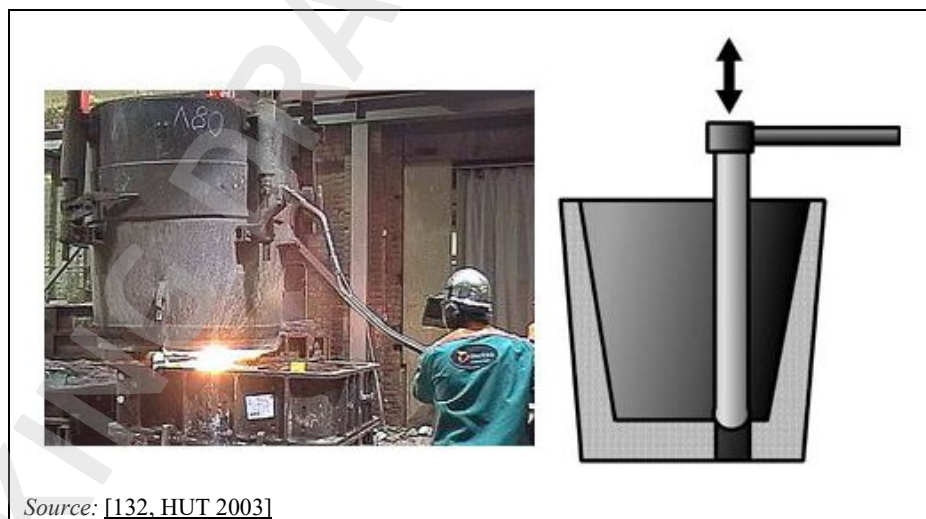


Figure 2.44: Bottom pour ladle for molten metal pouring

Automatic casting lines are often equipped with a pouring furnace. The working principle behind one example furnace is depicted in Figure 2.45. The casting line halts when a mould is in the correct position, i.e. under the pouring exit. Metal is poured during a fixed period by elevating a stopper. Because the metal level in the casting recipient is held constant, a fixed volume of molten metal is poured into the mould. The metal level in the furnace is controlled by a floating device, which controls the gas pressure inside the furnace. The casting furnace is refilled with metal from the melting furnace at fixed time intervals. [38, Vito 2001], [73, Brown, J. R. 2000]

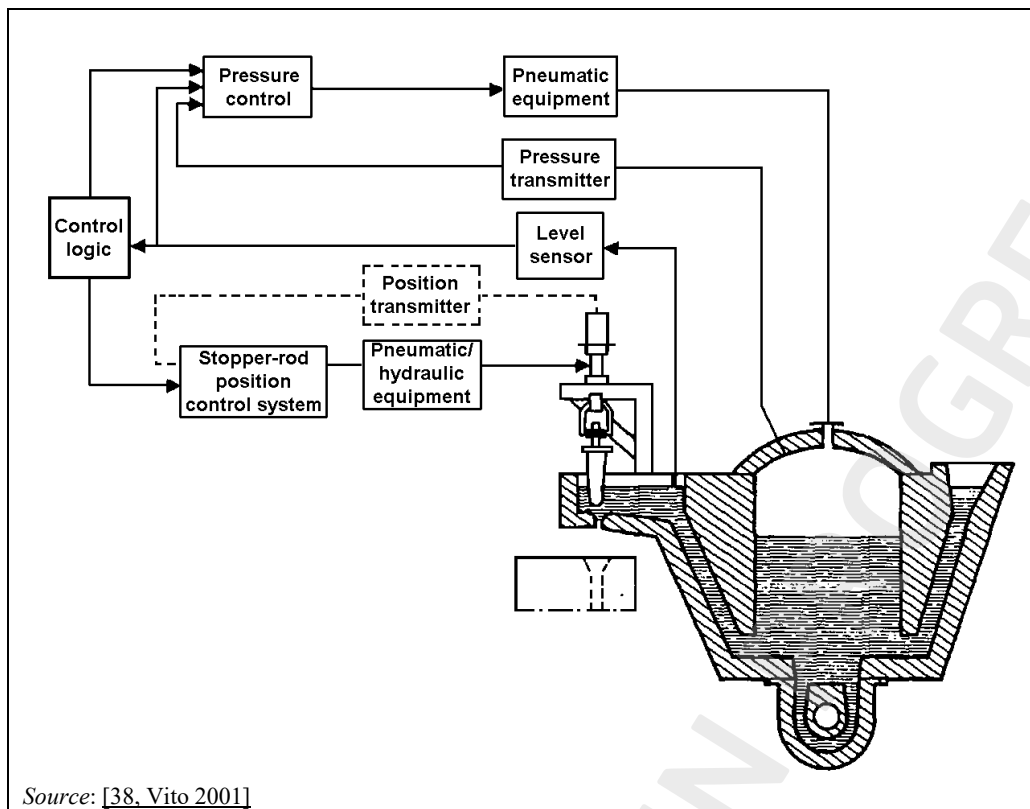


Figure 2.45: Pouring furnace

2.2.6.1.2 Solidification (first cooling)

The poured moulds are transported along the moulding line onto the cooling lines. The length of the cooling line determines the final temperature of the casting at the point of shake-out. This temperature must be low enough to provide the casting with sufficient strength during shake-out and further manipulation.

Big moulds are not moved during cooling. The cooling time can be up to several days. [38, Vito 2001]

2.2.6.1.3 Shake-out

In the case of individual moulding, clay or chemically bonded moulds can usually be destroyed by vibration. In most cases this is accomplished by placing the moulding box on a vibrating grate, using a crane to do this. As a result of the vibration, the sand is separated from the casting and the moulding box. The casting and moulding box remain on the grate rods, whereas the sand falls through and is subsequently reprocessed. The casting is usually transported to a cooling area for further cooling in ambient air (second cooling).

A similar shake-out procedure is often carried out in mechanised systems and older low-capacity automated systems (Figure 2.46). Here the moulding boxes are removed from conveyor belts, by means of hoists or other transfer equipment, and placed on vibrators. Finally, the castings are left to cool down or placed in a casting cooling device. In many systems, the sand casting is pressed out of the moulding box and a subsequent controlled cooling of the castings and sand is achieved in combined or separate cooling devices, such as in cooling drums, swing pipes, chain conveyors, fluidised bed coolers, etc.



Figure 2.46: Shake-out at the end of an automated moulding line

Vacuum bonded sand moulds are destroyed by releasing the vacuum. The casting bucket or moulding box, containing the loose sand and the casting, is emptied and then the casting is cooled by one of the described methods. [14, CAEF 1997]

2.2.6.1.4 Casting cooling (second cooling)

The controlled cooling of castings and sand is carried out in rotary drums, swing drums or on oscillating conveyor troughs. The casting is cooled in oscillating conveyors or in cable-car baskets. In many cases an airflow, which is often directed in the opposite direction to that of the casting, is used for cooling. In some cases, fine water jets are used in order to increase the cooling effect.

2.2.6.2 Casting in permanent moulds

2.2.6.2.1 Gravity and low-pressure die-casting

Gravity and low-pressure die-casting make use of a permanent steel die into which the melt is poured under the influence of gravity or a low-pressure gas. Sand cores can be used to form undercuts and complex interior shapes in the casting. Due to the rapid solidification process, permanent mould castings have a dense fine-grained structure with good strength characteristics.

The principle of low-pressure die-casting is shown in Figure 2.47. A metal die is mounted above a sealed furnace containing molten metal. A refractory-lined riser tube extends from the bottom of the die into the molten metal. When air is introduced into the furnace under low pressure (15–100 kPa) the molten metal rises up the tube to flow into a die cavity with low turbulence, the air in the die escaping through vents and the parting lines of the die. When the metal has solidified, the air pressure is released, allowing the still-molten metal in the riser tube to fall back into the furnace. After a further cooling time, the die is opened and the casting extracted. Due to the absence of feeders and risers, the casting yield is exceptionally high, generally over 90 %. A good dimensional accuracy and surface finish are possible and complex castings can be made using sand cores. This technique is typically used for aluminium castings, e.g. automotive parts such as wheels, cylinder heads, and electric motor housings, and for domestic kitchenware. The die must be coated to optimise the casting release and cooling. In general, a die coating is applied once per shift. The die life is normally around 30 000 – 50 000 shots. An example of a low-pressure die-casting machine is given in Figure 2.48.

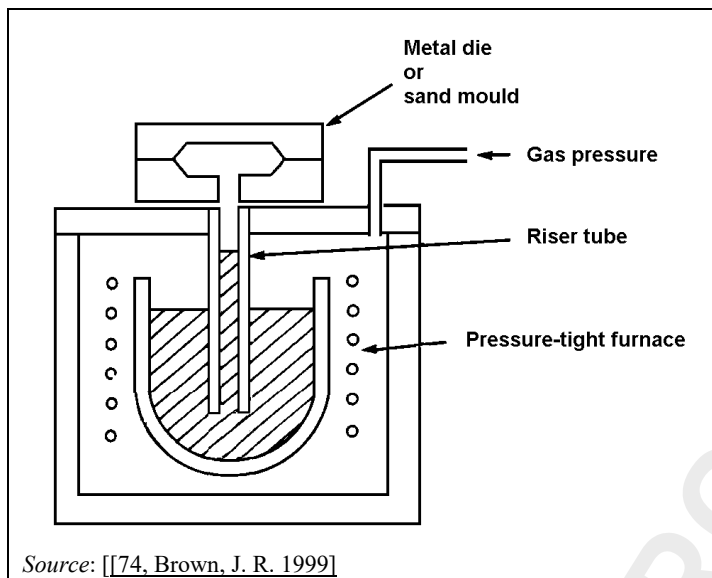


Figure 2.47: The principle of a low-pressure die-casting machine

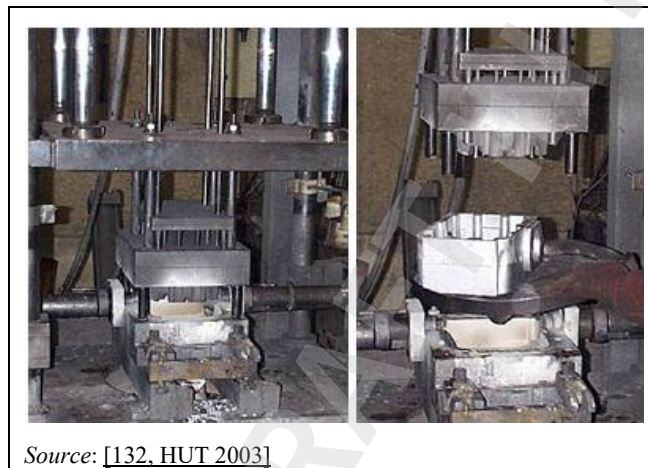


Figure 2.48: Low-pressure die-casting machine

In gravity die-casting, the molten metal is poured under gravity into a permanent mould or die. Gravity die-casting machines range from simple, hand operated rack and pinion die sets, manually poured, to carousel machines, which usually have a tilting mechanism for filling the die and which are often operated using a pouring robot. The dies are coated with a refractory-based coating, control the cooling rate. The time before the casting can be extracted from the die varies from 4 to 10 minutes depending on the type of casting. The process is therefore relatively slow, compared to pressure die-casting. To achieve reasonable output rates, a manual operator will operate two to four die sets in sequence, allowing an output of 30 – 60 castings an hour. Automatic carousel machines may have four to six stations with multiple die sets, allowing production rates of around one casting per minute to be achieved. The process is most widely used in aluminium casting for series' of 1 000 to more than 100 000 pieces per year for example for manifolds, cylinder heads, water pumps.

Permanent mould coatings are typically formulated using water as a carrier, a high temperature binder (normally sodium silicate) and a refractory filler or blend of fillers. There are two categories of coatings:

- insulating: containing blends of insulating minerals such as talc, mica, kieselguhr, titanium dioxide, alumina, etc.;

- lubricating: based on colloidal graphite or boron nitride to aid release of the casting.

Coatings are generally sprayed onto the die. Careful attention to die preparation, coating preparation and application and the type of coating equipment utilised can yield significant quality and productivity benefits.

[74, Brown, J. R. 1999]

2.2.6.2.2 High-pressure die-casting

The term 'die-casting' often implies 'high-pressure die-casting'. The process utilises a permanent die (metal mould) into which molten metal is forced under high pressure. The application of high pressure causes a high and turbulent metal flow, which allows the production of castings with high surface areas and low wall thicknesses. Dies are usually made from two blocks of steel, each containing part of the cavity, which are locked together while the casting is made. Due to the high metal pressure, the maximum size of the casting is limited by the maximum locking force of the casting halves. Retractable and removable cores are used to form internal surfaces. Due to the high metal pressures, only metal cores can be used. This limits the complexity of the casted piece. The metal is held under pressure until it cools and solidifies. The die halves are then opened and the casting is removed, usually by means of an automatic ejection system. Dies are preheated and lubricated before being used, and are either air- or water-cooled to maintain the desired operating temperature. Also, to maintain the working temperature in high-pressure die-casting (HPDC) injection moulds, thermoregulation with diathermic oil is often used. Two basic types of HPDC machines are used: hot-chamber or cold-chamber (see Figure 2.49).

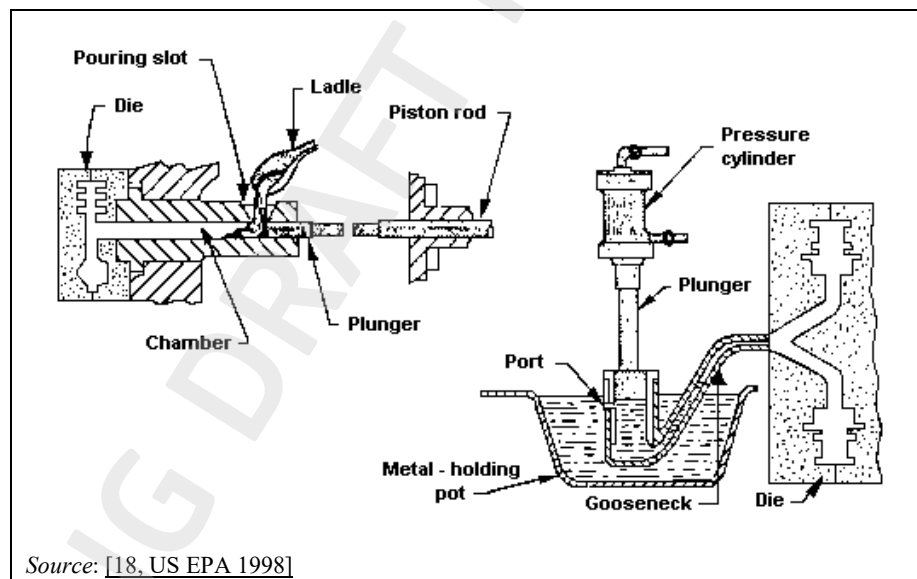


Figure 2.49: Cold-chamber and hot-chamber high-pressure die-casting devices

Hot-chamber HPDC machines comprise a molten metal reservoir, the die, and a metal-transferring device, which automatically withdraws molten metal from the reservoir and forces it under pressure into the die. A steel piston and a cylinder system with a gooseneck is used to create the necessary pressure within the die. A gooseneck machine utilises a cast iron channel to transfer the molten metal from the reservoir to the die. Pressures can range from a few bar to over 350 bar. Hot-chamber techniques are mainly used for zinc alloys and magnesium alloys.

Cold-chamber HPDC machines have molten metal reservoirs separate from the casting machine. Just enough metal for one casting is ladled or dosed into a small chamber, from which it is forced into the die under high pressure. Pressure is produced through a hydraulic system connected to a piston, and is typically in the range of a few hundred bar to 700 bar. In cold chamber machines,

the metal is just above the melting point and is in a slush-like state. Since the metal is in contact with the piston and cylinder for only a short period of time, the process is mainly applicable to aluminium alloys, and to a lesser extent magnesium alloys, zinc alloys, and even high melting point alloys such as brasses and bronzes.

Proper lubrication of the dies and plungers is essential for successful high-pressure die-casting. The die lubrication affects the casting quality, density, and surface finish, the ease of cavity fill, and the ease of casting ejection. Proper lubrication can also speed up the casting rate, reduce maintenance requirements, and reduce the build up of material on the die face. Although specific formulations are proprietary, in general, lubricants (also called release agents) are a mixture of a lubricant and a carrier material. Formulations may also include additives to inhibit corrosion, to increase stability during storage, and to resist bacterial degradation. Lubricating materials are typically mineral oils and waxes in water emulsions. Silicone oils and synthetic waxes are finding increased use. Both water-based lubricants and solvent-based lubricants are in use today. Water-based lubricants however dominate the market (95 %). The lubricant is applied to the open die by spraying, between each shot. Dilute solutions of lubricant are used (1:20 – 1:200 release agent:water ratio). Micro-spraying is used where possible. With appropriate casting geometry, it may be possible to use water-free systems as they provide good demoulding and lubrication. Often all types of release agents are applied depending on the casting and subsequent processes.

Electrostatic dry powder coatings are also currently available. Using this technique, a minimum amount of dry lubricant (e.g. 0.3 – 0.5 g/kg of injected aluminium) is applied to the mould at a temperature of 250 °C using electrostatic deposition. When it comes into contact with the hot mould, the powder coating distributed electrostatically melts and creates a highly efficient release film, without creating residual thickness and carbon formation. This constitutes a significant advantage over water-based lubrication systems. [193, Neto et al. 2009] Furthermore, by eliminating the use of water-based release agents, oil mist and waste water emissions are avoided.

High-pressure die-casting is not applicable to iron and steel and other high-melting-point alloys. The technique finds widespread application for aluminium, magnesium and zinc castings. Dies are expensive but can have a life of 150 000 shots or more. The process is therefore most suitable for long runs of castings. Furthermore, HPDC produces castings which have a high degree of dimensional accuracy and surface definition which may help to reduce or eliminate costly machining steps. Finally, castings with relatively thin wall sections can be produced using the HPDC method. This can result in substantial savings in material costs and reductions in component weight.

Relatively little waste is generated in the actual HPDC process. However, some gaseous and fume emissions occur during metal injection. Metal oxide fumes are generated as some of the metal vaporises and condenses. Gaseous emissions can originate from: the molten metal itself; the evolution of chemicals from the lubricant as it is sprayed onto the hot metal die and as it contacts the molten metal. Emissions to water may occur from any leakage or spillage of hydraulic oil or heating oil and from cooling water.

[18, US EPA 1998], [42, IHOBE 1998], [74, Brown, J. R. 1999], [120, TWG 2003], [134, CAEF 2020], [193, Neto et al. 2009]

2.2.6.2.3 Centrifugal casting

In centrifugal casting, a permanent mould rotates at high speed around its axis as the metal is poured. The speed of rotation and the metal pouring rate vary with the alloy and the size and shape being cast. The rotating axis is generally horizontal or under a small angle (Figure 2.50). Some specific devices apply rotation around a vertical axis. The resulting material has a very dense structure and properties that cannot be obtained with sand casting.

This technique is used to produce cylindrical products in cast iron, steel, and in alloys of aluminium, copper and nickel. Typical parts made by this process are pipes, boilers, pressure vessels, flywheels, cylinder liners and other parts that are axisymmetric.

[78, Hoppenstedt 2002]

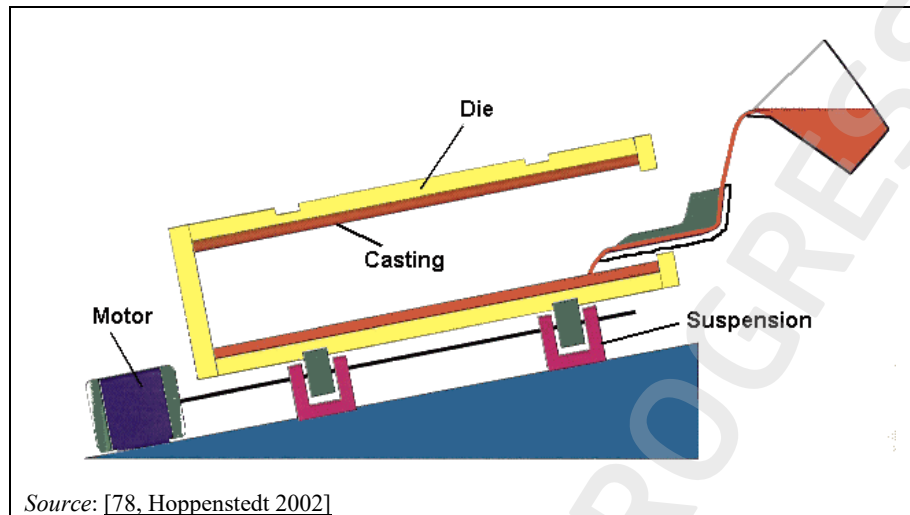


Figure 2.50: Schematic representation of a centrifugal casting machine

2.2.6.2.4 Continuous casting

Continuous casting is a high-productivity device for the production of bars, tubes and profiles, where through rapid cooling, a fine-grained material with good mechanical properties is obtained. In continuous casting, the molten metal is cast into a water-cooled die, which is open at the bottom or at the side (Figure 2.51). The die gives the desired form to the product. Through intensive cooling, the outside of the metal product solidifies, while it is slowly pulled out of the mould. Through continuous pouring and extraction as the product is pulled out of the mould, the product gets longer. A burner cuts the product whenever the desired product length is reached. This technique is used for both ferrous and non-ferrous casting. The technique is used for the casting of bars, slabs and sheets as a final step in iron, steel and non-ferrous metals production. Its use in this context is described in the NFM BREF [1, COM 2017] and the IS BREF [109, COM 2013].

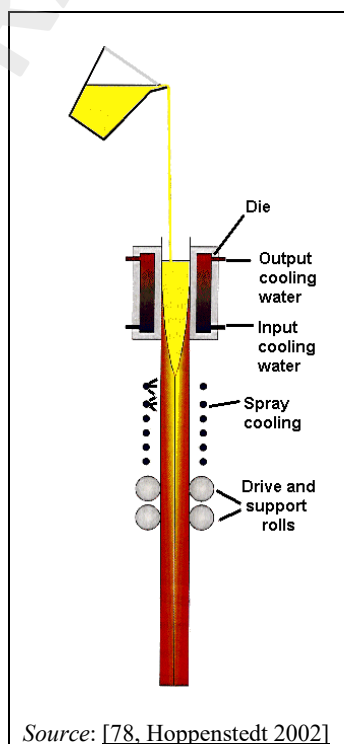


Figure 2.51: Schematic representation of a thread casting machine used for continuous casting

One of the most relevant continuous casting processes used in foundries for production of wire rod of aluminium and copper is the Properzi caster. [227, ES 2021]

This continuous casting technique has also been extended to aluminium alloys and other metals like zinc and lead. In this caster, the mould is formed by a rotating copper casting wheel which is closed with a steel belt also in rotation. The casting wheel diameter can be up to 2 600 mm. The liquid metal is delivered to the rotating copper casting wheel (temperature 660 – 740°C). As the liquid metal is fed continuously while the casting wheel and the steel belt are in permanent rotation, the bar rotates with the wheel. The principle of operation as well as the main components of the continuous caster are depicted in Figure 2.52.

From the moment the liquid metal is fed in, the product solidification process begins, while cooling takes place in a controlled way by adding pressurised water on the four sides that enclose the mould. Once a 180° rotation has been reached, the bar is in an inverted position and the gravity demoulding process takes place. This process is also helped by the volumetric contraction of the bar when the aluminium changes from a liquid state (density 2.7 g/cm³) to solid (apparent density 2.3 g/cm³). After demoulding, the cast bar is at a temperature between 350 °C and 575°C depending on the solidification conditions. It is immediately hot rolled to make wire rod coils.

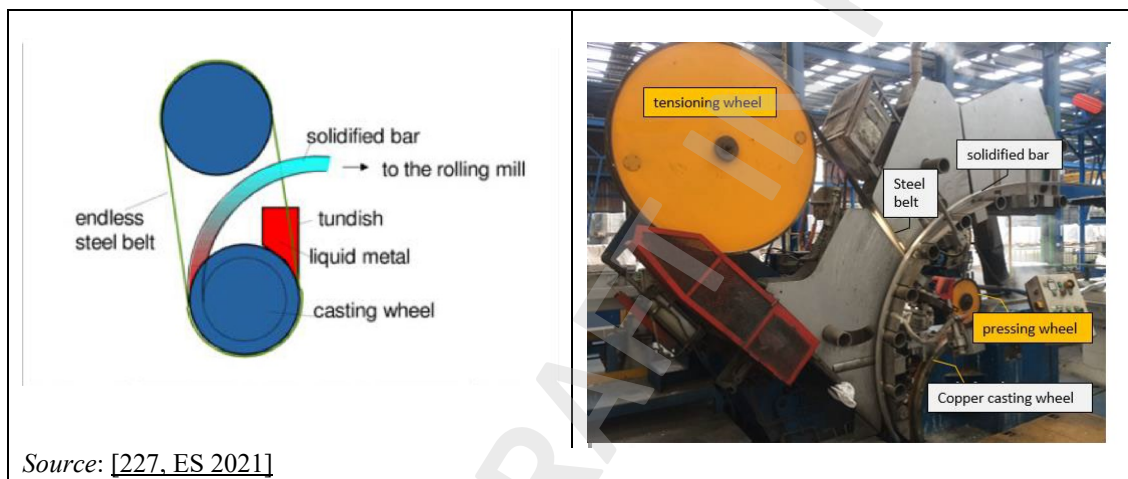


Figure 2.52: Continuous casting using a rotating copper casting wheel (left) including the main components (right)

A significant advantage of this type of caster is the solidification speed. Such a caster is more versatile compared to other technologies and works particularly well in the zone of low cooling speed, which is relevant to obtain a solidification bar with a small grain size. For practical reasons, there are also some limitations to this technology that limit the cooling rate:

- The casting wheel has to work within a speed range for the process to run continuously. At low rotational speeds, the cooling process is faster and more abrupt, with a risk of bar breakage.
- The addition of cooling water can be regulated but there are minimum flow rates necessary to prevent cold welding of the aluminium with the copper mould of the wheel.
- There are limitations to the section of the bar and diameter of the casting wheel conditioned by the design of the rolling mill.

2.2.7 Finishing and post-casting operations

Finishing of the raw castings encompasses all necessary treatments to yield a finished product. According to the process, various steps may be required, such as:

- removal of the running system;
- removal of residual moulding-sand from the surface and core remains in the casting cavities;
- removal of pouring burrs;
- repair of casting errors;
- preparation of the casting for mechanical post-treatment, assembly, thermal treatment, coating, etc.

In some cases, foundries also perform assembly, surface finishing and coating of the castings. However, these activities are not discussed in this document. Surface finishing and coating techniques are discussed in the STM BREF [171, COM 2006] and the STS BREF [208, COM 2020] [38, Vito 2001], [120, TWG 2003]

2.2.7.1 Removal of the running system

In the finishing of the raw castings and to remove the running system (see Figure 2.53), the following operations take place:

- *Beating, pressing:* In the case of brittle materials such as grey cast iron castings and white malleable cast iron, chamfers and feeders can generally be knocked off. Hydraulic equipment is increasingly being used for this task.
- *Grinding with grinding wheels:* These can be handheld, semi-automatic or automatic.
- *Cutting:* For the removal of massive pieces in carbon steel or low alloy steel, an oxygen-acetylene cutter is used. For cast iron or high alloy steel, oxygen-acetylene-powder or oxygen-LPG-powder cutters are used. In the case of cutting low alloyed steel, the castings and the alloy are sensitive for cracks, so the castings are cut cold or hot after a homogenisation heat treatment.
- *Sawing:* Materials which are sensitive to heat, such as aluminium alloys, are usually sawed.

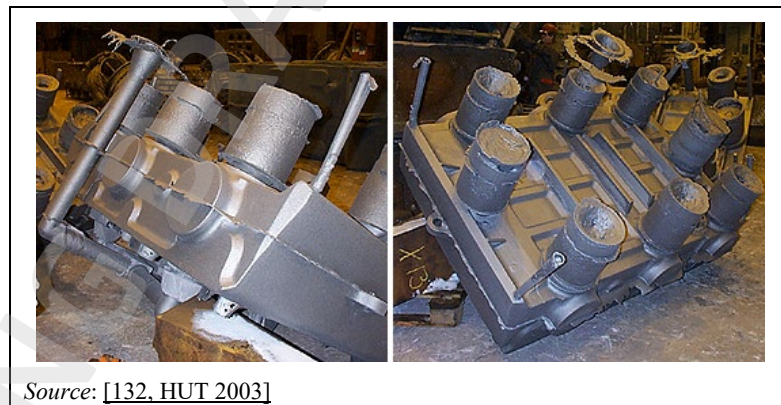


Figure 2.53: Casting with running and gating system

Through good design of the connection points, the feeding system may even get broken off during shake-out. This is mainly possible for grey iron. [14, CAEF 1997], [100, TWG 2002]

2.2.7.2 Sand removal

Sand removal from a cast is typically achieved by using a shake-out method. Using this technique, a vibrating table that agitates and shakes the cast is used to help dislodge the sand from the casting. The loose sand falls between holes on the table and into a collection box situated underneath. This

way the sand can be reused for future casting, saving more costs and offering recyclability options. For removal of internal cores (decoring), a decoring machine is used in which the casting oscillates and simultaneously rotates in order to remove cores from the casting and also break down the cores. These two methods are generally employed before shot blasting is carried out; this is used to further remove the adhered material in the internal passages of complex castings.

Final removal of the sand is performed in blasting cabins. The blasting medium is adapted to the material to be treated and varies from blasting grit to glass beads. The cleaning of model plates and permanent moulds is done with glass beads, aluminium beads or CO₂ ice grains. An example of castings before and after blasting is shown in Figure 2.54.

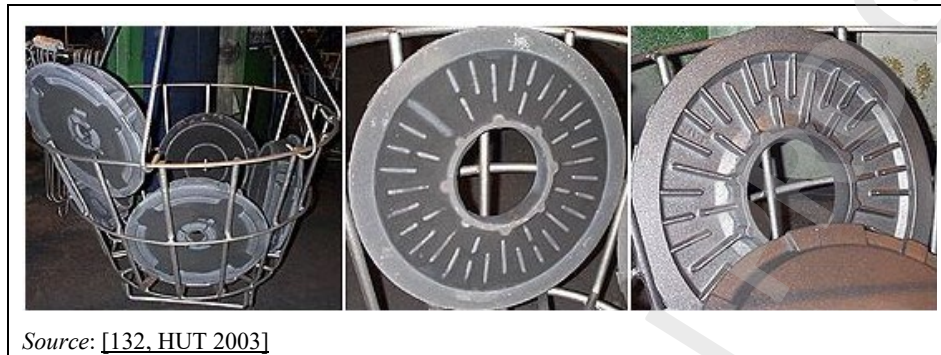


Figure 2.54: Castings before (L, C) and after (R) sand removal by blasting

Various blasting techniques exist. The acceleration of the grit is done with compressed air or turbine blades. The treatment is carried out in a closed room, with rubber-sealed doors.

The castings are suspended on a monorail and move batch wise through the blasting cabin. For smaller pieces, a specific moving belt is used. Big pieces are blasted manually, using a lance in an enclosed cabin. In this case, personal safety measures are very important. A helmet with a dust mask and respiratory equipment are required.

The coarse dust (sand and metal flakes) that is generated by blasting of the workpiece, is collected together with the grit. It is dedusted, magnetically separated and sieved. The fine fraction is removed from the exhaust air together with the coarse fraction, using a bag filter. Cleaning of the grit before internal re-use is of major importance as the presence of sand could cause a quick wearing of the throwing shovels.

2.2.7.3 Removal of burrs

Burrs, which occur at the point where mould and core pieces join, at veins and at other surface irregularities, are removed using grinding wheels and grinding stones. Grinding wheels are handheld or part of the grinding machines, whilst with grinding stones the casting is pressed against a rotating stone.

Other applied techniques include the following:

- *Slide grinding:* Grinding burrs and small amounts of other excess material on the casting surface can be removed without hand grinding. The parts are revolved in drums or vibrating containers together with abrasive shapes, causing them to be rubbed against each other and against the abrasive wheels. In a typical unit the castings are ground using a bed of pyramidal grinding stones, together with the addition of a water-soap emulsion. The roughness and the size of the grinding stones vary depending on the size of the castings

- *Tumbling*: This technique, also called blast removal, is used to remove thin burrs or small amounts of casting residue. During this process the burrs remove themselves in an airless blast cleaning process as a result of the parts being impacted together in a rotating drum. At the same time the edges are rounded-off. Sometimes the process is assisted by a liquid. Tumbling may increase surface tension and may affect cutting operations, increasing wear on tools and increasing demand for higher cutting force.



Figure 2.55: Burrs (L) and their removal using a grinding stone (C) and slide grinding (R)

Automation of these operations is difficult due to the variability in shape of the burrs and the need to fix the casting easily and quickly. Nevertheless, automatic grinding machines are increasingly being used in serial production. Raw casting parts are inserted into such machines to produce suitably worked parts which do not need any retooling or further manual grinding work.

Furthermore, the following techniques are applied in automated lines:

- *Punching*: Due to the use of cutting and forming techniques, serial casting parts are often designed in such a way that the unavoidable burr occurs in predetermined amounts which are easily accessible as far as processing is concerned. If the series is large enough, dedicated punching tools can be designed to quickly remove the burr and to provide the casting with a uniform contour.
- *Milling*: With the development of electronic controls for processing machines it has become increasingly easier to compile programs with which to process individual workpieces. Thus it is possible to use milling machines for smaller series instead of the punching machines with their single purpose tools. During such a process, the workpieces are taken up by the device and passed across a number of different milling machines.

Finally, welding may be carried out in order to join castings, as well as to manufacture and repair casting flaws. In most of these cases, arc welding is used. Depending on the requirements and equipment, the work is carried out either with hand operated stick electrodes or with welding wire and with or without inert gas. Scarfing is used on steel castings, which consists in applying grooves for stress relieve. This uses a cutting torch with a copper-coated carbon electrode.

[14, CAEF 1997], [38, Vito 2001], [100, TWG 2002]

2.2.8 Heat treatment

2.2.8.1 Introduction

For ferrous castings, there are basically two types of thermal treatments which can be applied: annealing and hardening. In the case of annealing, the tension caused in the workpiece as a result

of pouring, and the subsequent cooling down of the casting, is reduced and the structure is evened out. In the case of hardening, the level of heat is raised above the transformation temperature and the workpiece is subsequently rapidly cooled, in a process known as quenching. This causes the material properties to change. Different results may be obtained by the use of water, oil or air quenching. 'Quench and temper' is the name of the procedure in which the workpiece is reheated to the tempering temperature following quenching, and the quenching procedure is repeated.

The malleablising of iron is a thermal treatment which differs from annealing and hardening. Here, the malleable unfinished casting is either transformed to a white or black temperature casting depending on the procedure.

Many non-ferrous castings are used in an 'as-cast' condition, but certain applications require higher mechanical properties than 'as-cast' material. Possible treatments are annealing, controlled cooling, solution heat treatment, artificial ageing and precipitation treatment.

[14, CAEF 1997], [74, Brown, J. R. 1999]

2.2.8.2 Heat treatment furnaces

2.2.8.2.1 Chamber furnaces

Chamber furnaces are the most common furnace construction. Their actual design has been adapted in many sub-forms in order to meet the needs of the differing thermal treatments of various types of casting and production. Some examples of chamber furnaces are bogie hearth furnaces, top hat furnaces, hub open-hearth furnaces, etc. Chamber furnaces with continually running conveyance means are called tunnel furnaces. Heating is provided either electrically, or with gas or fuel oil.

For non-ferrous materials, some heat treatments are carried out close to the melting point of the casting, so accurate temperature control is needed. Forced air circulation is used to ensure that the temperature at all parts of the furnace is constant and equal.

[14, CAEF 1997], [74, Brown, J. R. 1999]

2.2.8.2.2 Shaft furnaces

Pipes, long waves and similar parts are often treated while suspended in a vertical position in shaft furnaces. In shaft furnaces, the heating is provided by electricity, gas or fuel oil.

2.2.8.2.3 Annealing furnaces

Chamber, top hat or tunnel furnaces are used to temper unfinished castings. The heating of such furnaces is carried out via electricity, gas or fuel oil.

2.2.8.3 Quenching

In thermal treatment processes, chilling is the cooling down of a workpiece at a greater speed than in calm air. This can be achieved by means of a rapid submersion in water or oil (see Figure 2.56), as well as by forced air-cooling. Care should be taken that the workpieces are cooled at a uniform rate. When submersing in fluids, either the parts must be moved or the fluid must be continually circulated to ensure a full and even cooling of all parts of the workpiece. In a similar principle, in air quenching the blowing procedure must be arranged so that the air covers the entire surface.

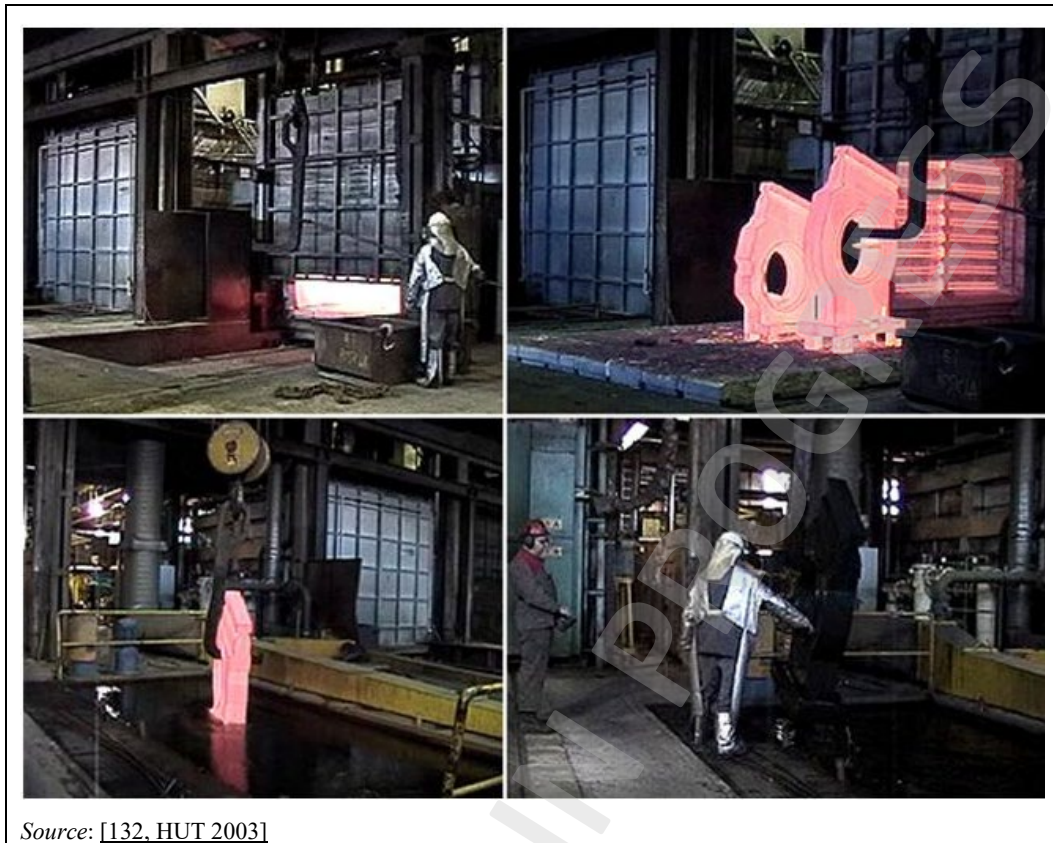


Figure 2.56: Quenching of a hot casting shortly after heat treatment

2.2.8.4 Heat treatment of ductile iron (SG iron)

It is obviously desirable to achieve the required metal properties in the ‘as-cast’ form to save further treatments being necessary, but this is not always possible because of variations in section thickness, etc. The heat treatment of the castings can eliminate carbides in thin sections, produce more consistent matrix structures and for a given structure, often improve its mechanical properties, especially by normalising the grain structure. Where tempered martensite structures are needed, heat treatment is essential.

[14, CAEF 1997], [73, Brown, J. R. 2000]

2.2.8.4.1 Stress relief

Stress relief consists of heating the castings at a rate of 50 – 100 °C/h to 600 °C (taking care not to exceed 610 °C), followed by soaking them for a minimum of one hour, plus an extra hour for every 25 mm of section thickness in the thickest section, and then cooling them at a rate of 50 – 100 °C/h or less. The castings must be adequately supported in the furnace so that they are not subjected to stress.

2.2.8.4.2 Breakdown of carbides

Thin section castings may contain carbides in the ‘as-cast’ structure. These can be eliminated by soaking the castings at 900 – 925 °C for 3 to 5 hours.

2.2.8.4.3 Annealing to produce a ferritic matrix

Annealing involves soaking the castings at 900 – 925 °C for 3 to 5 hours, followed by a slow cooling at around 20 – 35 °C/h through the critical temperature range (about 800 – 710 °C), and finally furnace cooling at, say, 50 – 100 °C/h to 200 °C.

2.2.8.4.4 Normalising to produce a pearlitic matrix

For normalising, a soaking of the castings above the critical temperature followed by air cooling is necessary. Again a soaking temperature of 900 – 925 °C is usually used, to ensure that the carbides are broken down. Forced air cooling is used to form pearlite. The type of heat treatment furnace available and the size of the load determines the process cycle that is possible. It may be necessary to adjust the metal composition with tin or copper to help the formation of fully pearlitic structures.

2.2.8.4.5 Producing hardened and tempered structures

Hardened structures are produced by austenitising the casting at 900 – 920 °C, followed by oil quenching. Tempering is usually carried out at 600 – 650 °C.

2.2.8.4.6 Austempered ductile iron (ADI)

Austempering is an isothermal heat treatment for producing ausferrite structures. It can double the strength of ductile iron whilst allowing it to retain good ductility and toughness. Wear resistance and fatigue properties are excellent, even to such a degree that ADI is comparable with wrought and hardened-tempered steel.

The ADI heat treatment is a two-stage process, as shown in Figure 2.57. Austenitising is carried out at 815 – 930 °C to fully transform the matrix to austenite. This is done either in a non-oxidising atmosphere furnace or in a high temperature salt bath. Temperatures and times are determined by the chemical composition, the section size and the grade of ADI required; 1 to 1.5 hours is usually adequate. Slow initial heating of the casting is desirable to avoid the risk of cracking the complex shapes. The castings are then quenched to the required isothermal heat treatment temperature, usually between 210 °C and 400 °C. This is usually done in a salt bath. The castings are held at this temperature for 1 to 2 hours to complete the transformation of austenite to ausferrite. Lower temperatures give high hardness, strength and wear resistance, while higher heat temperatures result in higher ductility and toughness. After the isothermal treatment, the castings are cooled to ambient temperature.

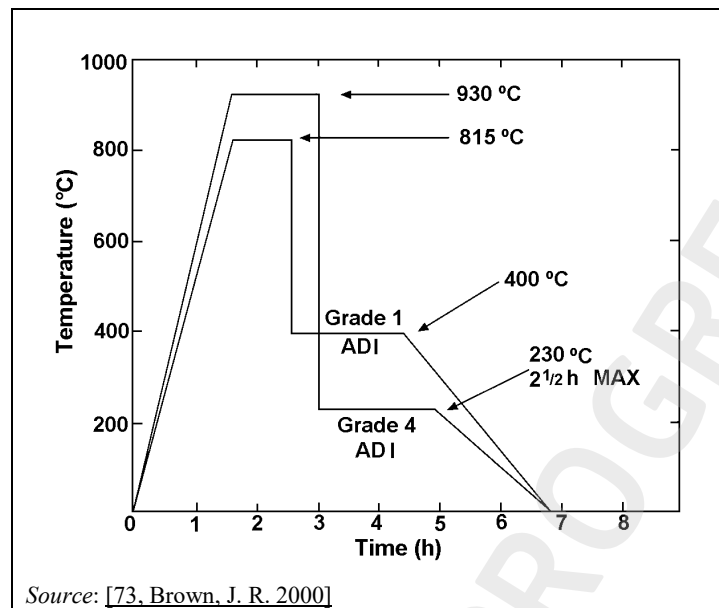


Figure 2.57: Typical austempering heat treatment stages

Unalloyed ductile irons may be austempered in sections of up to about 8 mm thickness. Thicker section castings require the addition of Mo or Ni to increase the hardenability.

Austempered ductile iron is used as a replacement for forged steel components in the agricultural, railway, automotive and general engineering industries; for example, for plough tips, digger teeth, spring brackets, rear axle brackets, gears, etc. ADI production is growing but its use is limited to some extent by the lack of suitable heat-treatment facilities.

[14, CAEF 1997], [73, Brown, J. R. 2000]

2.2.8.5 Heat treatment of steel

Steel castings are normally subject to a heat treatment before delivery, e.g. normalising, with this heat treatment leading to a structural change. Additionally, potential casting stresses have to be reduced (stress relief annealing). Many steel casting qualities have to be additionally tempered after stress relief anneal (hardening and tempering).

Most steel castings are subjected to a heat treatment to attain the desired mechanical properties and to a stress relief, to obtain the right corrosion resistance and to avoid the difficulties during the finishing operations. The heat treatment is defined according to the steel grade. To remove the chemical and structural segregations, annealing at high temperature is generally performed. Carbon and low alloy steels undergo:

- normalising and air cooling; or
- austenitising, quenching and tempering.

Austenitic or duplex stainless steels undergo a solution annealing and water quenching heat-treatment. Additional heat treatments such as for stress relief or post-weld treatment are also used to eliminate the internal stresses of the material.

[14, CAEF 1997], [100, TWG 2002], [120, TWG 2003]

2.2.8.6 Heat treatment of aluminium

Aluminium castings are heat treated for: homogenisation, stress relief, improved dimensional stability and machinability, optimised strength, ductility, toughness and corrosion resistance.

Most often the heat treatment is a compromise between varying effects, maximising the important properties of one often at the expense of others. The heat treatment of aluminium may involve: annealing, solution heat treatment, quenching, artificial ageing and precipitation treatment. The type of treatment applied is indicated by a suffix to the alloy designation. This is called the temper designation. For sand, gravity and low-pressure die-castings all treatments are possible, though not all are standardised. Pressure die-castings are not solution treated and quenched in the same way as sand, gravity and low-pressure die-castings. Entrapped gas bubbles can expand and cause casting defects. Heat treatment is not a common step for high-pressure die-castings; only about 1 % of this type of castings are subjected to heat treatment. All die-castings may be quenched from the die, precipitation treated and stress relieved without suffering any harmful effects. In the low pressure die casting production of aluminium wheels 90 % of the castings are subjected to heat treatment

[120, TWG 2003].

2.2.8.6.1 Stress relieving and annealing

Castings with changes of section, or of a complex shape are likely to develop internal stresses. These can then cause dimensional changes upon machining. To stabilise the casting and to remove internal stresses, castings are heated to a temperature of 200 °C for 5 hours, followed by slow cooling in the furnace.

2.2.8.6.2 Solution treatment and quenching

Castings are heated at temperatures just below the melting temperature and held there for a long time to take the alloying constituents into a homogeneous solid solution. The castings are then rapidly cooled by quenching to room temperature to retain the elements in solution. Water or special quenchants are used. The quench tanks are placed close to the furnace to ensure that rapid cooling is possible. Although sensitivity to the quench interval differs between alloys, good practice should limit the interval to 5 – 10 s.

2.2.8.6.3 Precipitation treatment

The controlled precipitation of alloying constituents is promoted by heating the casting to a temperature of between 150 °C and 200 °C. The casting strength and hardness are increased. The process is therefore also referred to as structural hardening. Each alloy has an optimal heat treatment cycle.

2.2.8.6.4 Artificial ageing

Some casting alloys increase in strength and hardness while left standing at room temperature. The process can take several weeks but can be speeded up by heating above room temperature and then sustaining this heat over time.

[74, Brown, J. R. 1999], [100, TWG 2002], [111, CTIF et al. 2002], [110, Zalensas, D. L. 1993]

2.2.9 Quality control

During quality control the finished casting is checked for compliance with the product requirements concerning e.g. dimensions, metal structure defects, surface structure. Depending on the type of casting and the size of the series, quality control can be achieved by visual inspection, with the use of measurement tools, or automatically.

In the production of aluminium wheels the castings are controlled via X-ray analysis. A standard image of a good casting is used for verification by a computer program. If there are any differences, the image is studied and assessed by a human operator. Random tests of the alloy are analysed with spectral analysis.

The quality control procedure informs the final decision to reject a casting or to allow its further shipment to the market. Rejected castings are brought back to the raw material input to be remelted.

[120, TWG 2003]

2.2.10 Sand reconditioning and reclamation

Since foundries make intensive use of sand as an inert primary material, the reclamation of this sand is a major point of consideration as part of its environmental performance.

There are two main processes: sand reconditioning and sand regeneration; they are briefly discussed in the following paragraphs.

A clear distinction must be made between green sand and chemically bonded sand. Green sand can be easily reconditioned after use. Indeed, recirculated green sand shows a better technical quality than new sand. All green sand foundries perform preparation of used sands (reconditioning).

Sand reconditioning

Sand reconditioning, also known as attrition or particulation, involves breaking down the sand from moulds or cores back to its original grain size. The sand is sieved, moistened and mixed with the necessary additives and binders. Only the parts that are mechanically or thermally worn (usually a fine fraction or dust) are removed from the sand cycle and disposed of externally or recycled. The sand is then cooled before being sent for storage, returned to the sand system or blended with new sand. At this stage, the sand grains are likely to retain a partial coating of spent binder. Green sand is used principally for moulds - for core making only in very specific cases. The main green sand preparation techniques are vibration, rotating drum or shot blasting.

Sand regeneration

Regeneration involves the further processing of the previously particulated sand to remove residual binder. The sand is returned to a quality similar to, or better than, that of new sand. To remove residual binder, more aggressive techniques are needed than for reconditioning. The regeneration of used sand concerns the cleaning of the sand grains from any adhesions (binder residues, resins, etc.) Special processing plants are required for this process. The regeneration can be done mechanically, thermally or with combined mechanical/thermal processes. It is energy-intensive and mainly used for large quantities of homogeneous used sand qualities. Mechanical regeneration produces a large proportion of dust, which cannot be recycled due to its organic content but should be disposed of. Regenerated sand is usually used as moulding sand (typically no-bake sand) and core sand.

The main regeneration techniques are:

- cold mechanical treatment;
- low energy attrition: friction, impact (for cold-setting resins);
- high energy attrition: pneumatic chafing, grinding, centrifugal friction;
- thermal treatment (usually in a fluidised bed);
- wet scrubbing.

Sands bonded with cold-setting resins may be regenerated using simple treatment techniques, due to the fragility of the binder layer. Mechanical regeneration systems are based on interparticle friction or impact.

Sands bonded with gas-hardened and thermosetting resins need more intensive treatment to remove the binder layer. These include grinding, pneumatic chafing and centrifugal friction. Thermal treatment involves the burning of the organic binder. Bentonite is inactivated by the high treatment temperature. For sand flows containing green sand, any thermal treatment should therefore be combined with a mechanical treatment.

Wet regeneration involves binder removal through interparticle grinding. This technique applies only for green sand and silicate or CO₂-bonded sands and is not widely applied.

Regeneration of green sand as a monosand flow finds limited implementation. For chemically bonded sands, mechanical regeneration is most widely applied (> 200 units in Germany in 1999) [33, ERM Lahmeyer International GmbH 1999]. The applicability of the various regeneration techniques and of the regenerated sand are summarised in Table 2.21 (monosands) and Table 2.22 (mixed sand). Each of the presented techniques will be discussed in more detail in the sections below.

The most important **monosand** flows for secondary regeneration are the core sands in non-ferrous foundries. Furthermore monosands are produced from mould and core-making with purely organic systems such as croning, furan resin and urethane cold-box. A smaller monosand stream is non-cured core sand, arising from broken or rejected cores in the core-making shop and the residual sand of core-making machines.

Mixed sands generally contain bentonite-bonded sand as well as chemically bonded sand. They are mainly generated in iron foundries and represent some 75 % of the total waste sand production.

Table 2.21: Fields of application of different regeneration systems for monosands

Type of sand	Regeneration technique	Regeneration equipment	Utilisation	Borderline conditions	Minimal quantity (tonne/h)
Organic monosystems					
Cold-setting resins	Mechanical or thermal	<u>Mechanical</u> : friction, impact, pneumatic chafing <u>Thermal</u> : turbulent bed, fluidised bed or rotary furnace	- for mould-making using cold-setting resins - 20 – 25 % substitution of new sand for cold-setting core-making	- mechanical: only if binder shells have become fragile enough upon pouring - the target values for regenerate quality must be met	1.5
Cold-Box, SO ₂ , Hot-Box and Croning sand	Mechanical or thermal	<u>Mechanical</u> : pneumatic chafing, centrifugal friction, fluidised bed chafing <u>Thermal</u> : turbulent bed, fluidised bed or rotary furnace	In core-making, as new sand substitute	- mechanical: only if binder shells have become fragile enough upon pouring - the orientative values for regenerate quality must be met - re-use of fines	0.75
Resol- ester methyl formate hardened sand	Mechanical	<u>Mechanical</u> : friction, impact, pneumatic chafing	With limitations, in mould-making with methyl formate sands	- regeneration as resol- ester cold setting but with lower yield - embrittlement of binder components	
Inorganic monosystems					
Green sand	Mechanical	pneumatic chafing, grinding	Renewal sand for green sand circuit	- requires predrying - re-use of fines	0.75
Sodium silicate sand	Mechanical		Only for making moulds and cores using sodium silicate sand	Embrittlement of binder components at 200 °C	0.5
<i>Source: [42, IHOBE 1998], [120, TWG 2003]</i>					

Table 2.22: Fields of application of different regeneration systems for mixed sands

Type of sand	Regeneration technique	Regeneration equipment	Utilisation	Borderline conditions	Minimal quantity (tonne/h)
Mixed organic systems	Mechanical or thermal	<u>Mechanical</u> : pneumatic chafing, centrifugal friction, fluidised bed chafing <u>Thermal</u> : turbulent bed, fluidised bed or rotary furnace	- core-making substituting new sand	- mechanical: only if binder shells have become fragile enough upon pouring - the orientative values for regenerate quality must be met - re-use of fines	0.75
Mixed sands containing bentonite	Mechanical or mechanical-thermal-mechanical	<u>Mechanical</u> : grinding, pneumatic chafing, fluidised bed chafing <u>Thermal</u> : turbulent bed, fluidised bed or rotary furnace	- core-making substituting new sand - renewal sand for the green sand circuit	- require pre-drying - combined thermal regeneration requires efficient mechanical regeneration to remove active bentonite - re-use of fines	0.75

Source: [42, IHOBE 1998]

The applicability of the various treatment systems is summarised in the following table and will be discussed further in the specific applicability sections.

Table 2.23: Applicability of various sand regeneration techniques to various sand types

	Simple mechanical systems	Cold mechanical			Wet regeneration	Thermal	Mechanical – thermal – mechanical
		Grinding	Impact drum	Pneumatic chafing			
Monosands							
Cold setting	x	x	x	x	x	x	0
Cold-box, SO ₂ , Hot-box, Croning	0	x	x	x	0	x	0
Silicate (CO ₂ or ester)	0	0	0	x	x	0	0
Green sand preparation	x	0	0	0	0	0	0
Green sand regeneration	0	x	0	x	x	0	0
Mixed sands							
Mixed organic	0	x	x	x	0	x	0
Mixed green + organic	0	x	0	x	x	0	x

x: Applicable; 0: Not applicable

The application of both reconditioning and regeneration in a mixed sand foundry in order to achieve a total reuse ratio of 92 % is shown in Figure 2.58. This simplified scheme does not take into account the various losses in the processing steps. The addition of new sand can be reduced to a minimum by integrating (the coarse fraction of) the filter dust sands (from the exhaust of hand forming lines, decorating lines, storage silos, etc.)

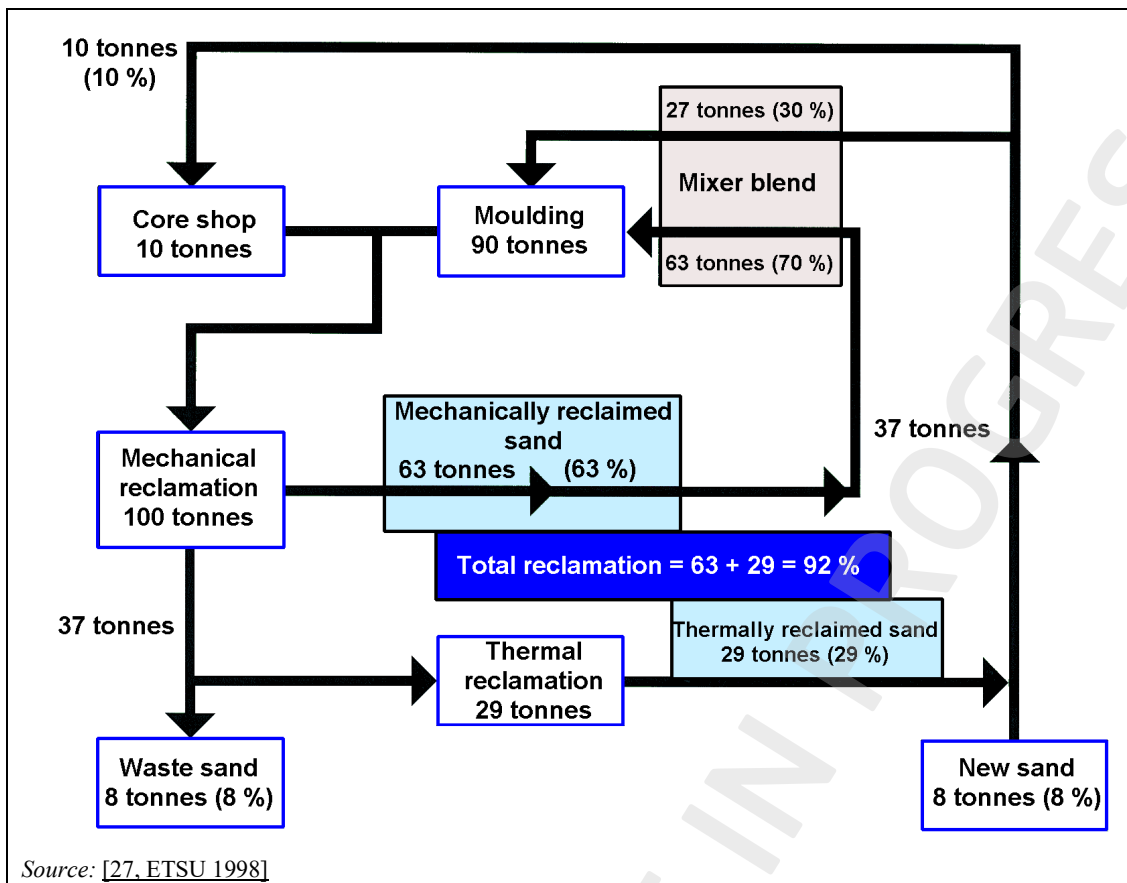


Figure 2.58: Sand balance diagram for a thermal/mechanical regeneration system

An overall reuse ratio of 92 %, as given above, is a normal value for mixed green sand/chemically bonded sand systems. Reuse ratios of up to 98 % have been reported. The actual ratio depends on the volume and chemical composition of the used cores. For furan cold setting monosands, values of more than 90 % are reported.

Generally, the mixing of different types of sands has a negative effect on the strength of the cores and subsequently the moulds made with the regenerated sand, although there are a few exceptions to this general principle. In order to produce a good quality regenerated sand it is therefore of great importance to keep non-compatible sand types separate. Optimisation of the reuse potential may therefore imply changing to compatible binder systems, if mixed sands are used, or the application of (shake-out) techniques that allow the separation of various sand types. Table 2.24 provides a cross-compatibility table.

Table 2.24: Compatibility of regenerated sources sands with various binders

Goal system Source system		Bentonite	Silicate	Cold-setting	Hot-box	Croning	Cold-box		
							Methyl-formate	Amine	SO ₂
Bentonite		+	0	0	-	0	0	0	
Silicate		0	+	-	-	-	-	-	
Cold-setting		+	-	+	-	0	0	+	
Hot-box		0	-	+	+	+	0	+	
Croning		+	+	+	+	+	+	+	
Cold-box	Methyl-formate	0	+	0/-	-	-	0	0	
	Amine	+	+	+	+	+	0	+	
	SO ₂	+	-	+	-	0	0	+	

+: Compatible, 0: Limited compatibility, -: Incompatible
 Source: [17, Winterhalter et al. 1992], [120, TWG 2003]

Reference literature

[17, Winterhalter et al. 1992], [27, ETSU 1998], [42, IHOBE 1998], [120, TWG 2003], [46, Metaalgieterij Giesen B.V. 1996], [57, Umweltbundesamt 2002], [100, TWG 2002],

2.3 Current consumption and emissions levels in foundries

The following sections present the consumption and emission data reported by the foundries (ferrous and non-ferrous) that took part in the 2020 SF data collection across the EU (in total 158 plants). The relevant plants are listed in Section 8.1.1 in which a list of installations/plants that participated in the 2020 data collection for the SF BREF review may be found.

The emission and consumption levels are presented and structured according to the environmental topics as follows:

For emissions to air, the reported levels are presented at process level for:

- metal melting;
- core-making and moulding using lost moulds;
- casting, cooling and shake-out using lost moulds;
- casting using alternative casting processes (i.e. lost foam);
- casting using permanent moulds;
- finishing;
- sand reconditioning and regeneration.

For emissions to water, water consumption, operational material efficiency, sand regeneration and quantity of residues sent for disposal, the reported levels are presented at plant level. Energy consumption data refer to both plant and process level.

Handling of Confidential Business Information (CBI)

Energy consumption data were considered CBI by the plant operators. In order to maintain data confidentiality, plant names are not directly mentioned in the graphs describing energy consumption but are replaced with anonymised and randomly attributed CBI codes. In addition, no contextual information (e.g. process parameters or techniques applied) is included as this could reveal the identity of the plants. All the consumption figures are presented in ascending order of the maximum specific energy consumption values.

2.3.1 Mass stream overview

The general mass stream overview for the foundry process is given in Figure 2.59. This scheme generally applies to both ferrous and non-ferrous foundries. Specific aspects of the various process steps and types are detailed below.

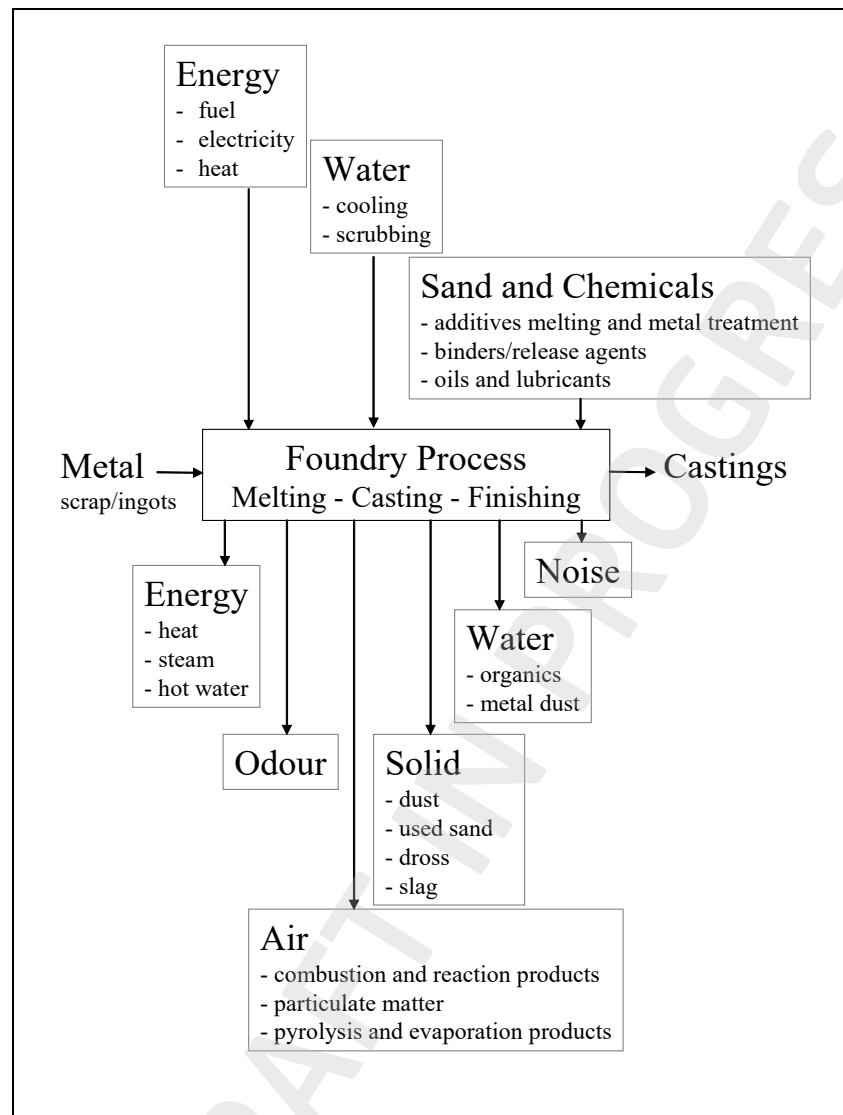


Figure 2.59: Mass stream overview for the foundry process

The inputs/outputs for the main furnace types used are also discussed in this section.

Table 2.25: Typical properties of melting furnaces used in ferrous foundries properties and emission data

Process	Steel			Cast iron				
	ELECTRIC ARC FURNACE	INDUCTION F.	INDUCTION F.	CUPOLA FURNACE			ROTARY F.	
Type	Acid lined	Basic lined	Coreless	Coreless	Cold blast	Hot blast	Hot blast – long campaign	
Subtype								
Energy source	Electricity	Electricity	Electricity	Electricity	Coke	Coke	Coke	Gas/fuel
Thermal efficiency ¹ (%)	60 – 70	60 – 70	50 – 60	50 – 60	30 – 40	40 – 45	35 – 45	50 – 60
Primary thermal efficiency ² (%)	21 – 25	21 – 25	15 – 20	15 – 20	30 – 40	40 – 45	35 – 45	35 – 45 ³
kWh/tonne metal charge	500 – 700	500 – 700	520 – 800	520 – 800	950 – 1200	800 – 900	810 – 1100	600 – 800
Batch/continuous	Batch	Batch	Batch	Batch	Continuous	Continuous	Continuous	Batch
Production rate ⁴ (tonnes/h)					2 - 10	8 - 70	8 - 70	
Furnace capacity ⁵ (tonnes)	2 – 50	2 – 50	0.01 – 30	0.01 – 30				1 – 20
Meltdown time (h)	1 – 4	1 – 4	1 – 2	1 – 2				2 – 4
Refining ability	Possible	Possible	No	No	Yes	Yes	Yes	No
Capital cost	High	High	High	High	Medium	High	High	Low
Slag production (kg/tonne metal charge)	10 – 40	20 – 80	10 – 20		40 – 80	40 – 80		20 – 60
Dust production ⁶ (kg/tonne metal charge)	5 – 8		0.06 – 1		5 – 13	4 – 12		0.3 – 2.9
<p>1 Indicated values give an order of magnitude but largely depend on exploitation conditions, such as metal temperature, furnace capacity and production rate.</p> <p>2 Efficiency of electrical power generation assumed to be 35 %.</p> <p>3 Taking into account energy consumption for oxygen production and the raw materials, such as graphite and FeSi, to substitute the oxidised elements during melting.</p> <p>4 For continuous processes only.</p> <p>5 For batch processes only.</p> <p>Source: [14, CAEF 1997], [38, Vito 2001], [100, TWG 2002], [120, TWG 2003] and comments from CTIF</p>								

Table 2.26: Typical properties of melting furnaces properties for in aluminium melting

	Units	Rotary furnace	Hearth type furnace	Shaft furnace	Crucible furnace		
Subtype			One chamber		Fuel heated	Resistance heated	Induction
Energy sources		Fuels (liquid, gaseous)	Fuels (liquid, gaseous)	Fuels (liquid, gaseous)	Fuels (liquid, gaseous)	Electricity	Electricity
Thermal efficiency ¹	%	15 – 40	<30 – 57	35 – 65	15 – 40	65	65 – 70
Primary thermal efficiency ²	%	15 – 40	<30 – 57	35 – 60	15 – 40	22	22 – 25
Spec. energy demand ³	kWh/t Al ⁴	600 – 1250	975 – 1150	540 – 900 <i>610 – 720</i>	900 – 1200 <i>610 – 680</i>	750 <i>470 – 590</i>	475 – 640 <i>440 – 470</i>
Batch/continuous		Batch	Batch	Continuous	Batch	Batch	Batch
Melting capacity	t or t/h ⁵	3 – 10	0.5 – 30	0.5 – 7 (-15)	0.1 – 1.2	0.1 – 0.4	0.2 – 25
Holding capacity	t	n.a	n.a	1 – 20	0.1 – 1.5	0.1 – 1.5	0.15 – 6
Meltdown time	h	2 – 4	3 – 4	n.a	0.5 – 1	4 – 5	0.2 – 0.5
Refining ability		Low	Low	Low	Good	Very good	Low
Loss by burning	%	n.d	n.d	1 – 3	1 – 2	1 – 2	1 – 2
Abatement techniques		Fabric filter for bigger installations	Fabric filter for bigger installations	Fabric filter for bigger installations	Typically not necessary due to small furnace size	Not necessary	Not necessary

¹ Definition: the relationship between the heat of the molten bath and the fuel heat supplied; indicated values give an order of magnitude but largely depend on the exploitation conditions, such as the metal temperature.

² Efficiency of electrical power generation (fuels) assumed to be 35 %.

³ Depends on heat recovery measures; only valid for melting; values given by [52, Eurofine 2002] *in italics*.

⁴ Units 'per tonne Al' refer to tonne of molten aluminium alloy.

⁵ For batch-type furnaces the unit is t and for continuous type furnaces the unit is t/h.

Sources of information: VDG internal survey; Aluminium Taschenbuch, Band 2, 15. Auflage, Aluminium Verlag GmbH, Düsseldorf, 1996; Aluminium recycling, Aluminium Verlag GmbH, Düsseldorf, 2000; [52, Eurofine 2002]; comments CTIF

Source: [52, Eurofine 2002] and comments from CTIF and VDG, table updated based on CAEF comments [210, TWG 2022]

2.3.1.1 Inputs/outputs in metal melting

The inputs and outputs of the main types of furnaces used in ferrous or non-ferrous foundries are summarised below. In this document, melting refers to the production of ferrous or non-ferrous molten metal using furnaces. This also includes remelting of molten metal and heat conservation of molten metal in holding furnaces.

The main inputs and outputs for cupola furnaces are presented in the following table.

Input	Output
– Ferrous material (iron pigs, sponge iron, steel scrap, foundry returns ...)	– Metal alloy (cast iron)
– Alloying metal (ferro-alloys ...)	– Dust (metal content)
– Flux (limestone...)	– CO/CO ₂ , SO ₂ , NO _x
– Energy (coke, gas, oil, electricity)	– HF
– Oxygen	– Dioxins, furans
– Cooling water	– Organic pollutants
– Water	– Slag
	– Waste refractory lining

In cold blast operation, the coke consumption between the charges is generally 90 – 120 kg/tonne metal charge, but can be less than 70 kg/tonne metal charge, e.g. in the case of counterweights. Accounting for the amount of coke in the bed gives a total coke consumption of 110 – 140 kg/tonne metal charge. As the calorific value of European cokes is 8.5 kWh/kg, this corresponds to a calorific input of 950 – 1 200 kWh/tonne metal charge.

The total coke consumption rate in a hot blast cupola is generally 110 – 145 kg/tonne metal charge. However, as the average steel percentage is 50 %, and the recarburisation consumes about 1.5 % of the metallic charge, the real burned coke ratio is 95 – 130 kg/tonne metal charge, which is 810 – 1 100 kWh/tonne metal charge. This corresponds to a thermal efficiency of 35 % to 45 %.

Depending on the plant layout, the energy consumed by the fume treatment equipment and the holding furnace, as given in Table 2.27, must be added. German data indicate a specific electricity use for the flue-gas cleaning equipment of around 20 kWh per tonne of good casting. [100, TWG 2002]

Table 2.27: Average energy consumption for off-gas treatment and holding

Energy carrier type	Average consumption kWh/tonne metal charge
Gas for the combustion chamber	40
Electricity for the flue-gas cleaning equipment (fans, etc.)	40
Electricity for the holding furnace	60
<i>Source: [100, TWG 2002]</i>	

The main inputs and outputs for electric arc furnaces are presented in the following table.

Input	Output
- Ferrous material (steel scrap, foundry returns swarf, pig iron ...)	- Metal alloy (cast steel)
- Alloying metal (ferro-alloys ...)	- Dust (metal content, refractory)
- Flux (limestone ...)	- NO _x , CO ₂ , CO
- Energy (electricity, gas, oil)	- Organic air pollutants, HC
- Oxygen	- Metal oxide fumes
- Electrodes	- Slag (CaO, SiO ₂ , MgO)
	- Waste refractories

The main inputs and outputs for rotary furnaces are presented in the following table.

Input	Output
- Ferrous material (iron pigs, steel scrap, swarf, foundry returns ...)	- Metal alloy (cast iron)
- Alloying metal (ferro-alloys ...)	- Dust
- Carburising agents, flux	- Organic and metallic fumes
- Energy (electric, oil, gas)	- Slag
- Cooling water	- Refractory waste

The main inputs and outputs for induction furnaces in iron and steel foundries are presented in the following table.

Input	Output
- Ferrous material (iron pigs, steel scrap, swarf, foundry returns ...)	- Metal alloy (cast iron, cast steel)
- Alloying metal (ferro-alloys ...)	- Dust
- Carburising agents, flux	- Organic and metallic fumes
- Energy (electric)	- Slag
- Cooling water	- Refractory waste

The main inputs and outputs for induction furnaces in aluminium foundries are presented in the following table.

Input	Output
- Aluminium ingots, foundry returns	- Molten aluminium
- Electrical energy	- Dust
- Cooling water	- Used refractory

The main inputs and outputs for Argon Oxygen Decarburisation Converters are presented in the following table.

Input	Output
- Molten steel	o Decarburised steel
- Alloying metals (ferro-alloys)	o Metal oxide dust and fumes (Fe, Mn, Cr, Ni)
- Al, FeSi, lime	o Gases (CO ₂ , CO, inert gases)
- O ₂ , N ₂ , Ar	o Slag (CaO, SiO ₂ , AlO ₃)

The main inputs and outputs for shaft furnaces are presented in the following table.

Input	Output
- Aluminium ingots, foundry returns	- Molten aluminium
- Energy	- Dust
- Deoxidation and gas removal products	- NO _x , CO
	- Used refractory

The main inputs and outputs for crucible furnaces are presented in the following table.

Input	Output
- Aluminium ingots, foundry returns or liquid aluminium if used as a holding furnace	- Molten aluminium
- Electrical energy or fuel	- Dust

2.3.1.2 Inputs/outputs in moulding and core-making

Moulding with clay-bonded sand

The main inputs and outputs in moulding with clay-bonded sand (green sand moulding) are presented in the following table.

Input	Output
- Sand	- Green sand moulds
- Bonding clay (e.g. bentonite)	- Dust (silica fines, partially burnt-out clay, unburned coal dust and ash)
- Coal dust, dextrin	
- Water (to prepare moulding mix)	

The composition of the bentonite added to the sand depends on the specific properties of both the sand and the bentonite, as well as on the desired strength and gas permeability of the finished mould. The table below gives some parameters of clay-bonded sand, as obtained from a selection of 105 sand samples taken from iron foundries.

Table 2.28: Typical properties of green sand, measured on 105 sand samples from 105 iron foundries

Parameter	Units	Average	% of samples in range of average \pm 10 %		Maximum value	Minimum value
			Range	%		
Water content	%	4.1	3.4 – 4.5	48	6.9	2.4
Bentonite content	%	8.3	7.5 – 9.1	45	11.9	5.6
Density	g/cm ³	0.940	1.00 – 0.85	75	1.06	0.73
Loss on ignition	%	5.0	4.5 – 5.5	20	15.0	1.0
Compressive strength	N/cm ²	18.6	16.7 – 20.5	54	24.5	13.2

Source: [16, Winterhalter et al. 1992]

Further additives are mixed in the green sand mixture [73, Brown, J. R. 2000]:

- *Coal dust:* Used mainly in iron foundries, but also to a lesser degree in some non-ferrous foundries. Coal dust levels in green sand vary from 2 % or 3 % for small castings to 7 % or 8 % for heavy section castings. Too much coal dust can give rise to holes in the castings or in misruns. Various coal dust replacement products exist. They are generally added in a slightly altered concentration compared to the coal dust.

- *Cereal binders*: Starch and dextrin are used mainly in steel foundries to avoid defects caused by silica expansion and to control moisture excess in the sand mix. Effective additions of cereal binders to new green sand facing mixes are between 0.5 % and 0.75 %. In unit-type green sands, part of the cereal is destroyed during the casting process. The recommended addition on each recycle is 0.1 % to 0.25 %, depending on the amount of cereal burn-out and on the dilution by cores and new sand.

Moulding with unbonded sand (V-process)

The main inputs and outputs for moulding with unbonded sand (V-process) are presented in the following table.

Input	Output
– Dry sand	– Moulds
– PE sheets	– Dust
– Energy (to produce and maintain vacuum)	

The thermal shock induced by the contact of the molten metal breaks up the sand grains, generating dust that is mostly emitted during shake-out. The remaining dust in the sand has to be removed in order to allow the reuse of the sand for moulding. Using this method, only a small amount of dust should be generated during the filling of the moulding boxes.

This process is of interest because of its very low environmental impact. However, as its cycle involves many steps, the moulding rate is low and the gap between starting times for each new different casting is lengthy. Moreover, investment costs are very high. As a consequence, this process has found only limited application.

Moulding and core-making with chemically bonded sand

The main inputs and outputs for moulding and core-making with chemically bonded sand are presented in the following table.

Input	Output
– Sand	– Sand moulds and cores
– Resin	– Excess reagents
– Catalyst, hardener, additives	– Reaction products
	– Dust

The consumption levels of the various types of binders, hardeners, catalysts and additives are given in Table 2.29.

Table 2.29: Consumption levels of various resins, catalysts, hardeners and additives for chemically bonded sand preparation

Hardening type	Resin type	Resin addition % on sand weight	Catalyst/hardener type	Catalyst/hardener addition % on resin weight	Additive type	Additive Addition % on sand weight
Cold-setting	Furan	0.8 – 1.5	Sulphonic acid	25 – 60	Silane	0.1 – 0.2
	Phenolic	1 – 2	Sulphonic acid	25 – 50	n.a	n.a
	Polyurethane	0.8 – 1.5	Pyridine derivat	2 – 6	n.a	n.a
	Resol	1.0 – 1.5	Ester	22 – 25	n.a	n.a
	Alkyd oil	1.0 – 2.0	Isocyanate	18 – 20	Catalyst	0.002 – 0.2
	Ester silicate	2.0 – 4.5	Ester	10 – 15	n.a	n.a

Hardening type	Resin type	Resin addition % on sand weight	Catalyst type	Catalyst addition % on sand weight	Additive type	Additive Addition % on sand weight
Gas hardening	Phenolic/Furan	0.8 – 1.2	SO ₂	0.3 – 3	Peroxide	0.1 – 0.5
	Polyurethane Cold-box	1.0 – 1.8	Amine	0.05 – 0.15	n.a	n.a
	Resol	1.2 – 1.8	Methyl fomate	0.3 – 0.5	n.a	n.a
	Resol	2 – 2.5	CO ₂	0.7 – 1.25	n.a	n.a
	Acryl/Epoxy	1.2 – 1.6	SO ₂	0.02 – 0.05	Peroxide	0.05 – 0.06
	Silicate	2 – 4	CO ₂	1 – 2	n.a	n.a
Hardening type	Resin type	Resin addition % on sand weight	Catalyst type	Catalyst addition % on resin weight	Additive type	Additive Addition % on sand weight
Thermosetting	Oil	0.8 – 4			n.a	n.a
	Warm-box furfuryl alcohol-based	1.0 – 1.5	Cu salts of sulphonic acids	10 – 30	n.a	n.a
	Hot-box phenolic or furan based	1.2 – 3.0	Ammonium salts	10 – 25	n.a	n.a
	Croning phenolic	1.5 – 5	Hexamethylene-tetramine	15	n.a	n.a

Source: [73, Brown, J. R. 2000], [120, TWG 2003]

Emissions for the cold-setting processes can be described as follows [14, CAEF 1997]:

- *Phenolic*: Vapours of formaldehyde and phenol may be emitted because of the vapour pressure of these constituents. However, as the polymerisation occurs at ambient temperature, these vapour pressures are low and, given the consumption rates, the emissions are insignificant.
- *Furan*: Vapours of formaldehyde, phenol, furfuryl alcohol and alcohols may be emitted because of the vapour pressure of these constituents. However, as the polymerisation occurs at ambient temperature, these vapour pressures are low and, given the consumption rates, the emissions are insignificant.
- *Polyurethane*: Vapours of formaldehyde, phenol, isocyanate and aromatic solvents may be emitted because of the vapour pressure of these constituents. As the polymerisation occurs at ambient temperature, the vapour pressures of the components are low and, given the consumption rates, the emissions are insignificant. Obnoxious odours may be generated in the moulding area but are not likely to cause external nuisance.
- *Resol-ester*: The resin contains unreacted phenol and formaldehyde, but their emissions are extremely low and environmentally insignificant.
- *Alkyd-oil*: During production of the moulds and cores, there are no emission problems, unless they are cured by heat, in which case odour problems may occur.
- *Ester silicate*: This process does not generate any emission problems.

Emissions for the gas-hardened processes can be described as follows [14, CAEF 1997]:

- *Cold-box*: Vapours of formaldehyde, phenol, isocyanate and aromatic solvents are emitted in low quantities, in spite of their low vapour pressures. Aromatic solvent emissions are highest during purging. The most significant emission is that of amines, which have low odour detection thresholds and can create an external nuisance. Amines are hazardous, with a relatively low exposure value limit, and possess a strong characteristic smell at very low concentrations.

- *Resol-ester*: The resin contains unreacted phenol and formaldehyde, but their emission levels, even during the gassing and purging periods, are very low. Methyl formate is not toxic, does not have an unpleasant smell and its exposure value limit is relatively high.
- *Resol-CO₂*: The resin has low contents of unreacted phenol and formaldehyde, and their emission levels, even during the gassing and purging periods, are very low.
- *SO₂ hardened phenolic and furan resin*: The resins and the prepared sands generate formaldehyde emissions. The major emission problem is caused by sulphur dioxide, which is very hazardous.
- *SO₂ hardened epoxy/acrylic*: Minimal emissions are generated during the core-making process.
- *CO₂ silicate*: This process does not generate any emission problems during moulding or core-making.

Emissions for the hot curing processes can be described as follows:

- *Hot-box emissions*: The patterns are generally heated by open air gas burners, producing combustion gas emissions. The off-gas may contain phenol, ammonia, formaldehyde and monoisocyanates (if the resin contains nitrogen).
- *Warm-box emissions*: Compared to the hot-box process, the emissions are significantly lower. The emissions do not contain phenol or ammonia, and also formaldehyde emissions are diminished by a factor of 4. As the pattern temperature is also lower compared to the one used for the hot-box process, the working conditions are also improved. The environmental impact is considered to be relatively low.
- *Shell emissions*: Compared to the hot-box process, cured sand consumption is very low. However, the pre-coated sand contains two to three times more resin, but as the pattern temperatures are approximately the same, the resulting impact on working conditions is similar.
- *Linseed oil emissions*: As the oils are often in solution in organic solvents such as naphtha or kerosene, a large amount of VOCs are generated by curing, which may result in an external odour nuisance. This problem is even more persistent during pouring. These problems, as well as poor productivity, are some of the reasons for the reduction in interest in the use of this process.

[14, CAEF 1997]

2.3.2 Emissions to air

2.3.2.1 Metal melting

2.3.2.1.1 Dust emissions

The reported levels of dust emissions to air from metal melting are presented in the following figures:

- Figure 2.60: Dust emissions to air from metal melting in cast iron foundries using induction, rotary or EAF;
- Figure 2.61: Dust emissions from metal melting in cast iron foundries using CBC or HBC;
- Figure 2.62: Dust emissions from metal melting in steel foundries;
- Figure 2.63 and Figure 2.64: Dust emissions from metal melting in NFM foundries.

Some statistical data on the reported dust emission data (maximum values) in relation to the furnace type are presented in the following table.

Table 2.30: Statistical evaluation of the reported dust emission data

Parameter /Furnace type	Number of EPs	Number of plants	90 th percentile	Average	Median	10 th percentile
			mg/Nm ³			
CBC	9	6	11.67	4.25	1.75	0.45
HBC	24	20	56.14	163.5	6.8	1.33
Crucible	13	7	9.7	3.9	2.0	0.43
EAF	8	8	-	2.16	1.0	-
Induction (electric coreless)	77	18	11.6	3.53	1	0.42
Medium-frequency crucible induction	27	11	6.94	2.96	2	0.18
Net/mains frequency crucible induction	11	1	6.9	4.05	1	0.6
Rotary	6	1	-	6.4	2	-
Radiant roof	3	2	-	2.64	2	-
Resistance	5	1	-	2.63	1	-
Reverbatory (hearth)	19	5	12.34	6.41	5	1.92
Shaft	49		14.02	5.84	3	1.1

Source: [169, TWG 2021]

For cupola furnaces, particle sizes range from less than 1 µm up to 10 mm, with 50 % less than 100 µm. However, 5 % to 20 % are smaller than 2 µm, which makes the dust collection more difficult. Cupola dust is primarily made up of coke, silica, rust and limestone, as shown in Table 2.31.

Table 2.31: Typical composition of cupola dust (in weight per cent)

Substance	Composition (wt%)	
	[14, CAEF 1997]	[61, Charbonnier et al. 1998]
Iron oxide	30 – 60	15 – 25
SiO ₂	± 25	15 – 30
Coke dust	3 – 15	n.d
MnO	3 – 10	2 – 5
Al ₂ O ₃	1 – 3	2 – 5
MgO	1 – 3	0 – 2
CaO	<1	5 – 10
S	<2	n.d
ZnO, depending on the charge	<3	0 – 30 Zn*
PbO, depending on the charge	<1	0 – 5 Pb*

* In the form of oxides and silicates; applicable for Zn-enriched dusts.
Source: [14, CAEF 1997], [61, Charbonnier et al. 1998]

2.3.2.1.2 Metal emissions

The reported levels of Pb emissions to air from metal melting are presented in the following figures:

- Figure 2.67: Pb emissions to air from melting in cast iron foundries using CBC or HBC;
- Figure 2.68: Pb emissions to air from melting in NFM foundries.

2.3.2.1.3 PCDD/F emissions

In melting processes, dioxins may be produced if the conditions that give rise to such pollutants are present at the same location and time in the process. These conditions are:

- the presence of chloride ions – these can arise from contaminated scrap, from the use of coal, coke, fuel oil or from certain fluxes;
- the presence of organic carbon – this may arise from contaminated scrap and from coal, coke or oil used as a fuel;
- temperature conditions between 250 °C and 450 °C, with a sufficient gas residence time in this temperature interval;
- the presence of a catalyst such as copper;
- the presence of oxygen.

In evaluating the risk of dioxin formation, a distinction can be made between non-ferrous and ferrous foundries:

- Non-ferrous foundries: When only ingots and internal scrap are melted, the risk of dioxin formation in the melting stage is very low. The melting of pure non-ferrous metals lacks the presence of both the chlorine and carbon required for dioxin (re)formation. However, the remelting of external non-ferrous scrap materials for metal production may involve a risk of dioxin formation.
- Ferrous foundries: Depending on the furnace type and metal load the conditions for dioxin formation could occur. Considering the high temperatures in the melting furnace, dioxin emission (if occurring at all) will mainly generate from de-novo synthesis. The abovementioned conditions can be used to evaluate the risk of dioxin formation.

Dioxin emission data have been gathered in the SF BREF data collection from a broad range of melting furnaces. The data are summarised in Table 2.32.

Reported levels of PCDD/F emissions to air from metal melting are presented in Figure 2.65 for cast iron foundries and in Figure 2.66 for NFM foundries.

Some statistical data on the reported PCDD/F emission data (maximum values) are presented in the following table.

Table 2.32: Statistical evaluation of the reported PCDD/F emissions data

Furnace type	Number of EPs	90 th percentile	Average	Median	10 th percentile
		ng WHO-TEQ/Nm ³			
CBC	8	0.16	0.07	0.0255	0.0146
HBC	7	1.93	0.69	0.04	0.0077
Rotary	3	0.0368	0.02	0.02	0.014
Induction (electric coreless and medium-frequency crucible) in cast iron foundries	16	0.0115	0.01	0.01	0.00035
Shaft	14	0.191	0.06	0.0085	0.003
<i>Source: [169, TWG 2021]</i>					

Additional data on PCDD/F emissions are available in the DIOFUR project. Dioxin emission range for various furnace type are presented in Table 2.33 for cupolas (HBC and CBC), Table 2.34 for rotary furnaces and Table 2.35 for electric arc furnaces.

Table 2.33: Dioxin emission range for cupolas

Furnace type	ng I-TEQ/Nm ³
Hot blast cupola	0.0017 – 0.4166
Cold blast cupola	0.0010 – 0.3290
<i>Source: [180, DIOFUR 2010]</i>	

Table 2.34: Dioxin emission range for rotary furnaces

Furnace type	ng I-TEQ/Nm ³
Rotary (small)	0.0160 – 0.0190
Rotary (big)	0.0019 – 0.0022
<i>Source: [180, DIOFUR 2010]</i>	

Table 2.35: Dioxin emission range for electric arc furnaces

Furnace type	ng I-TEQ/Nm ³
Electric Arc 1	0.0019 – 0.0023
Electric Arc 2	0.0020 – 0.0370
<i>Source: [180, DIOFUR 2010]</i>	

2.3.2.1.4 NO_x emissions

The reported levels of NO_x emissions to air from metal melting and ladle preheating are presented in the following figures:

- Figure 2.69: NO_x emissions from melting in cast iron foundries using HBC;
- Figure 2.70: NO_x emissions from melting in cast iron foundries using CBC or rotary furnaces;
- Figure 2.71: NO_x emissions from melting in NFM foundries.

Some statistical data on the reported NO_x emission data (using maximum emission values) in relation to the furnace type are presented in the following table.

Table 2.36: Statistical evaluation of the reported NO_x emission data

Parameter /Furnace type	Number of EPs	90 th percentile	Average	Median	10 th percentile
		mg/Nm ³			
CBC	11	70	35	34	8.0
HBC	15	158	94	77.0	27
Crucible	14	52	31.0	31.5	16
EAF	3	-	14	8	-
Induction (electric coreless and medium-frequency crucible)	23	13	7	4.0	2
Rotary	5	-	106	526	-
Radiant roof	2	-	15	-	-
Reverbatory (hearth)	14	110	51	26	17
Shaft	47	60	31	27	10
<i>Source: [169, TWG 2021]</i>					

2.3.2.1.5 CO emissions

The reported levels of CO emissions to air from metal melting and ladle preheating are presented in the following figures:

- Figure 2.72: CO emissions to air from melting in cast iron foundries using CBC, HBC or rotary furnaces;
- Figure 2.73: CO emissions to air from melting in NFM foundries.

Some statistical data on the reported CO emission data (using maximum emission values) in relation to the furnace type are presented in the following table.

Table 2.37: Statistical evaluation of the reported CO emission data

Parameter /Furnace type	Number of EPs	90 th percentile	Average	Median	10 th percentile
		mg/Nm ³			
CBC	5	-	4809	219	-
HBC	18	881	388	66	16
Crucible	8	115	53	19	8
Induction (electric coreless and medium-frequency crucible)	20	36	21	13	9
Rotary	4	-	29	18	-
Radiant roof	5	-	4	4	-
Reverbatory (hearth)	10	142	58	11	4
Shaft	37	118	60	16	4

Source: [169, TWG 2021]

2.3.2.1.6 SO₂ emissions

The reported SO₂ emissions to air from metal melting and ladle preheating are presented in the following figures:

- Figure 2.74: SO₂ emissions to air from melting in cast iron foundries using HBC, CBC or rotary furnaces;
- Figure 2.75: SO₂ emissions to air from melting in NFM foundries.

Some statistical data on the reported SO₂ emission data (using maximum emission values) in relation to the furnace type are presented in the following table.

Table 2.38: Statistical evaluation of the reported SO₂ emission data

Parameter /Furnace type	Number of EPs	90 th percentile	Average	Median	10 th percentile
		mg/Nm ³			
CBC	11	220	112	70	51
HBC	16	185	80	50	18
Crucible	4	-	7	6	-
Induction (electric coreless and medium-frequency crucible)	11	13	6	4	0
Rotary	3	-	67	46	-
Radiant roof	5	-	13	3	-
Reverbatory (hearth)	6	-	12	10	-
Shaft	12	8	9	5	1

Source: [169, TWG 2021]

2.3.2.1.7 TVOC emissions

The reported levels of TVOC emissions to air from metal melting are presented in Figure 2.76 (cast iron foundries) and Figure 2.77 (NFM foundries).

Some statistical data on the reported TVOC emission data (using maximum emission values) in relation to the furnace type are presented in the following table.

Table 2.39: Statistical evaluation of the reported TVOC emission data

Parameter /Furnace type	Number of EPs	90 th percentile	Average	Median	10 th percentile
		mg/Nm ³			
CBC	7	-	45.6	7.5	-
HBC	4	-	26.5	18.5	-
Crucible	12	17.5	8.6	6.5	2.1
EAF	3	-	10.8	9.4	-
Induction (electric coreless and medium-frequency crucible)	25	51.6	65.1	6.8	1.9
Reverbatory (hearth)	10	22.5	14.5	12.8	1
Shaft	27	38.5	15.6	10	3.6

Source: [169, TWG 2021]

2.3.2.1.8 HCl emissions

The reported levels of HCl emissions to air from metal melting are presented in Figure 2.78 (cast iron foundries) and Figure 2.79 (NFM foundries).

Some statistical data on the reported HCl emission data (using maximum emission values) are presented in the following table.

Table 2.40: Statistical evaluation of the reported HCl emission data

Parameter	Number of EPs	90 th percentile	Average	Median	10 th percentile
		mg/Nm ³			
HCl	36	7.1	4.3	0.8	0.3

Source: [169, TWG 2021]

2.3.2.1.9 HF emissions

The reported levels of HF emissions to air from metal melting are presented in Figure 2.80 (cast iron foundries) and Figure 2.81 (NFM foundries).

Some statistical data on the reported HF emission data (using maximum emission values) are presented in the following table.

Table 2.41: Statistical evaluation of the reported HF emission data

Parameter	Number of EPs	90 th percentile	Average	Median	10 th percentile
		mg/Nm ³			
HF	36	2.9	1.4	0.5	0.1

Source: [169, TWG 2021]

2.3.2.1.10 Figures for emissions to air

The figures related to emissions to air which are presented in this section and the following relevant sections are composed of several parts (sections):

- The upper part (first section) of the figure always shows the maximum, average and minimum concentrations for the reporting period. Below the x-axis, additional contextual information is included such as the emission point code, the monitoring frequency and the number of measurements done each year.
- In the second part (section) of the figure, additional information is given such as the maximum mass flow values over the 3 reporting years.
- The third part (section) of the figure contains contextual information (e.g. the type of furnace used in the case of metal melting, the type of resins used in the case of moulding). In the case of furnaces, this information is complemented by two additional figure sections providing information on the associated process(es) (melting, remelting, holding, preheating, ladle heating) and the type of fuel used.
- The last section of the figure contains information on the applied techniques.

The explanations for the abbreviations used in the graphs can be found in the Glossary.

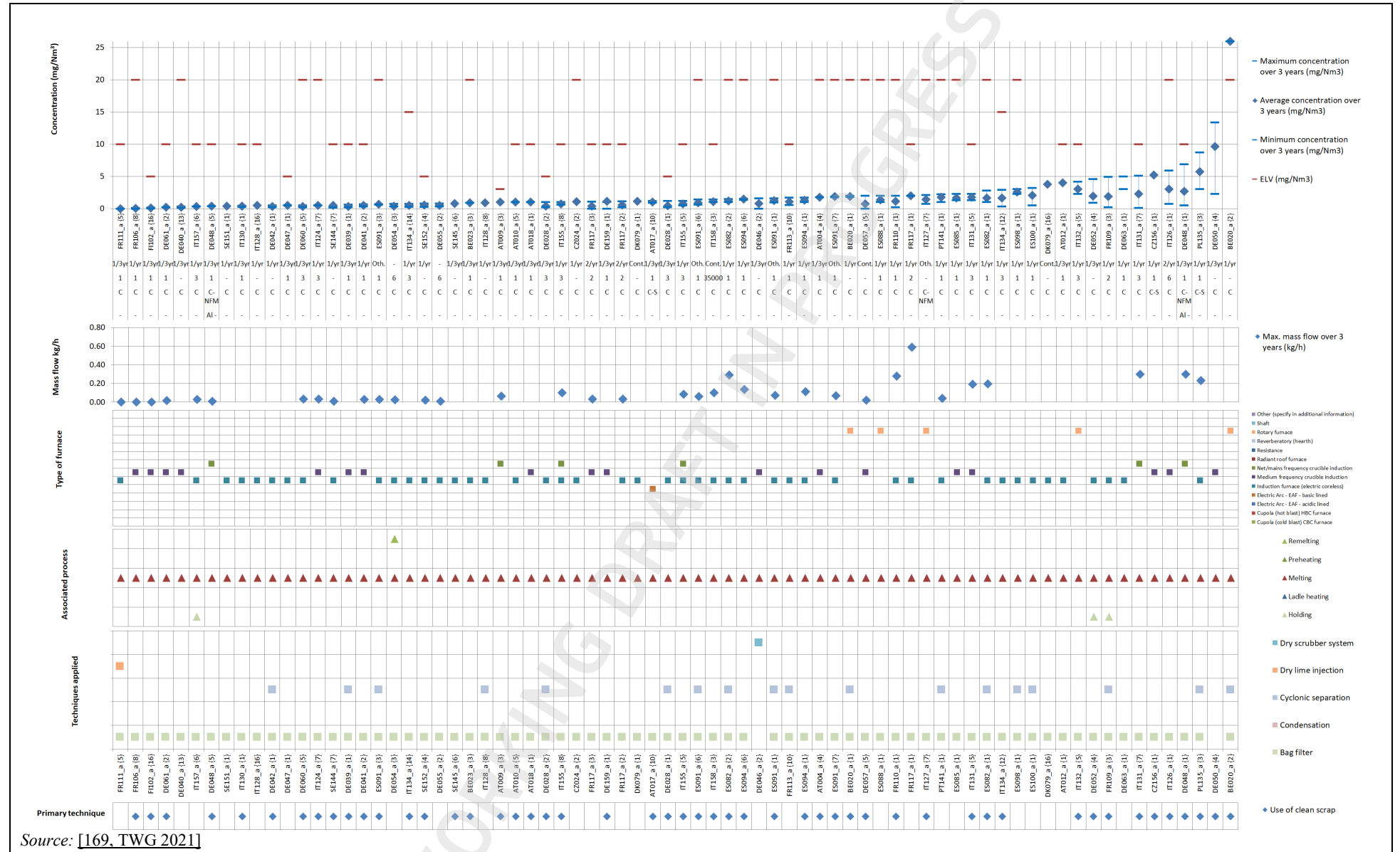


Figure 2.60: Dust emissions to air from metal melting in cast iron foundries using induction, rotary or EAF

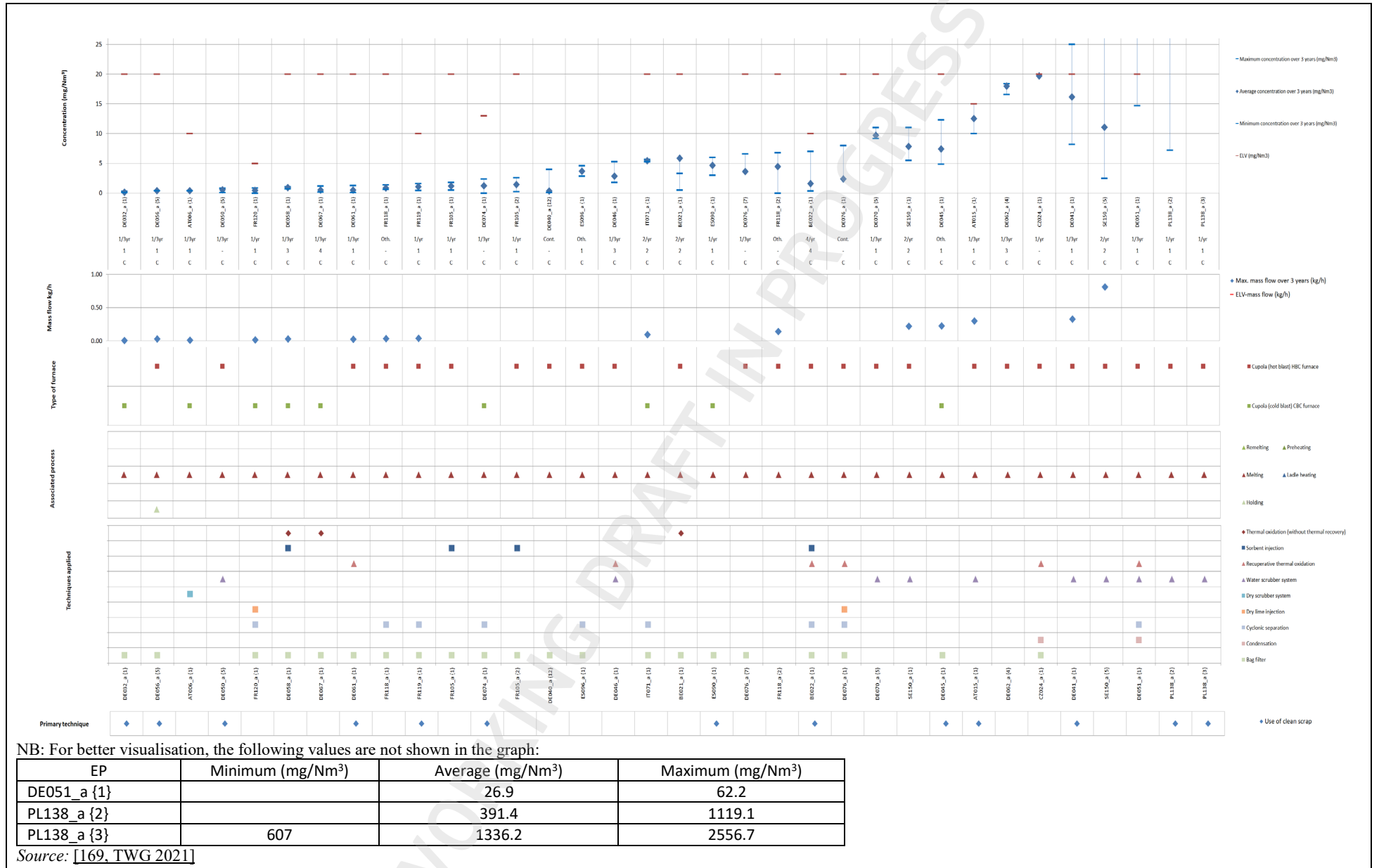


Figure 2.61: Dust emissions to air from metal melting in cast iron foundries using CBC or HBC

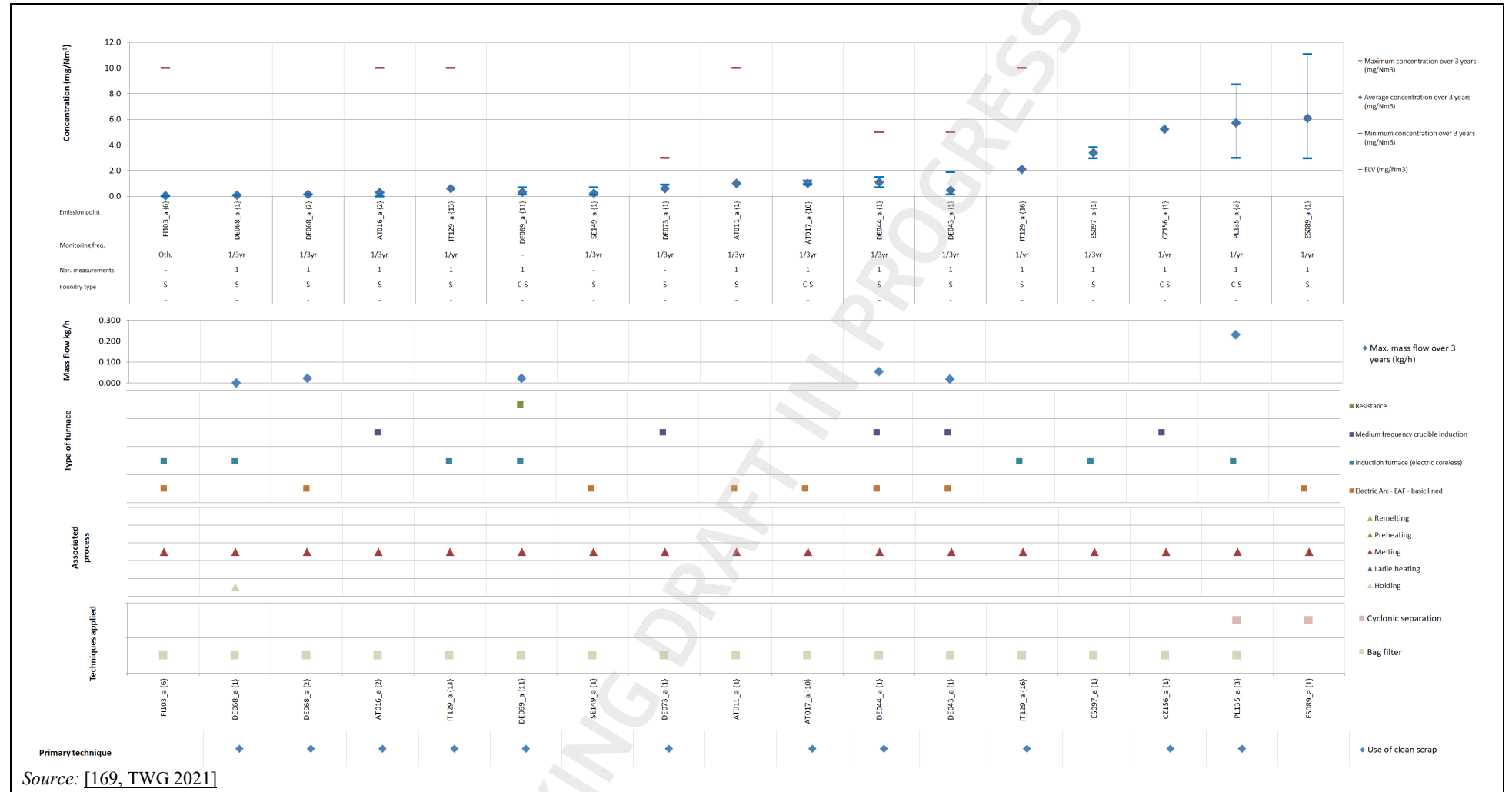


Figure 2.62: Dust emissions to air from metal melting in steel foundries

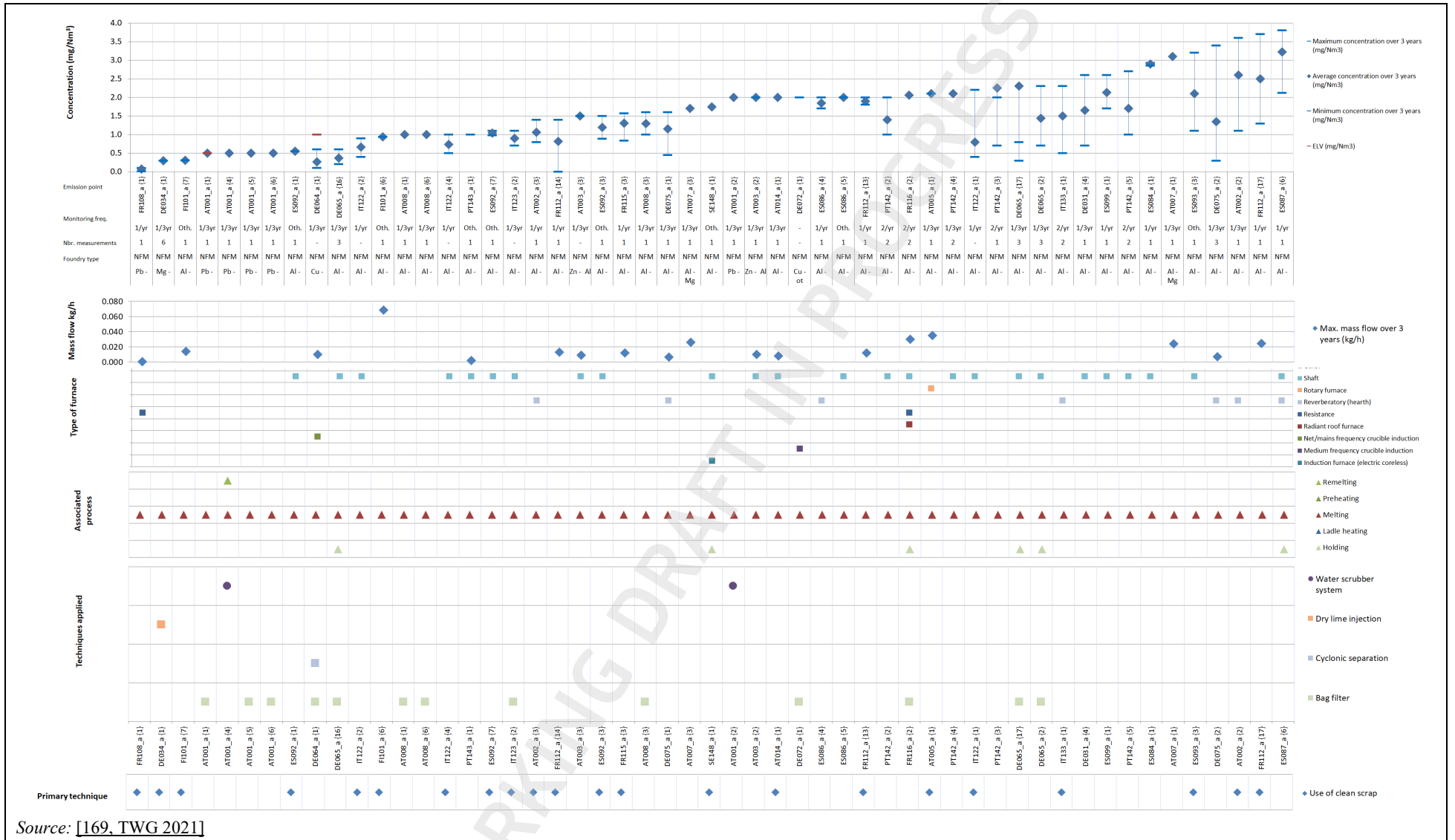


Figure 2.63: Dust emissions to air from metal melting in NFM foundries (1/2)

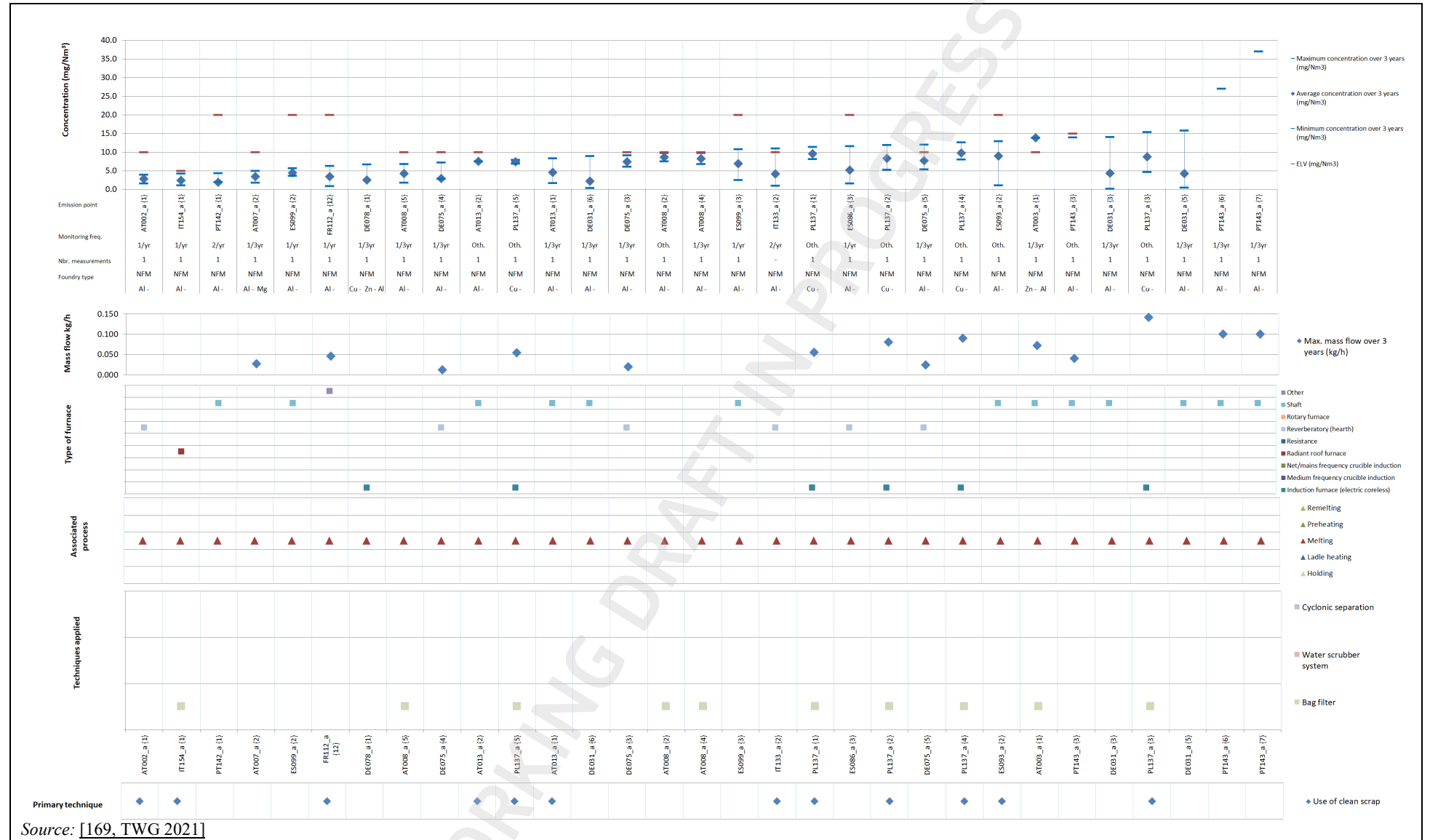


Figure 2.64: Dust emissions to air from metal melting in NFM foundries (2/2)

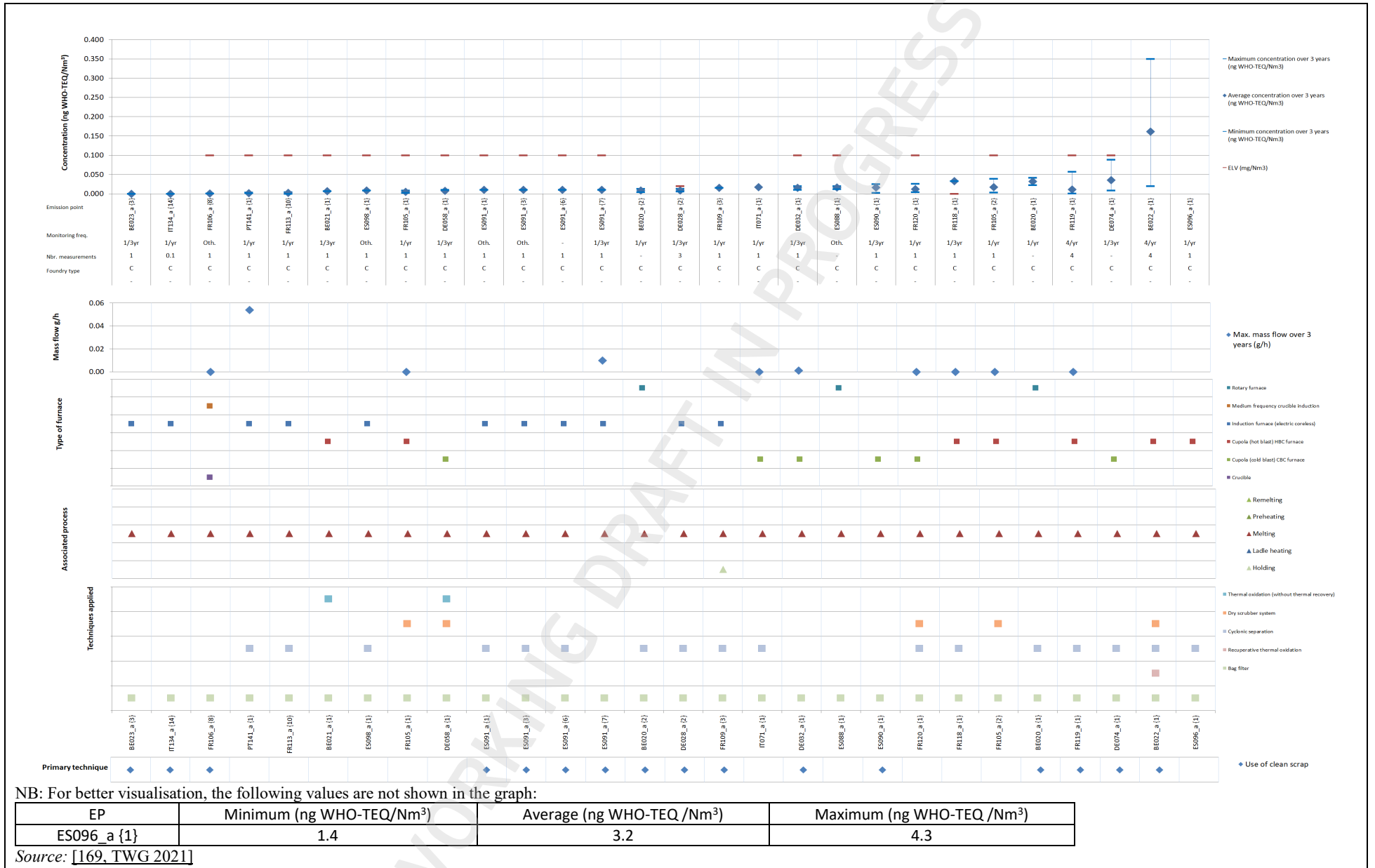


Figure 2.65: PCDD/F emissions to air from metal melting in cast iron foundries

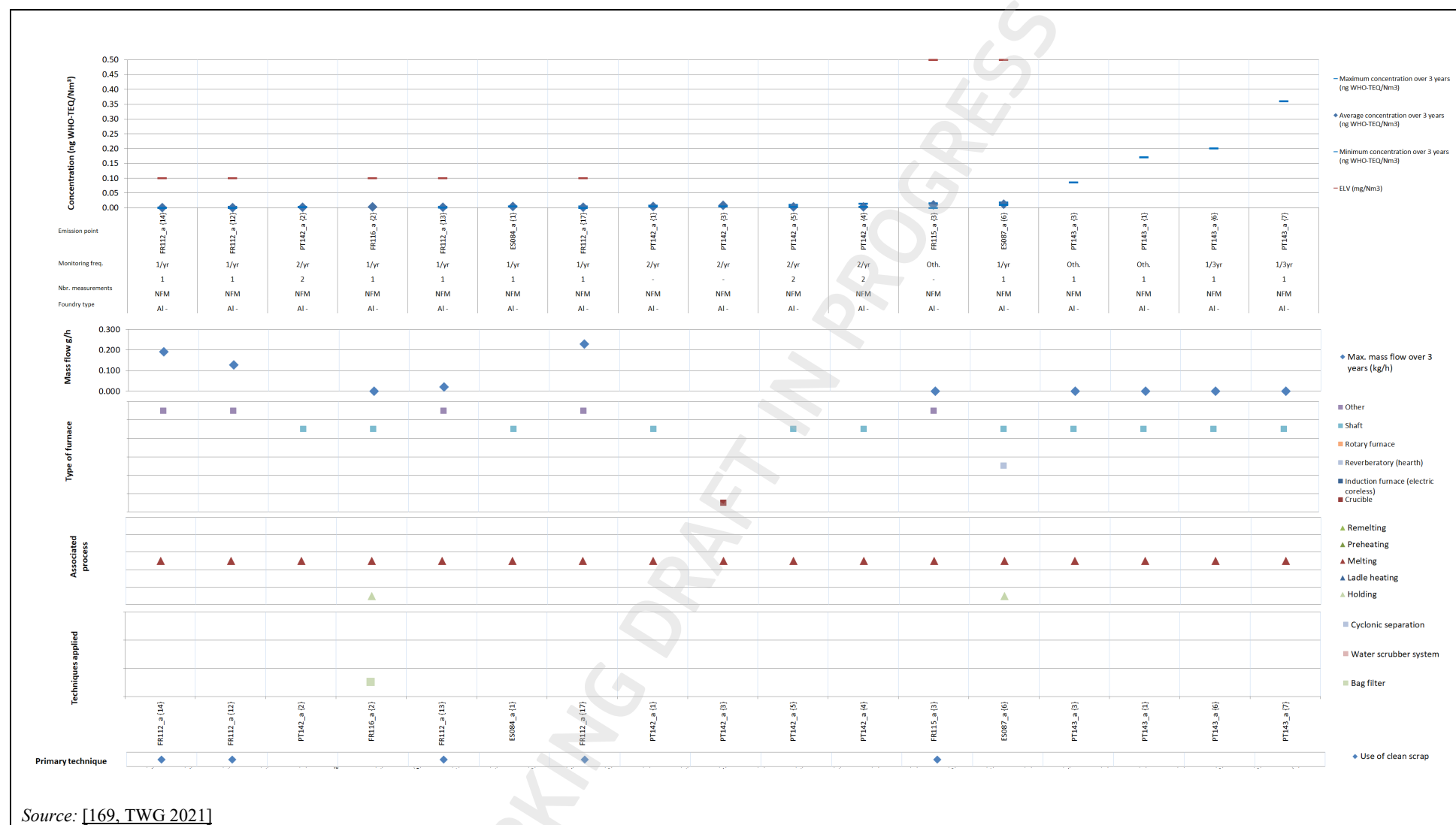


Figure 2.66: PCDD/F emissions to air from metal melting in NFM foundries

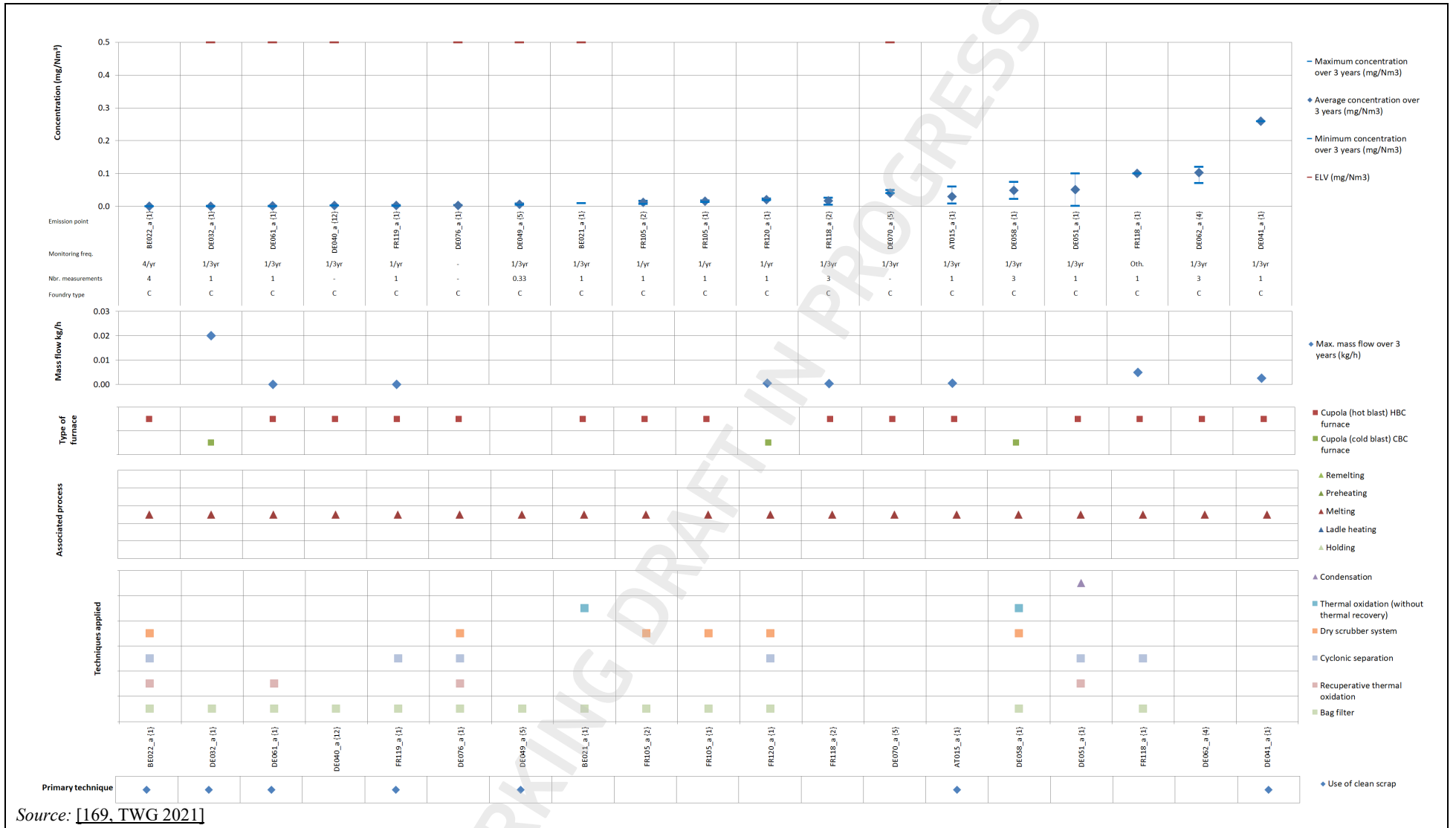


Figure 2.67: Pb emissions to air from metal melting in cast iron foundries using CBC or HBC

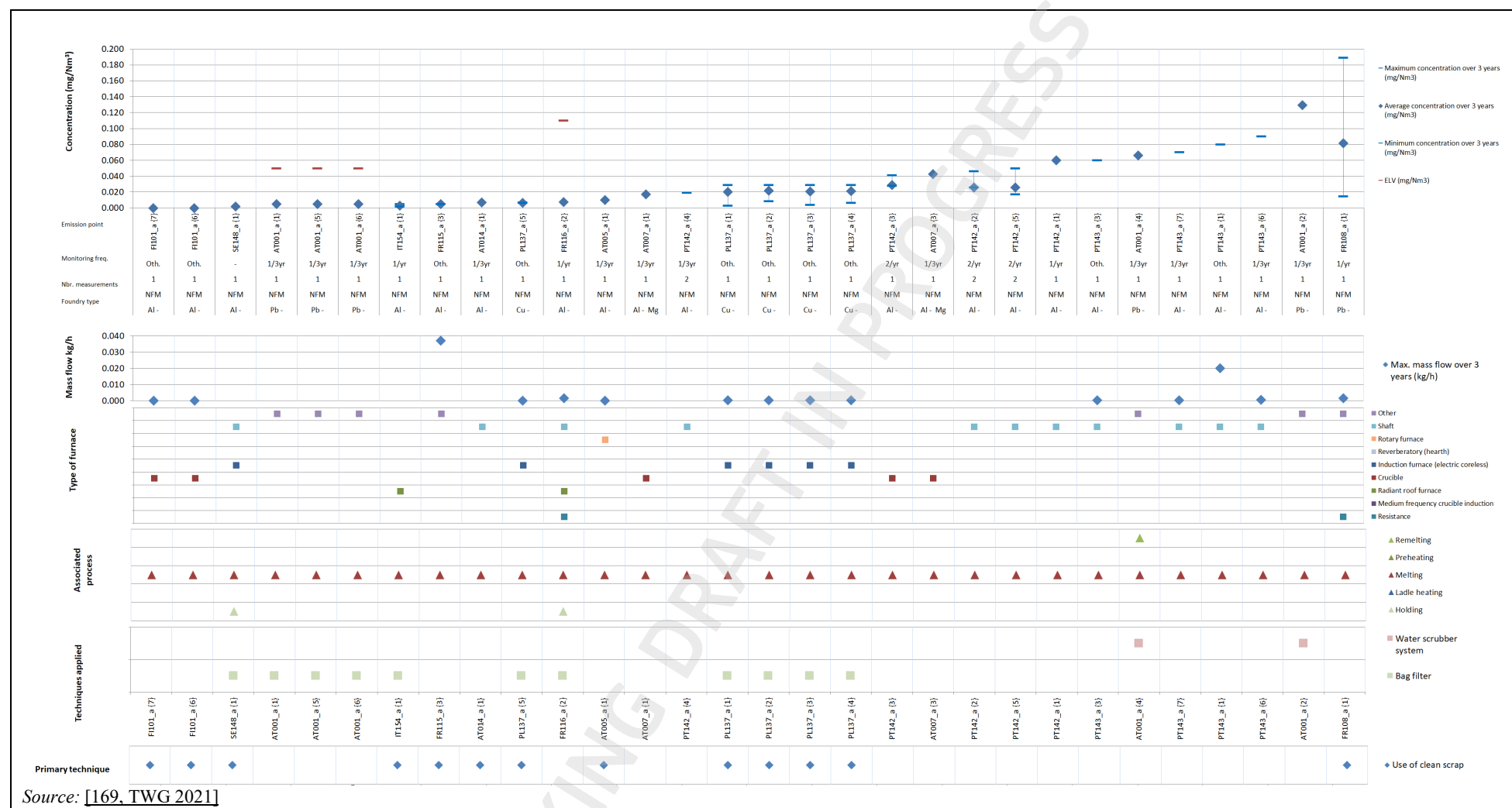


Figure 2.68: Pb emissions to air from metal melting in NFM foundries

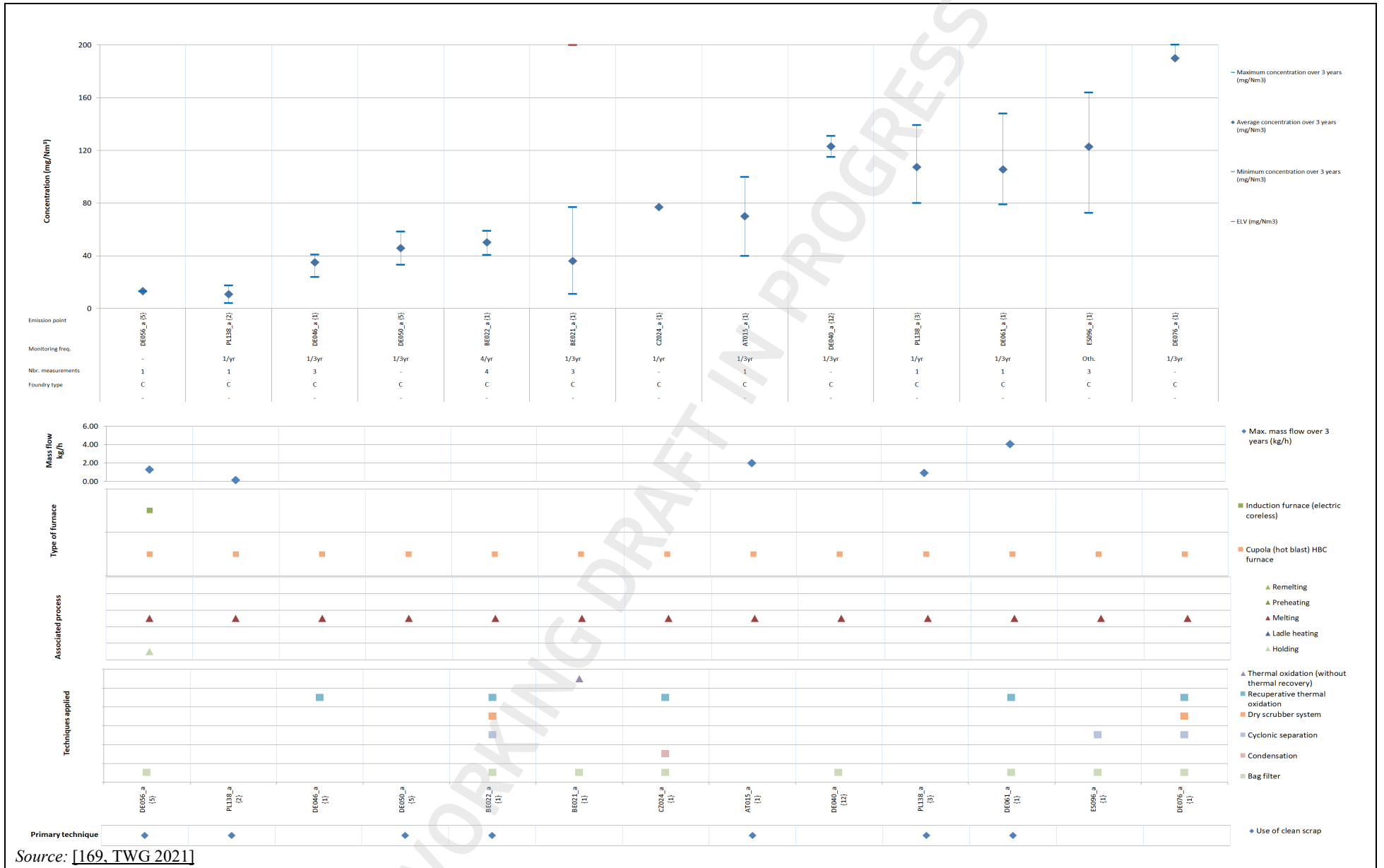


Figure 2.69: NOx emissions to air from metal melting in cast iron foundries using HBC

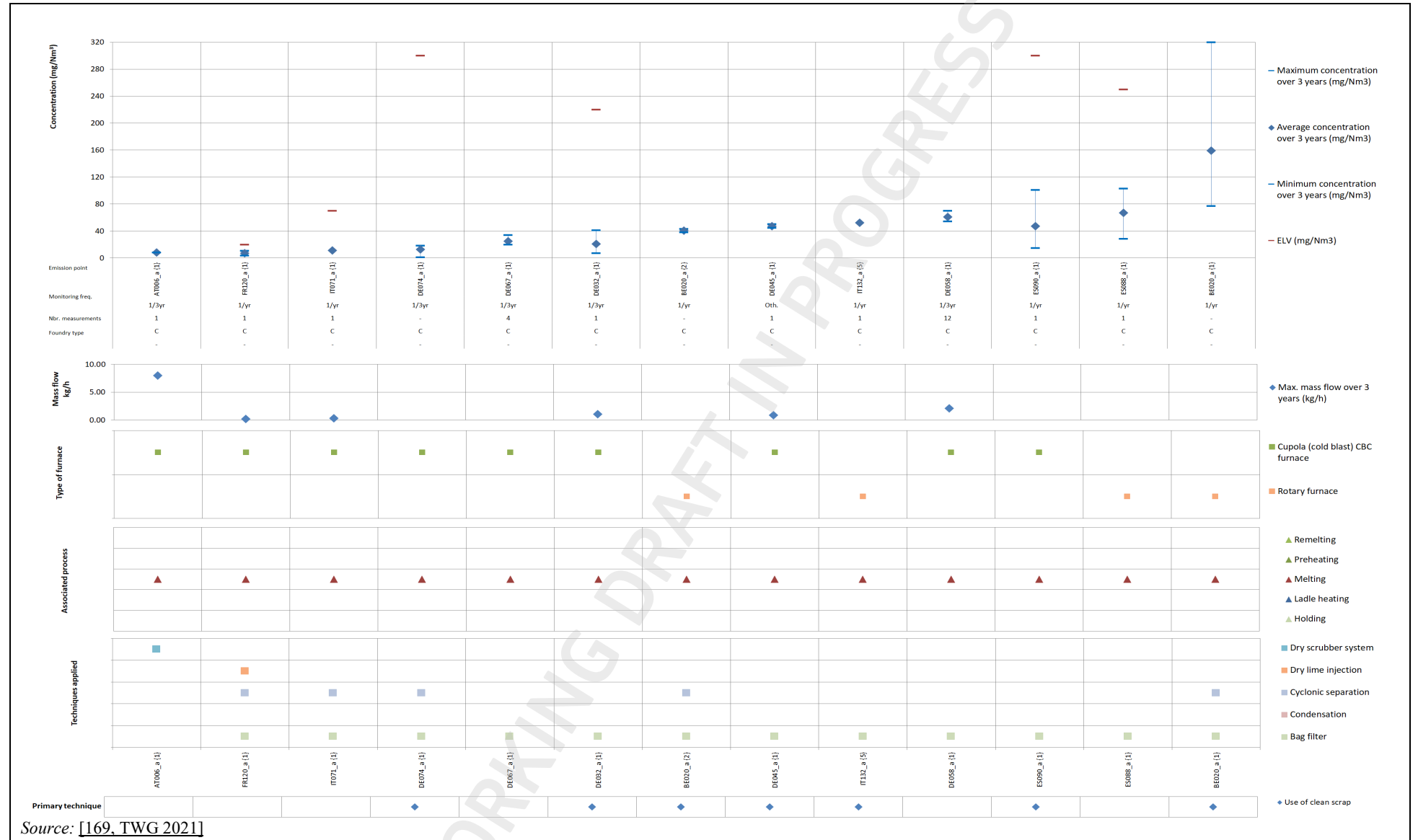


Figure 2.70: NO_x emissions to air from metal melting in cast iron foundries using CBC or rotary furnaces

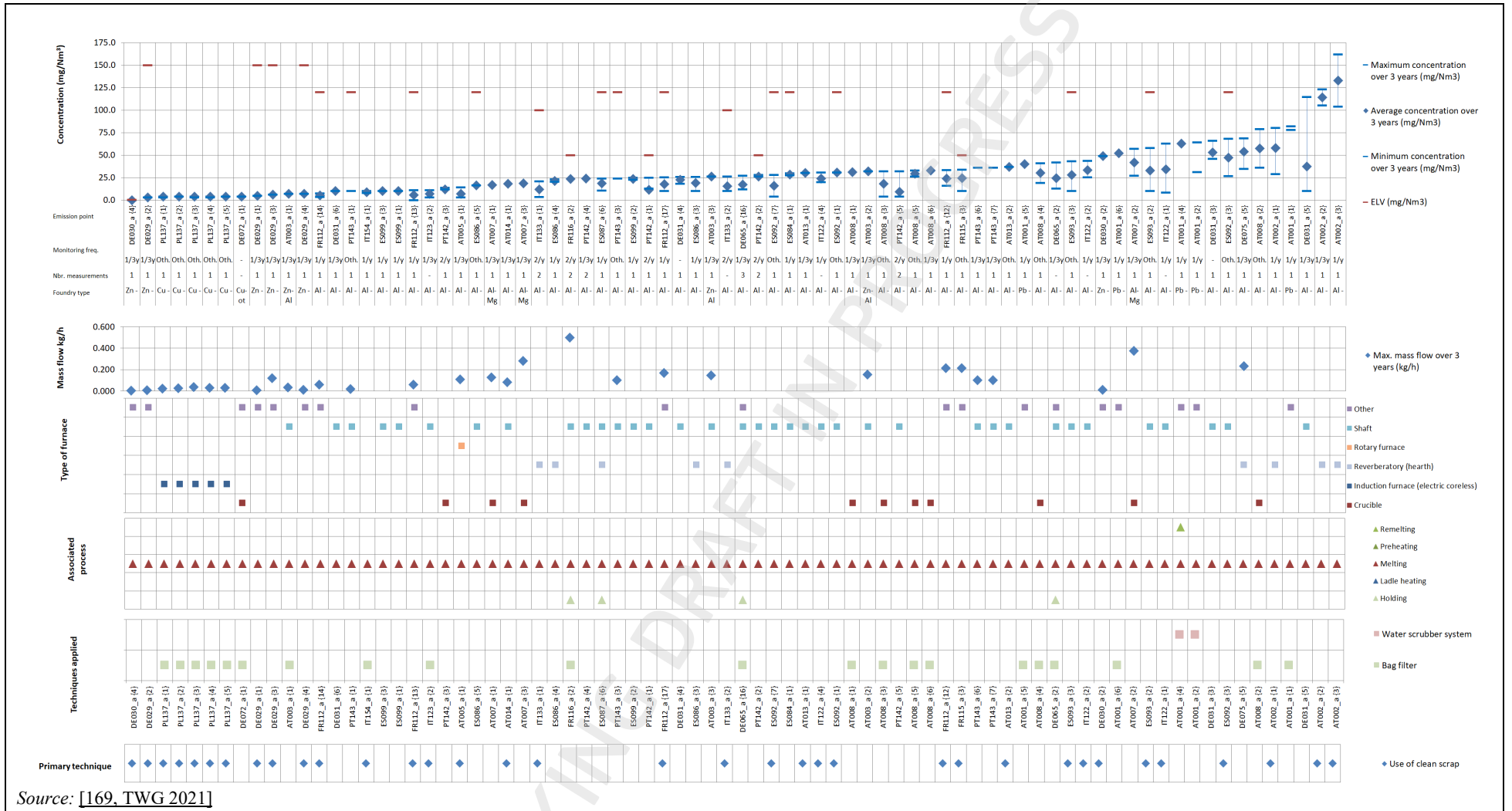


Figure 2.71: NOx emissions to air from metal melting in NFM foundries

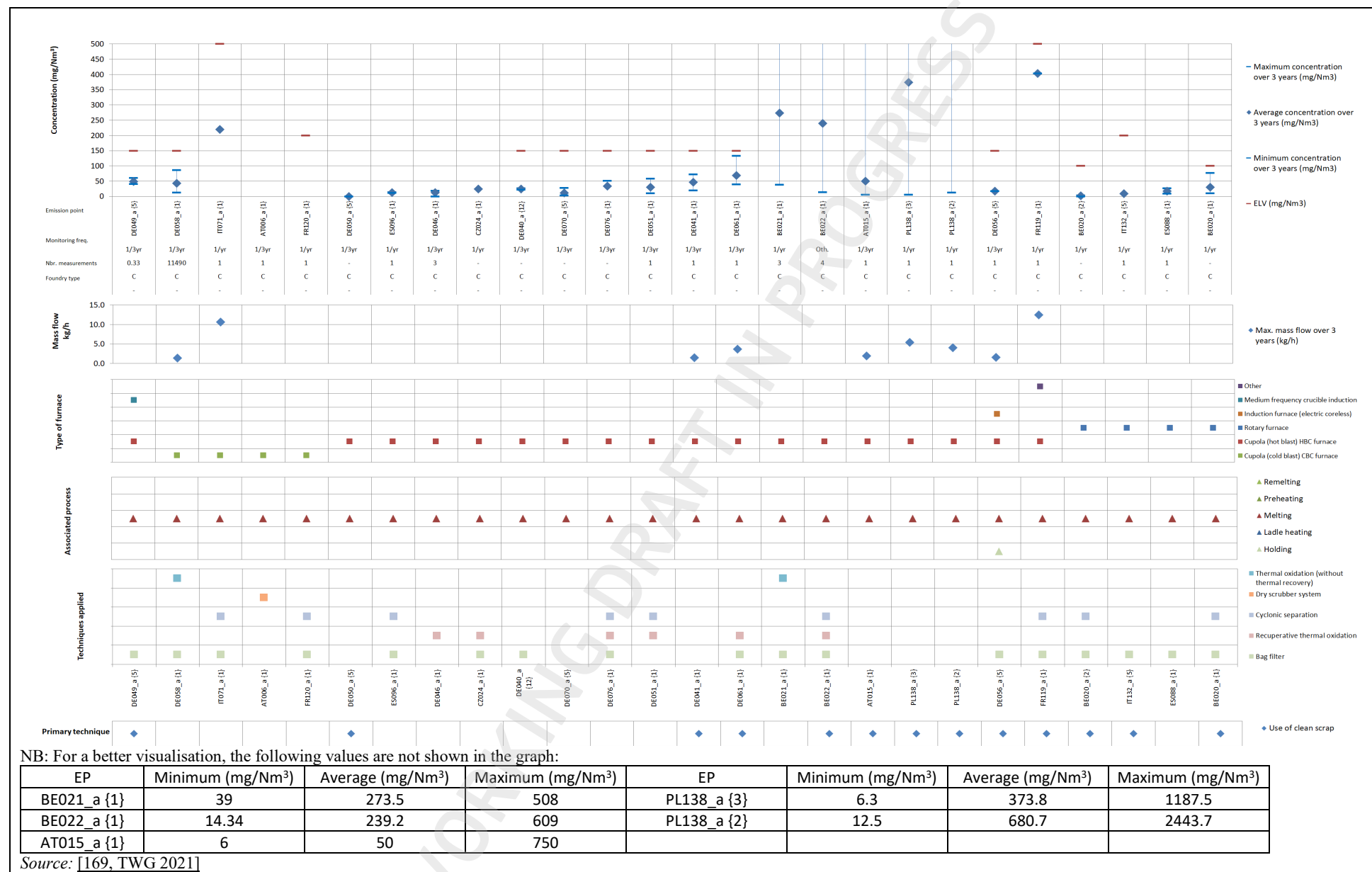


Figure 2.72: CO emissions to air from metal melting in cast iron foundries using CBC, HBC or rotary furnaces

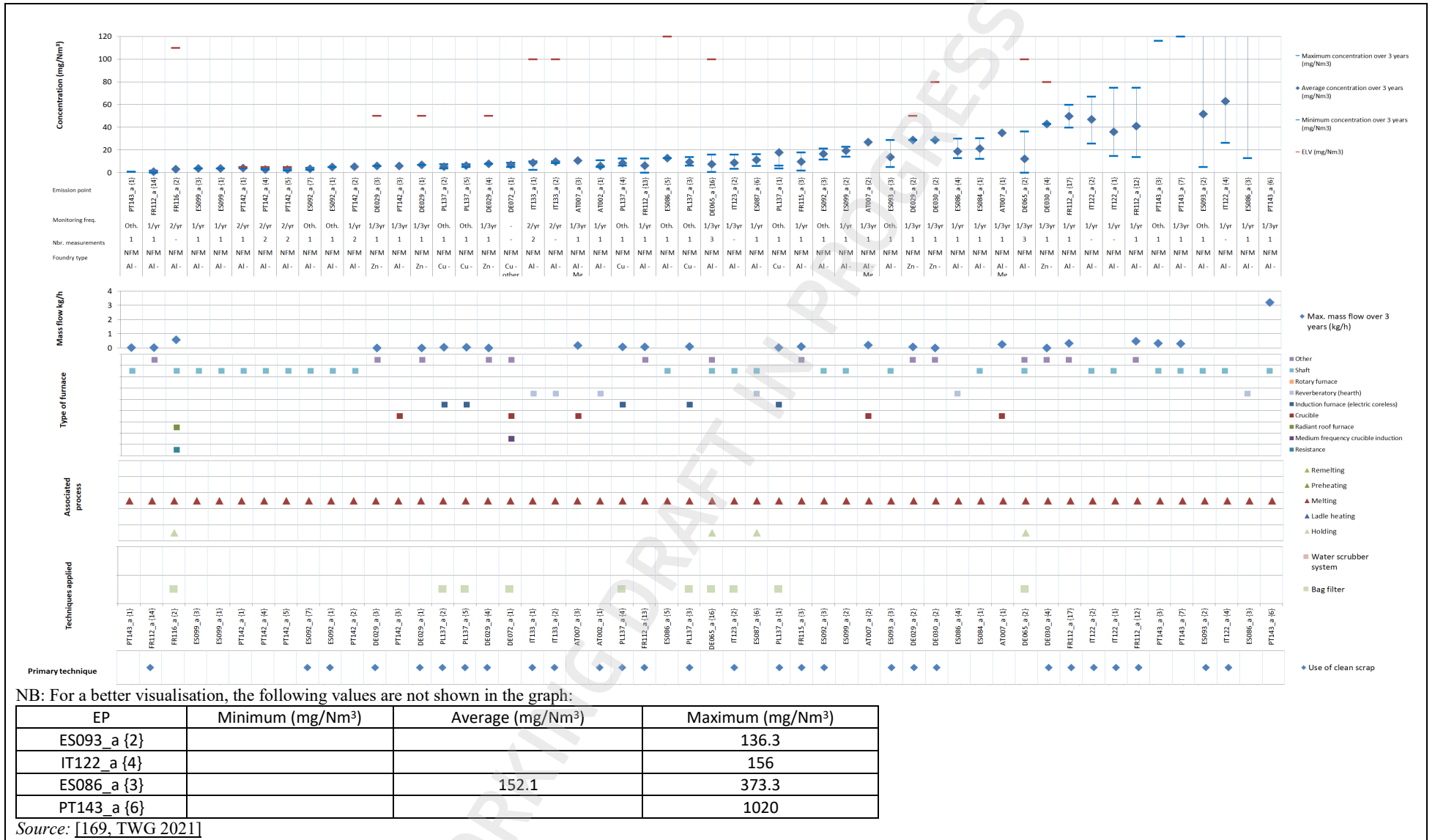


Figure 2.73: CO emissions to air from metal melting in NFM foundries

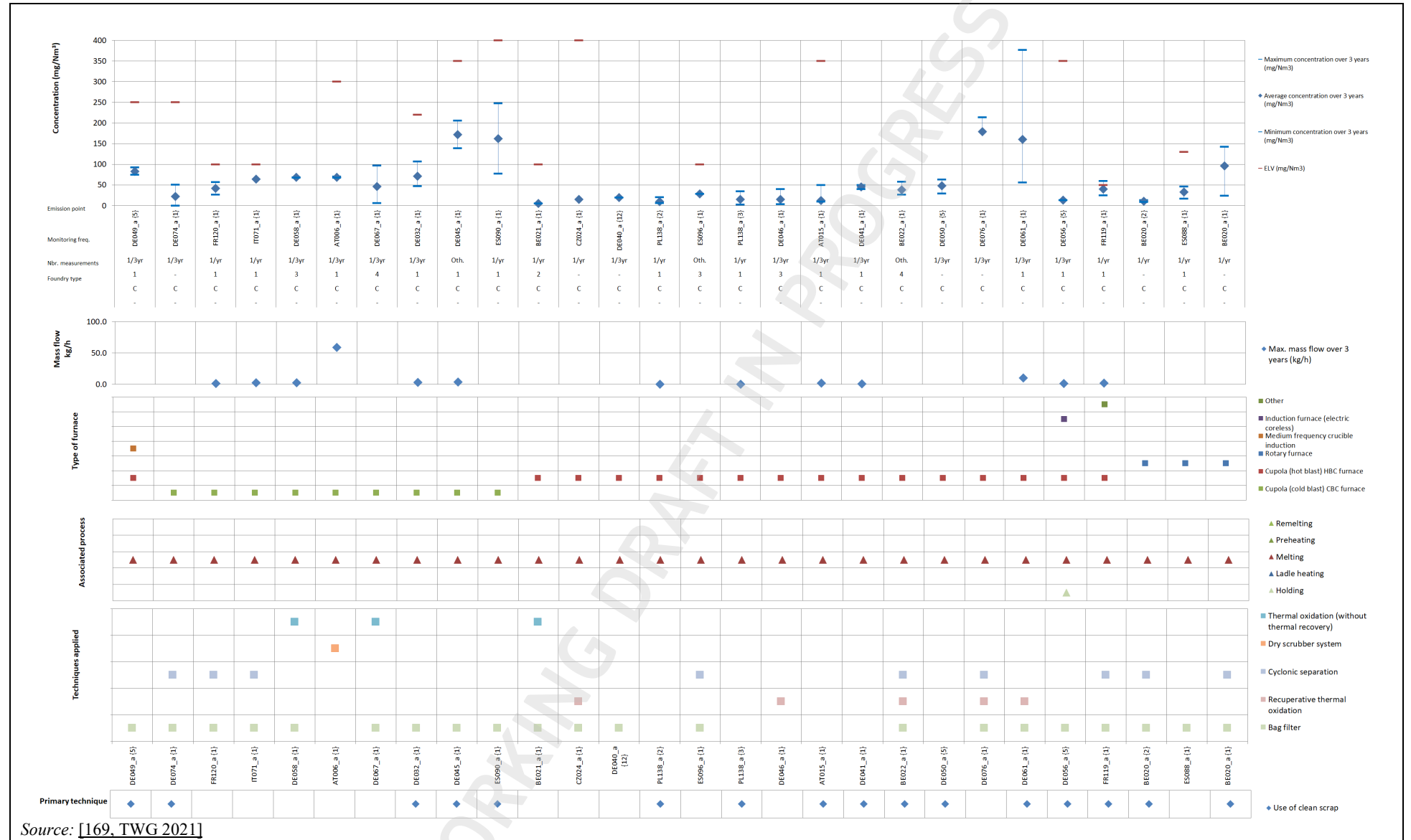


Figure 2.74: SO₂ emissions to air from metal melting in cast iron foundries using HBC, CBC or rotary furnaces

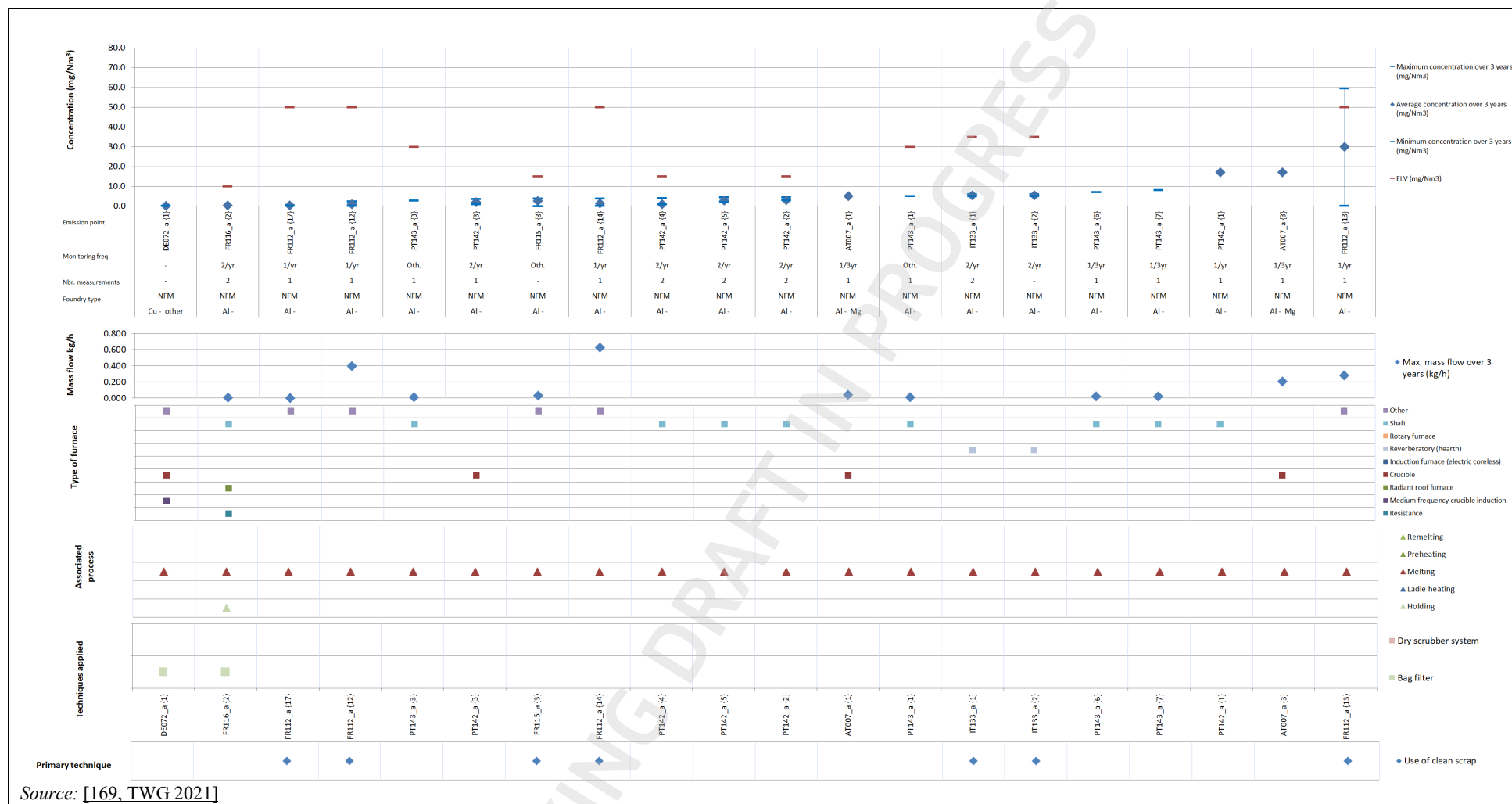


Figure 2.75: SO₂ emissions to air from metal melting in NFM foundries

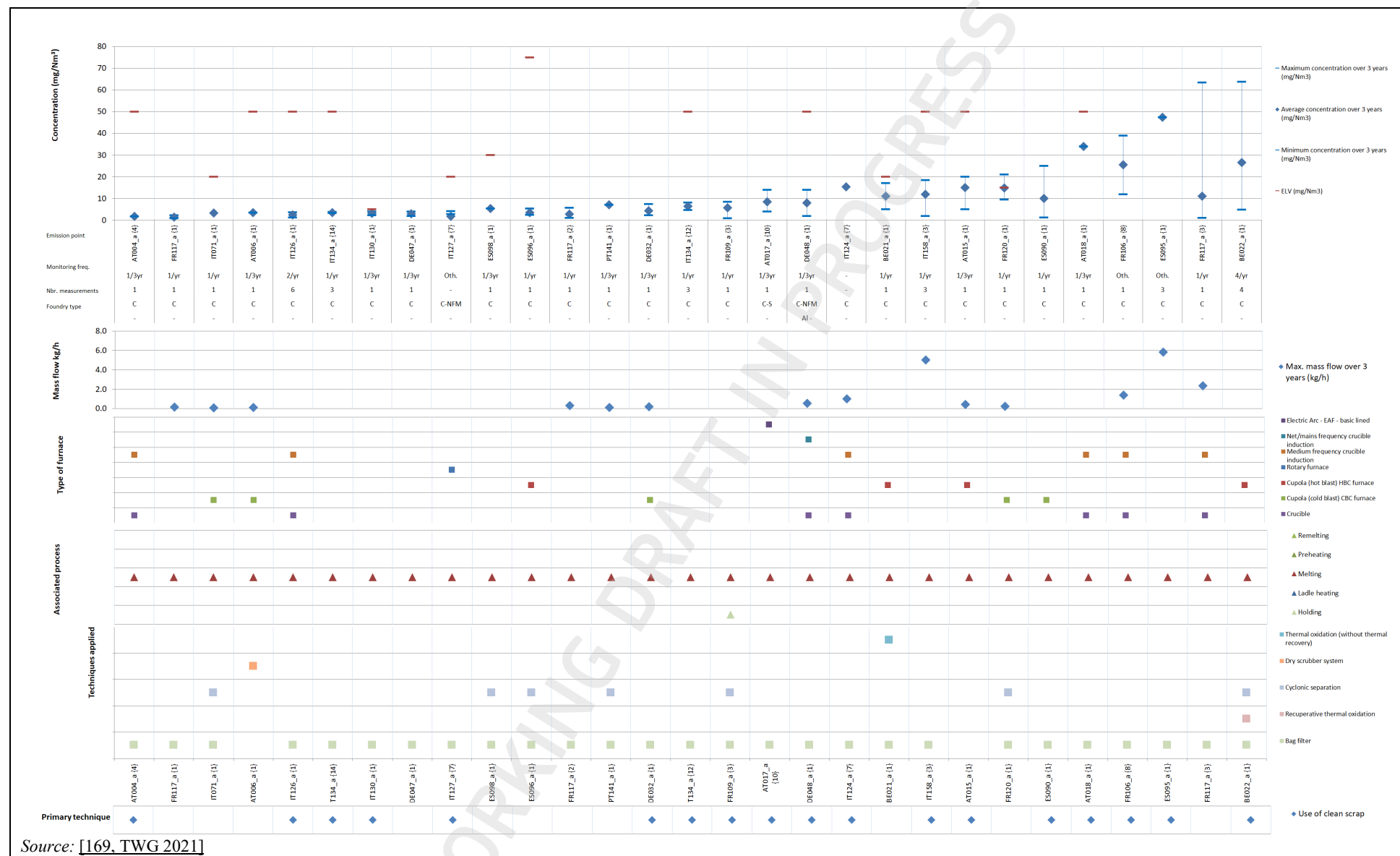


Figure 2.76: TVOC emissions to air from metal melting in cast iron foundries

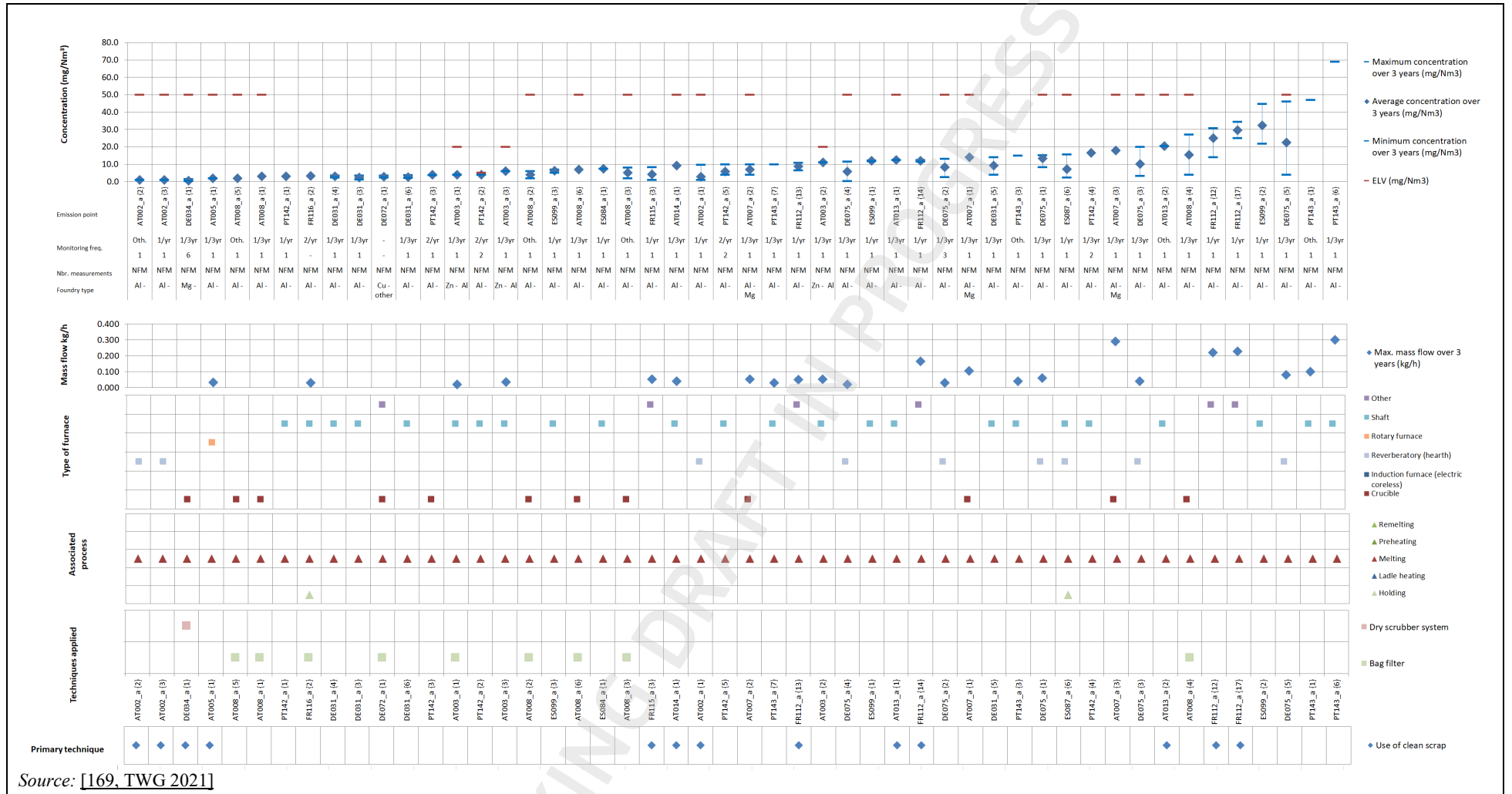


Figure 2.77: TVOC emissions to air from metal melting in NFM foundries

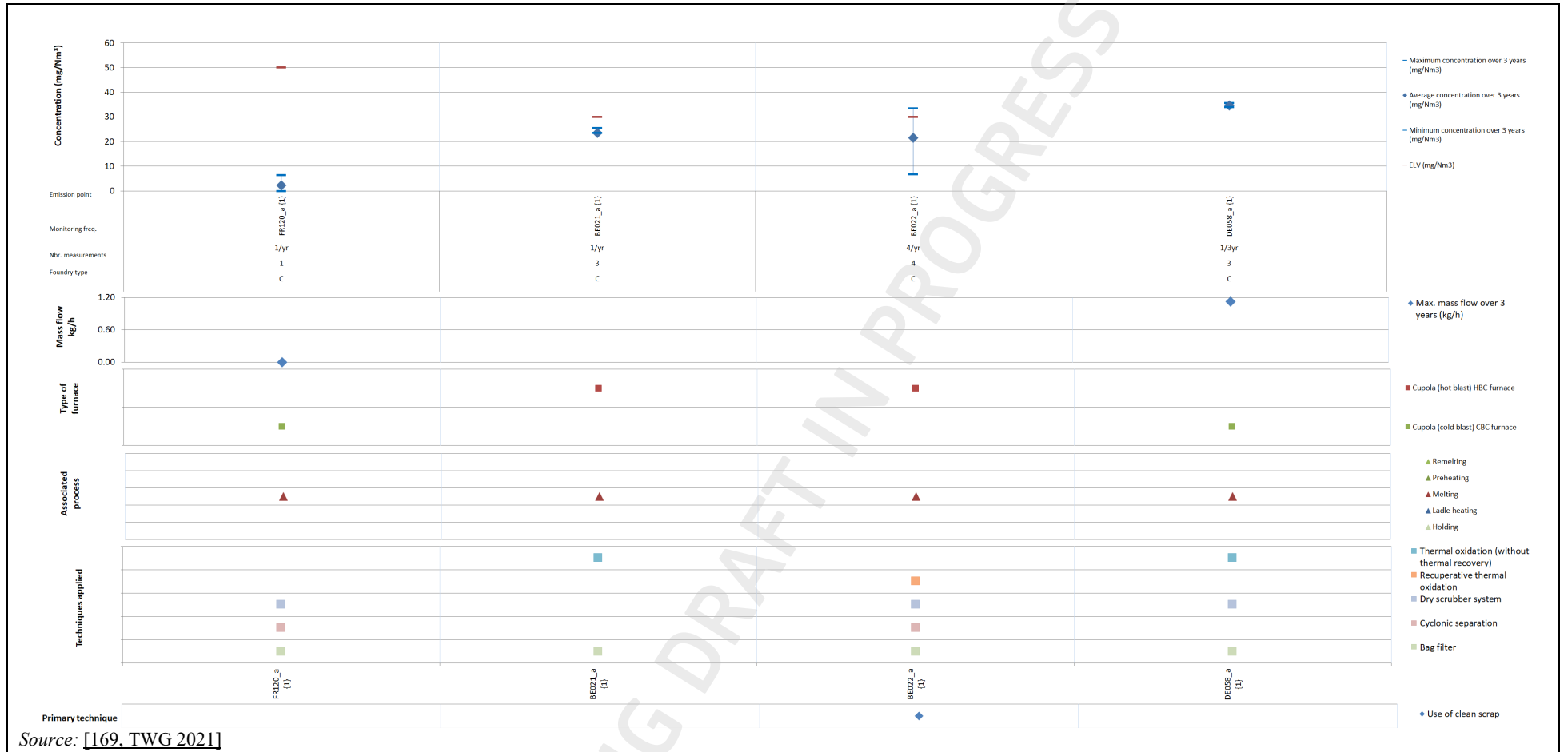
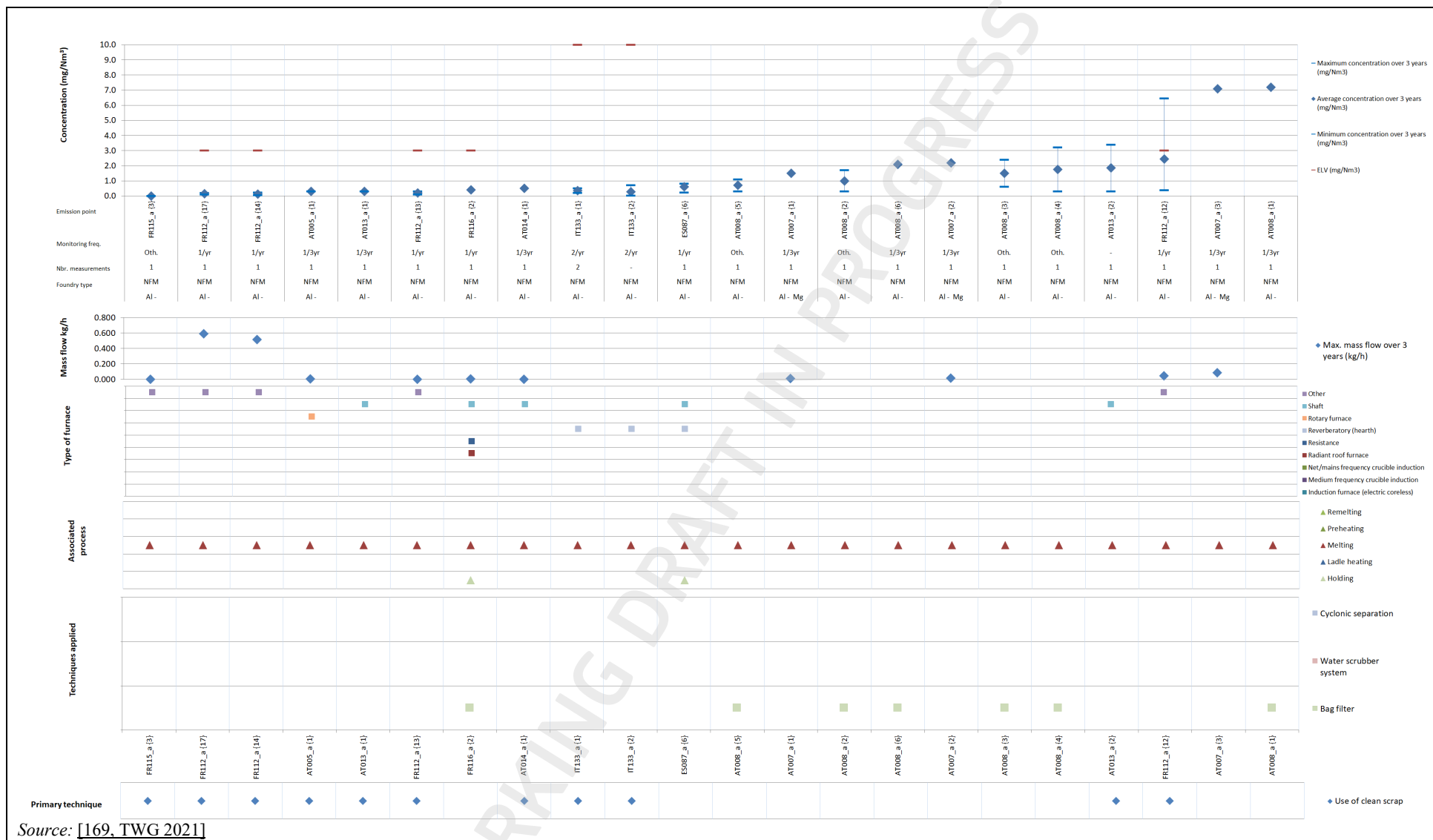


Figure 2.78: HCl emissions to air from metal melting in cast iron foundries using CBC or HBC



Source: [169, TWG 2021]

Figure 2.79: HCl emissions to air from metal melting in NFM foundries

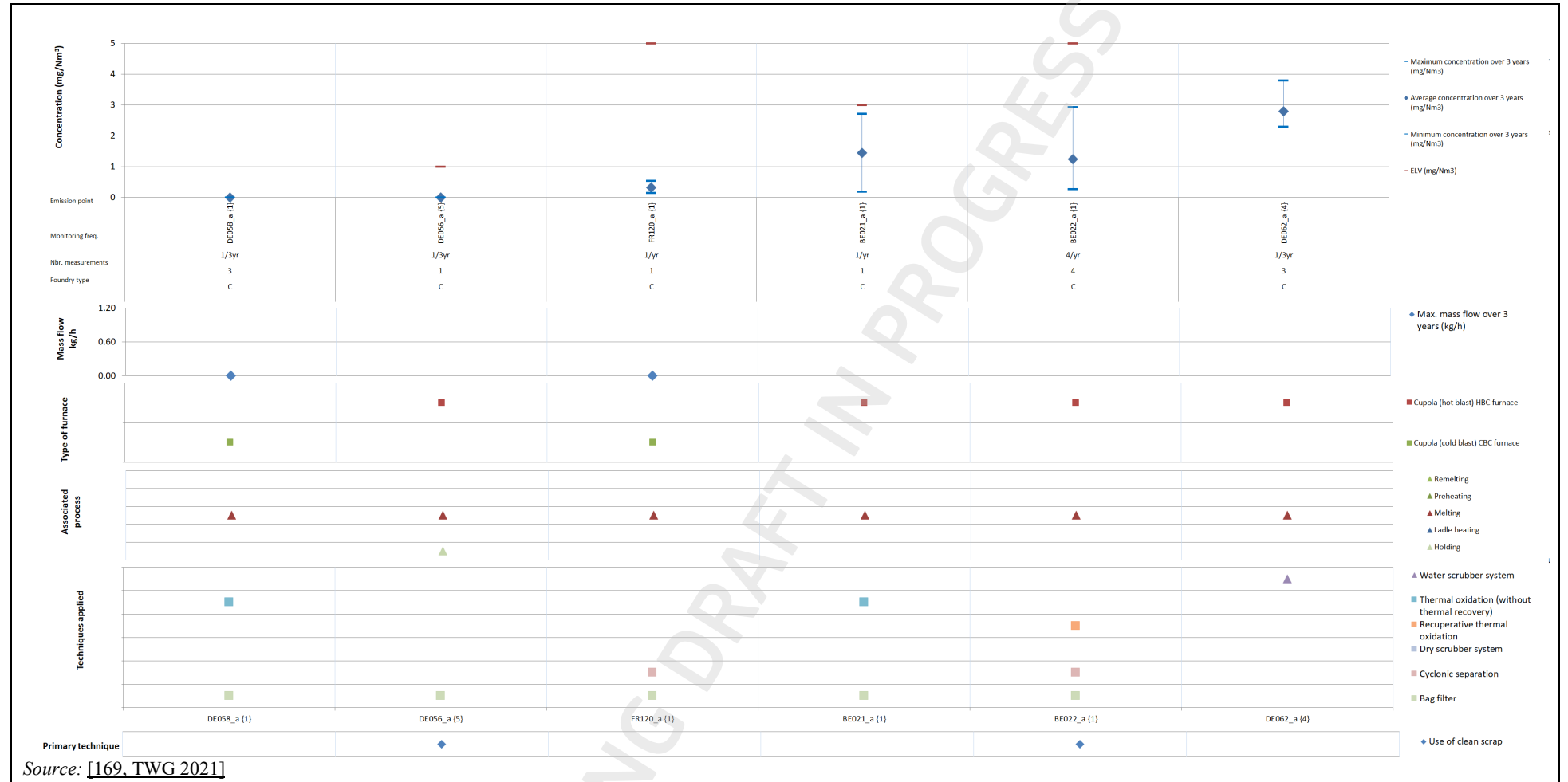


Figure 2.80: HF emissions to air from metal melting in cast iron foundries using CBC or HBC

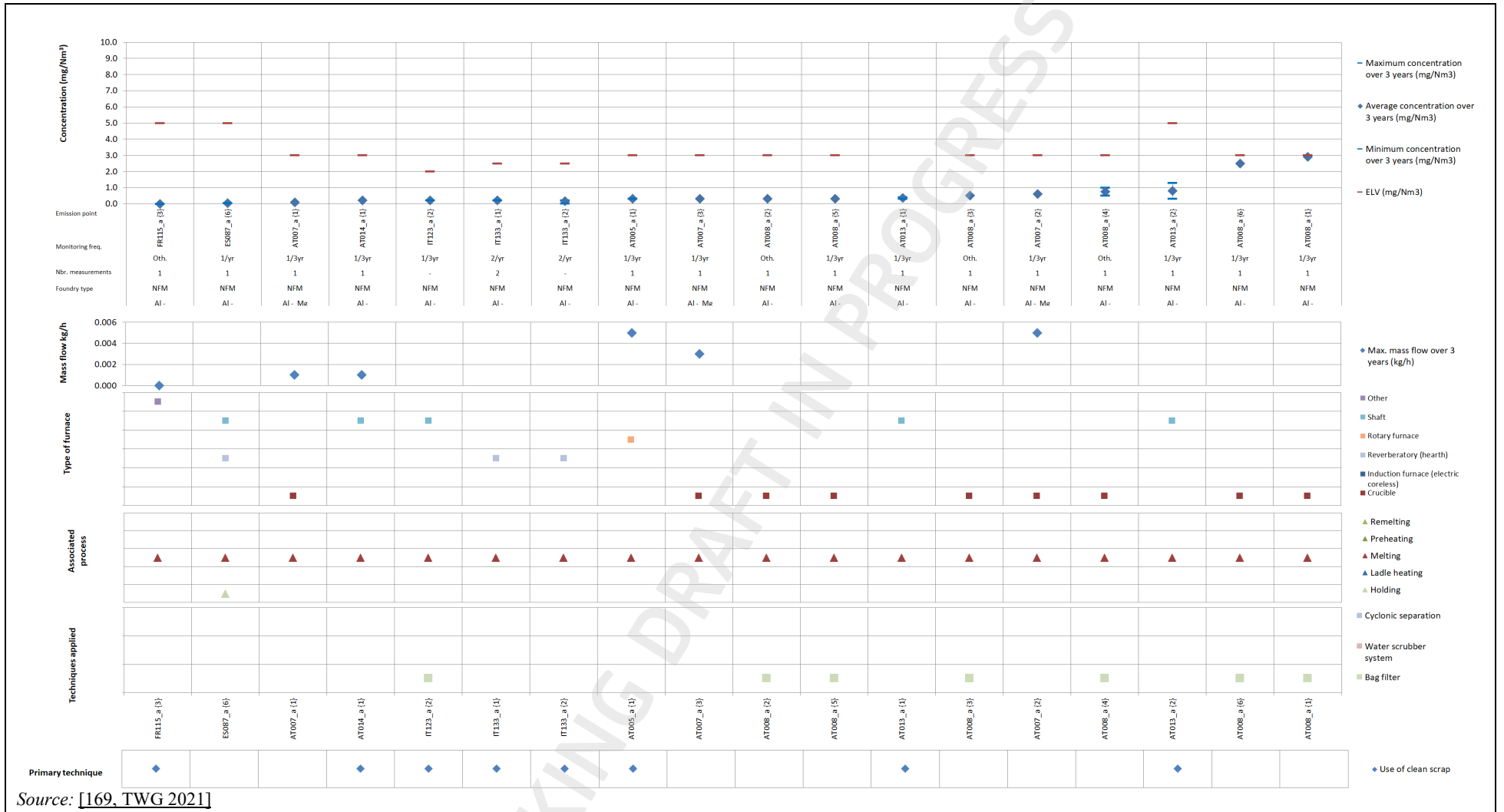


Figure 2.81: HF emissions to air from metal melting in NFM foundries

2.3.2.2 Heat treatment

In the following sections, emission data for the heat treatment process are presented.

2.3.2.2.1 Dust emissions

The reported levels of dust emissions to air from heat treatment are presented in the following table.

Table 2.42: Dust emission data for heat treatment

Emission point	Associated process	Fuel type	Minimum concentration	Average concentration over 3 years	Maximum concentration over 3 years	ELV-concentration	Combination of techniques	Monitoring frequency	Monitoring method	Total number of measurements conducted	Type of foundry
FR112/EP15	Furnace 3	Electric energy - Natural gas	0	0.2215	0.443	20	No technique used	1/yr	EN 13284-1	2	NFM – Al
DE065/EP18	Furnace 6	Natural gas	0.3	0.4	0.5	10	No technique used	1/3yr	EN 13284-1	3	NFM – Al
AT002/EP4	Furnace 9	Natural gas	0.6	0.6	0.6	10	No technique used	-	EN 13284-1	1	NFM – Al
DE065/EP7	Furnace 6	Natural gas	0.2	0.45	0.7	5	No technique used	1/3yr	EN 13284-1	6	NFM – Al
DE065/EP13	Furnace 5	Natural gas	0.2	0.45	0.7	10	Bag filter - thermal oxidiser	1/3yr	EN 13284-1	6	NFM – Al
AT006/EP5	Furnace 5, Furnace 6, Furnace 7, Furnace 8	Natural gas	1	1	1	10	No technique used	1/3yr	EN 13284-1	3	Cast iron foundries
ES086/EP13	Furnace 5	Natural gas	1.3	1.3	1.3	20	No technique used	-	EN 13284-1	1	NFM – Al
ES086/EP14	Furnace 5	Natural gas	1.3	1.3	1.3	20	No technique used	-	EN 13284-1	1	NFM – Al
ES086/EP15	Furnace 4	Natural gas	1.3	1.3	1.3	20	No technique used	-	EN 13284-1	1	NFM – Al
DE065/EP10	Furnace 5	Natural gas	0.2	0.65	2.4	10	Bag filter	1/3yr	EN 13284-1	6	NFM – Al
FR112/EP19	Furnace 6	Electric energy - Natural gas	1.5	2.27	3.04	20	No technique used	1/yr	EN 13284-1	2	NFM – Al
DE065/EP11	Furnace 5	Natural gas	0.2	2.15	5.4	10	Bag filter	1/3yr	EN 13284-1	6	NFM – Al
DE065/EP14	Furnace 5	Natural gas	1.6	4.3	10	10	Bag filter - thermal oxidiser	1/3yr	EN 13284-1	9	NFM – Al

2.3.2.2.2 NO_x emissions

The reported levels of NO_x emissions to air from heat treatment are presented in the following table.

Table 2.43: NO_x emission data for heat treatment

Emission point	Associated process	Fuel type	Minimum concentration over 3 years	Average concentration over 3 years	Maximum concentration over 3 years	ELV-concentration	Maximum mass flow over 3 years (kg/h)	ELV-mass flow (g/h)	Combination of techniques	Monitoring frequency	Monitoring method	Total number of measurements reported	Type of foundry
FR112/EP15	Furnace 3	Electric energy - Natural gas	0	0.515	1.03	120	0.16	0.09	No technique used	1/yr	EN 14792	2	NFM – Al
ES093/EP6	Furnace 6	Natural gas	10.3	10.3	10.3	300	-	-	No technique used	Other	EN 14792	2	NFM – Al
ES086/EP13	Furnace 5	Natural gas	16.13	16.13	16.13	615	-	-	No technique used	Other	EN 14792	1	NFM – Al
DE065/EP7	Furnace 6	Natural gas	1	8.05	17.4	80	-	-	No technique used	1/3yr	EN 14792	0	NFM – Al
ES086/EP14	Furnace 5	Natural gas	24	24	24	615	-	-	No technique used	Other	EN 14792	1	NFM – Al
ES086/EP15	Furnace 4	Natural gas	24	24	24	615	-	-	No technique used	Other	EN 14792	1	NFM – Al
DE065/EP12	Furnace 5	Natural gas	4.7	13.6	26.5	100	-	-	No technique used	1/3yr	EN 14792	6	NFM – Al
DE065/EP18	Furnace 6	Natural gas	11	19.2	27.8	200	-	-	No technique used	1/3yr	EN 14792	9	NFM – Al
ES092/EP2	Furnace 2	Electric energy - Natural gas	28.7	32.9	37.1	300	-	-	No technique used	Other	EN 14792	2	NFM – Al
FR112/EP19	Furnace 6	Electric energy - Natural gas	10.8	25.5	40.2	120	0.0303	0.09	No technique used	1/yr	EN 14792	2	NFM – Al
DE065/EP13	Furnace 5	Natural gas	37.9	40.4	45	100	-	-	Bag filter - thermal oxidiser	1/3yr	EN 14792	6	NFM – Al
ES092/EP4	Furnace 4	Electric energy - Natural gas	20.5	54.35	88.2	300	-	-	No technique used	Other	EN 14792	2	NFM – Al
ES093/EP7	Furnace 7	Natural gas	89.4	89.4	89.4	300	-	-	No technique used	Other	EN 14792	1	NFM – Al
DE065/EP14	Furnace 5	Natural gas	84.5	95.87	104	250	-	-	Bag filter - thermal oxidiser	1/3yr	EN 14792	9	NFM – Al
AT006/EP5	Furnace 5, Furnace 6, Furnace 7, Furnace 8	Natural gas	259	263	268	-	-	-	No technique used	1/3yr	EN 14792	3	Cast iron foundries
AT002/EP4	Furnace 9	Natural gas	289	292	295	350	-	-	No technique used	1/3yr	EN 14792	1	NFM – Al

2.3.2.2.3 CO emissions

The reported levels of CO emissions to air from heat treatment are presented in the following table.

Table 2.44: CO emission data for heat treatment

Emission point	Associated process	Fuel type	Minimum concentration over 3 years	Average concentration over 3 years	Maximum concentration over 3 years	ELY-concentration	Combination of techniques	Monitoring frequency	Monitoring method	Total number of measurements	Type of foundry
DE065/EP7	Furnace 6	Natural gas	1.7	2.15	2.8	80	No technique used	1/3yr	EN 15058	0	NFM – AI
DE065/EP12	Furnace 5	Natural gas	1.3	1.85	3.4	100	No technique used	1/3yr	EN 15058	6	NFM – AI
FR112/EP15	Furnace 3	Electric energy - Natural gas	0	5.35	10.7	-	No technique used	1/yr	EN 15058	2	NFM – AI
DE065/EP13	Furnace 5	Natural gas	9.5	11.25	12.6	80	Bag filter, thermal oxidizer	1/3yr	EN 15058	6	NFM – AI
ES086/EP13	Furnace 5	Natural gas	17.23	17.23	17.23	625	No technique used	Other	EN 15058	1	NFM – AI
ES086/EP14	Furnace 5	Natural gas	22.2	22.2	22.2	625	No technique used	Other	EN 15058	1	NFM – AI
ES093/EP6	Furnace 6	Natural gas	10.3	18.3	26.3	100	No technique used	Other	EN 15058	2	NFM – AI
DE065/EP14	Furnace 5	Natural gas	7.8	19.47	26.6	80	Bag filter, thermal oxidiser	1/3yr	EN 15058	9	NFM – AI
ES093/EP7	Furnace 7	Natural gas	34.55	34.55	34.55	100	No technique used	Other	EN 15058	1	NFM – AI
ES086/EP15	Furnace 4	Natural gas	47.03	47.03	47.03	625	No technique used	Other	EN 15058	1	NFM – AI
ES092/EP4	Furnace 4	Electric energy - Natural gas	3.8	26.3	48.8	100	No technique used	Other	EN 15058	2	NFM – AI
ES092/EP2	Furnace 2	Electric energy - Natural gas	83.8	83.9	84	100	No technique used	Other	EN 15058	2	NFM – AI
DE065/EP18	Furnace 6	Natural gas	70.9	85.27	96.6	100	No technique used	1/3yr	EN 15058	9	NFM – AI
FR112/EP19	Furnace 6	Electric energy - Natural gas	369	369	369	-	No technique used	1/yr	EN 15058	1	NFM – AI

2.3.2.3 Nodularisation of cast iron

In the nodularisation of cast iron, significant amounts of magnesium oxide may be generated depending on the nodularisation method employed. The efficiency, the qualitative assessment of flue-gas generation and the complexity of the various nodularisation methods are compared in Table 2.45.

Table 2.45: Comparison of various nodularisation procedures

	Sandwich	Tundish cover	Plunging	Flow through	Wire injection	Inmold	Ductilator
Mg- take-up efficiency (%)	35 – 50	45 – 60	40 – 60	40 – 50	20 – 50	70 – 90	60 – 75
Flue-gas generation	High	Low	Low	Low	Low	No	High
Comment	Easy operation	Optimised sandwich but more maintenance	High maintenance	High maintenance	Expensive installation	Different design of pouring system	High maintenance
<i>Source: [38, Vito 2001], [120, TWG 2003]</i>							

The list of plants which reported applying nodularisation is presented in the following table.

Table 2.46: List of plants reported nodularisation

Applied process for nodularisation	Number of plants	Plant codes
Ductilator method	1	AT004.
Core wire injection	20	AT017, IT132, PL138, AT018, BE022, BE023, CZ156, DE028, DE032, DE042, DE045, DE051, DE056, DE074, ES100, FR106, FR110, IT071, IT124, PL135.
G Fischer converter method	3	DE049, DE050, DE051.
Sandwich method	14	ES088, FI102, DE060, DE069, DK079, ES095, ES098, FR104, FR106, IT130, IT131, PL135, PT140, PT141.
Tundish Cover method	13	AT009, DE028, DE039, ES082, ES094, FR109, IT131, IT134, IT155, IT158, SE144, SE145, SE152.
Pour over technique	9	BE019, CZ026, CZ156, DE041, DE048, DE057, DE067, ES091, IT124.
Inmold process	5	BE021, DE028, DE069, FR106, IT126.
Plunging method	1	ES096.
Flow through treatment method	2	FR109, IT155.
NI	2	IT127, IT125.
<i>Source: [169, TWG 2021]</i>		

The reported levels of dust emissions to air from the nodularisation of cast iron are presented in Figure 2.82.

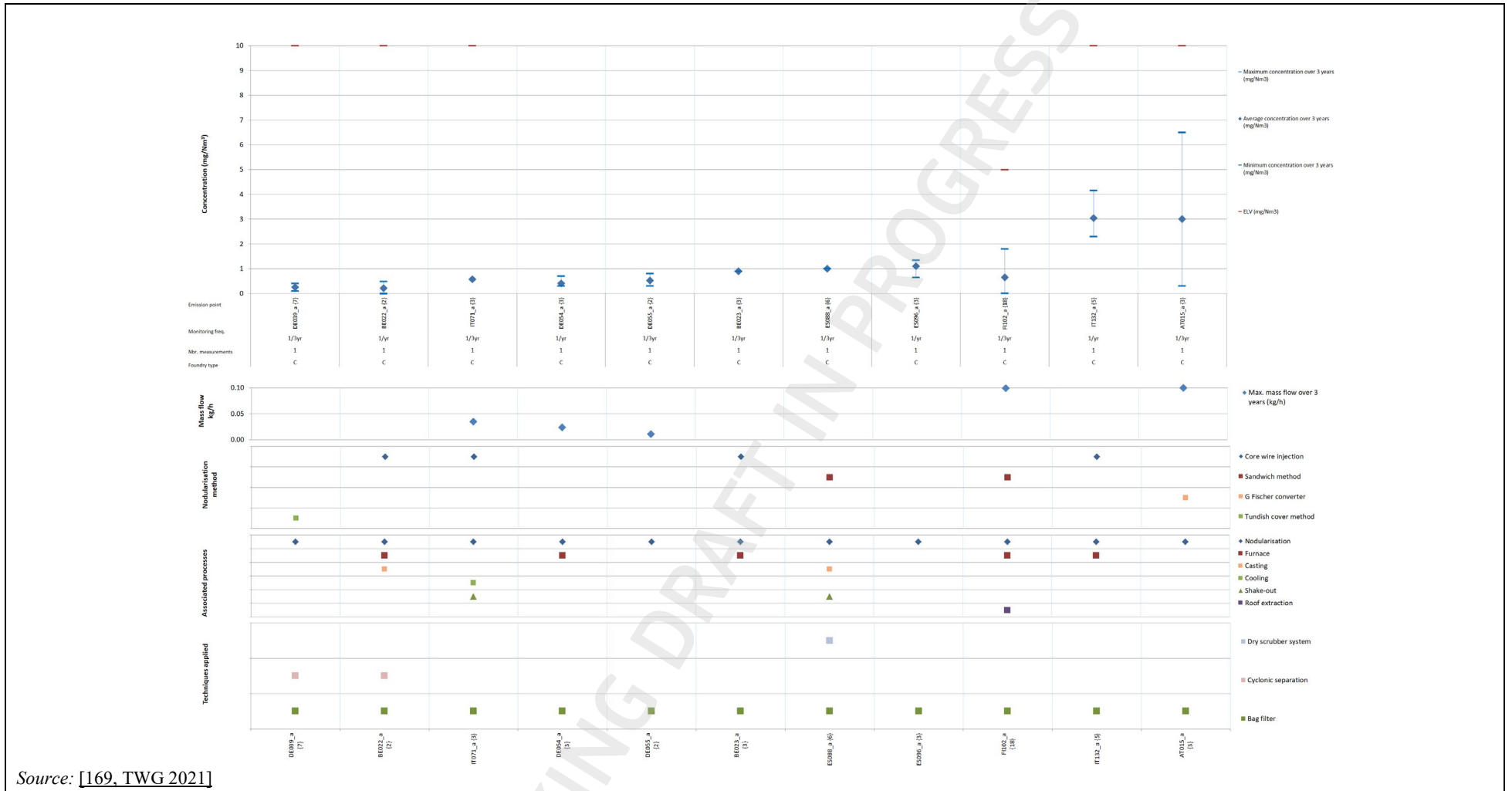


Figure 2.82: Dust emissions from nodularisation of cast iron

2.3.2.4 Steel refining

2.3.2.4.1 Argon Oxygen Decarburisation (AOD) converter

The inputs/outputs for the AOD converter are summarised in the following table.

Input	Output
- Molten steel	◦ Decarburised steel
- Alloying metals (ferro-alloys)	◦ Metal oxide dust and fumes (Fe,Mn,Cr,Ni)
- Al, fesi, lime	◦ Gases (CO ₂ , CO, inert gases)
- O ₂ , N ₂ , Ar	◦ Slag (CaO, SiO ₂ , AlO ₃)

2.3.2.4.1.1 Input

The AOD converter is used mainly in the production of low-carbon stainless steels and, in special cases, carbon and low-alloy steels: to remove impurities such as carbon, sulphur and oxides and also to decarburise high-chromium stainless steels. The processed material is liquid steel that has been melted in EAFs or in induction furnaces and afterwards poured off into the vessel through ladles. The technique is most common in the steel industry, but it is also applied in foundries, although to only a limited extent. For decarburisation, oxygen is injected in the converter and oxidises carbon into CO gas, which escapes from the liquid metal. No energy source is used except for the energy from the combustion reaction between oxygen and carbon during oxidation and, afterwards, between oxygen and aluminium (and/or silicon) during reduction.

The consumption of carbon ranges from 0.4 % to 1 %, being about 50 – 120 m³ of CO per tonne of steel and 25 – 60 m³ oxygen. To eliminate sulphur it is necessary to use a high-basicity slag in a completely reduced liquid steel. Reduction materials, such as aluminium or silicon, and lime are charged in the AOD converter. The consumption levels depend on the quality of the steel grade and are given in Table 2.47.

Table 2.47: Consumption levels for the AOD treatment of steel

Compound	Consumption (per tonne of steel)
CO	50 – 120 m ³
O ₂	25 – 60 m ³
Al	1 – 2.5 kg
Lime	10 – 20 kg
Si	1 – 2 kg
Ar	1 – 5 m ³
<i>Source: [100, TWG 2002]</i>	

2.3.2.4.1.2 Emissions

Dust emissions are comparable to EAFs' dust emissions, both in quantity and quality. AOD dust emissions have lower levels of residuals (organic) from the scrap charge, but on the other hand have a higher level of metal oxide (Cr, Ni), as it is mainly stainless steel which is processed in AOD vessels.

The exhaust gases of an AOD consist of carbon monoxide and inert gas. The rate of carbon monoxide evolution depends on the tuyères' oxygen injection rate and the oxygen efficiency, or per cent of oxygen which reacts with carbon. This oxygen efficiency, or 'carbon removal efficiency', as it is traditionally labelled in AOD operation, varies during the course of an AOD blow, in response to combined variables of the bath carbon level, temperature, bath chemistry, and the mixture of injected gases.

The CO and inert gas mixture leaves the vessel approximately at the bath temperature. The CO mixture exiting the vessel is mixed with excess air in order to fully burn the CO to CO₂ very early in the exhaust duct. This is done to prevent the presence of combustible or explosive mixtures persisting downstream into the duct to the filter equipment.

In addition, the generated slag is particularly ‘clean’ from metal oxides, since, due to the peculiarity of the process, they are usually consumed. The slag composition is given in Table 2.48.

Table 2.48: AOD slag composition

Compound	%
CaO	50 – 70
Al ₂ O ₃	5 – 25
SiO ₂	10 – 25
MgO	5 – 15
<i>Source: [100, TWG 2002]</i>	

Two plants (AT017 and FR104) reported the use of AOD for steel refining. The reported dust emissions are presented in the following table.

Table 2.49: Reported dust emissions from the AOD converter

Plant/ Emission point (EP)	Associated process	Applied dust abatement technique	Reported dust emission levels (mg/Nm ³)
FR104/EP2	AOD converter	Fabric filter	2.3 – 2.6
<i>Source: [169, TWG 2021]</i>			

2.3.2.4.2 Vacuum Oxygen Decarburisation Converter (VODC)

The VODC process involves decarburisation under reduced pressure. It is much less used than the AOD process. The technique consumes 1 Nm³ Ar per tonne of steel, shows low chromium oxidation and has a silicon consumption of 3 – 5 kg/tonne. The VODC allows the production of ultra-low-carbon and nitrogen grades. [100, TWG 2002]

The use of VODC was reported by two plants (DE068 and FR103). The reported dust emissions are presented in the following table.

Table 2.50: Reported dust emissions from the VODC

Plant/ Emission point (EP)	Associated processes	Applied dust abatement technique	Reported dust emission levels (mg/Nm ³)
FR103/EP6	Electric arc furnaces A and D, induction furnace KJ, VODC, ladle heatings	Fabric filter	0.02 – 0.05
<i>Source: [169, TWG 2021]</i>			

2.3.2.4.3 Steel deoxidation

For deoxidation, aluminium is commonly used in the form of a stick. Additions vary from 0.1 % for medium-carbon steel to 0.2 % for low-carbon steel. Recovery is between 35 % and 80 %. Mechanical feeding of aluminium wire is also used. [73, Brown, J. R. 2000].

Six plants in the SF data collection reported the use of deoxidation: BE019, DE044, PL135, PT140 and SE146. [169, TWG 2021]

2.3.2.5 Aluminium melt treatment

For the combination of degassing and cleaning in an impeller station, a mixture of argon or nitrogen with 3 % Cl₂ is generally used. For degassing alone, the gases Ar or N₂ are generally used without Cl₂. The applied flow and degassing time depend on the type of alloy used and the size of the treatment vessel. The consumption of modification agents, grain refiners and fluxes depends on the type of alloy, but is generally in the order of 100 g to 1 kg per 50 kg of molten metal.

For aluminium melting, the information reported during the SF BREF data collection is as follows [169, TWG 2021]:

- DE066/EP1: This plant reported Cl₂ emissions < 0.1 mg/Nm³ using pure N₂ (in the form of tablets or gas) as a degassing agent. No Cl₂ use was reported.
- PT143 (EPs 1, 3 and 6): This plant reported using fluoride-based degassing agents (no Cl₂ use). For EP3, Cl₂ emissions were < 0.1 mg/Nm³. For EP1, Cl₂ emissions were < 0.1 mg/Nm³ in 2018 and 2019, but emissions of 2 mg/Nm³ were reported in 2013. For EP6, Cl₂ emissions were < 0.1 mg/Nm³ in 2018 and 2019, but emissions of 11 mg/Nm³ were reported in 2017.
- PT142 (EPs 1 to 5): This plant reported Cl₂ emissions typically within the range of < 0.1 mg/Nm³ to 0.6 mg/Nm³ using pure N₂ (in the form of tablets or gas) as a degassing agent. No Cl₂ use was reported.

Based on these data, it appears that plants which reported chlorine emissions data did not actually report the use of chlorine as a degassing agent. For some of the relatively high values which were reported (by Plant PT143), it is thought that these emissions may be linked to the use of Cl₂ in the past (e.g. PT143/EP1 – 2013) or from occasional use (PT143/EP6). For these plants, the requirement to monitor Cl₂ may be an old requirement in the permit of these installations: some of these foundries are actually not using chlorine anymore but may still continue monitoring. The general consensus in the Technical Working Group is that chlorine gas is not used in foundries as a degassing agent anymore.

2.3.2.6 Pattern-making

In the data collection, 11 plants (10 cast iron foundries: AT006, AT012, FR104, DK079, DE060, IT130, IT157, SE145, IT127, SE153) and 1 steel foundry: AT016) reported emissions from pattern-making (sometimes including the painting of the pattern – see Plant IT 130).

All plants reported the use of fabric filters, except one (IT130). All plants reported dust emissions, only one plant reported emissions of formaldehyde (IT157), and two plants reported TVOC emissions (AT006, IT130). For dust, all the plants that reported a dedicated emission point for pattern-making reported very low emissions within the range of 0.3 – 3.5 mg/Nm³. The TVOC emissions reported ranged from 3.9 mg/Nm³ to 4.6 mg/Nm³ and the formaldehyde emissions were all below 0.2 mg/Nm³.

2.3.2.7 Moulding using lost moulds and core-making

Mould and core production involves mixing sand with various chemicals, in some cases followed by a heating step. Gaseous or volatile reaction-products and excess reagents are emitted. Table 2.51 presents a survey of the emissions and other environmental impacts during the mixing, setting and storage of the moulds and cores.

Table 2.51: Environmental impact from binder systems

System name and binder constituents	Setting method and relative energy requirement	Emissions to air during mixing and setting	Other environmental impacts
GREEN SAND Clay Coal dust or substitute Water	Pressure – low	Particulate matter – no significant emission to the environment	Sand spillage around conveyors needs to be avoided to reduce the likelihood of fugitive emissions. Abatement from the mixing process is not essential (the process is usually self-contained with displaced air vented to the foundry)
SHELL SAND Phenol - formaldehyde (Novalak) Resin	Heat - high	Formaldehyde* Ammonia* Phenol* Aromatics HCN	Odour can be an issue as the shell machines are normally extracted to air
ALKALINE PHENOLIC Resol - Alkaline phenol-formaldehyde resin 1. Gas hardened (alkaline phenolic cold-box) 2. Self-setting (alkaline phenolic no-bake)	Gas hardened with methyl formate vapour – low Cold-set with esters - low	Formaldehyde* Phenol* Methyl formate Formaldehyde* Phenol* Esters	
PHENOLIC URETHANE 1. Gas hardened: Cold-box 2. Self-setting (phenolic urethane no-bake)	Amine vapour – low Self-set with substituted pyridine – low	Isocyanate (MDI) Amine* Formaldehyde* Phenol Isocyanates (MDI) Formaldehyde* Phenol	Odour is frequently a problem – where DMEA is used odours arise and abatement is essential. This may be incineration or gas scrubbing (using sulphuric or phosphoric acids) – the latter gives rise to liquors, which are a special waste. Where TEA is used scrubbing is only required if odour problems arise
FURAN Combination resins of: Phenol Urea Furfuryl alcohol Formaldehyde	Cold-set with acids – low	Formaldehyde* Phenol* Furfuryl alcohol* Hydrogen sulphide Acid mists	Resins and acids must be kept apart (unless sand is present) as they are vigorously exothermic when in contact
HOT-BOX Combination resins of: Phenol Urea Furfuryl alcohol Formaldehyde	Heat – high	Formaldehyde* Acids Furfuryl alcohol* Phenol* Ammonia Isocyanic acid Methyl isocyanate	Odour can be an issue as the shell machines are normally extracted to air
OIL SAND Linseed oil and starch	Heat – high	Acrolein* Complex organics	Odour can be an issue as the core ovens are often extracted to air

System name and binder constituents	Setting method and relative energy requirement	Emissions to air during mixing and setting	Other environmental impacts
CO₂ PROCESS Sodium silicate	Gas hardened with CO ₂ gas – low	None	
SILICATE ESTER Sodium silicate	Cold-set with esters – low	Esters	

Note 1: All the above processes give rise to spent sand (including broken cores, spillage and mixer residues) that may go to landfill.
Note 2: Substances marked with * are those most likely to give rise to odour from the process referred to.
Note 3: Any resin binder component would be regarded as special waste for disposal purposes and if spilled could give rise to a risk of contamination of water systems.
Note 4: Amines and methyl formates used for gas hardening are highly flammable and odorous. The avoidance of leaks in storage is essential.
Source: [41, Teknologisk 2000], [62, UK Environment Agency 2002], [120, TWG 2003], [124, Lilja et al. 2000]

2.3.2.7.1 Dust emissions

The reported levels of dust emissions to air from core-making and moulding using lost moulds are presented in Figure 2.83, Figure 2.84 and Figure 2.85.

Some statistical data on the reported dust emission data are presented in the following table.

Table 2.52: Statistical evaluation of the reported dust emission data

Parameter/ process	Number of data	Number of EPs	Number of plants	90 th percentile	Average	Median	10 th percentile
				mg/Nm ³			
Moulding	137	60	29	8.34	3.37	1.83	0.22
Core-making	128	56	31	6.62	1.96	1.06	0.33

NB: The data above refer to EPs that are associated with only one process, either moulding or core-making.
Source: [169, TWG 2021]

2.3.2.7.2 Amines emissions

The reported levels of amines emissions to air from core-making are presented in Figure 2.86.

Some statistical data on the reported amines emission data are presented in the following table.

Table 2.53: Statistical evaluation of the reported amines emission data

Parameter/ process	Number of data	Number of EPs	Number of plants	90 th percentile	Average	Median	10 th percentile
				mg/Nm ³			
Moulding	7	3	3	-	0.56	-	-
Core-making	88	45	24	2.06	0.79	0.39	0.04

NB: The data above refer to EPs that are associated with only one process, either moulding or core-making.
Source: [169, TWG 2021]

2.3.2.7.3 Formaldehyde emissions

The reported levels of formaldehyde emissions to air from core-making and moulding using lost moulds are presented in Figure 2.87, Figure 2.88 and Figure 2.89.

Some statistical data on the reported formaldehyde emission data are presented in the following table.

Table 2.54: Statistical evaluation of the reported formaldehyde emission data

Parameter/ process	Number of data	Number of EPs	Number of plants	90 th percentile	Average	Median	10 th percentile
				mg/Nm ³			
Moulding	28	12	8	2.80	0.83	0.16	0.04
Core-making	53	24	16	4.93	1.29	0.25	0.03

NB: The data above refer to EPs that are associated with only one process, either moulding or core-making.
Source: [169, TWG 2021]

2.3.2.7.4 Benzene emissions

The reported levels of benzene emissions to air from core-making and moulding using lost moulds are presented in Figure 2.90 and Figure 2.91.

Some statistical data on the reported benzene emission data are presented in the following table.

Table 2.55: Statistical evaluation of the reported benzene emission data

Parameter/ process	Number of data	Number of EPs	Number of plants	90 th percentile	Average	Median	10 th percentile
				mg/Nm ³			
Moulding	27	13	9	4.22	1.63	0.95	0.05
Core-making	16	8	6	0.20	0.11	0.11	0.01

NB: The data above refer to EPs that are associated with only one process, either moulding or core-making.
Source: [169, TWG 2021]

2.3.2.7.5 Phenol emissions

The reported levels of phenol emissions to air from core-making and moulding using lost moulds are presented in Figure 2.92, Figure 2.93 and Figure 2.94.

Some statistical data on the reported phenol emission data are presented in the following table.

Table 2.56: Statistical evaluation of the reported phenol emission data

Parameter/ process	Number of data	Number of EPs	Number of plants	90 th percentile	Average	Median	10 th percentile
				mg/Nm ³			
Moulding	32	12	8	5.17	1.80	0.86	0.05
Core-making	23	11	9	1.06	0.35	0.15	0.01

NB: The data above refer to EPs that are associated with only one process, either moulding or core-making.
Source: [169, TWG 2021]

2.3.2.7.6 TVOC emissions

The reported levels of TVOC emissions to air from core-making and moulding using lost moulds are presented in Figure 2.95, Figure 2.96 and Figure 2.97.

Some statistical data on reported TVOC emission data are presented in the following table.

Table 2.57: Statistical evaluation of the reported TVOC emission data

Parameter/ process	Number of data	Number of EPs	Number of plants	90 th percentile	Average	Median	10 th percentile
				mg/Nm ³			
Moulding	25	11	9	47.64	26.93	19.35	9.92
Core-making	67	29	12	297.42	108.81	56.00	11.96
NB: The data above refer to EPs that are associated with only one process, either moulding or core-making. Source: [169, TWG 2021]							

2.3.2.7.7 Figures for emissions to air

The structure of the figures presented in this section is explained in Section 2.3.2.1.10.

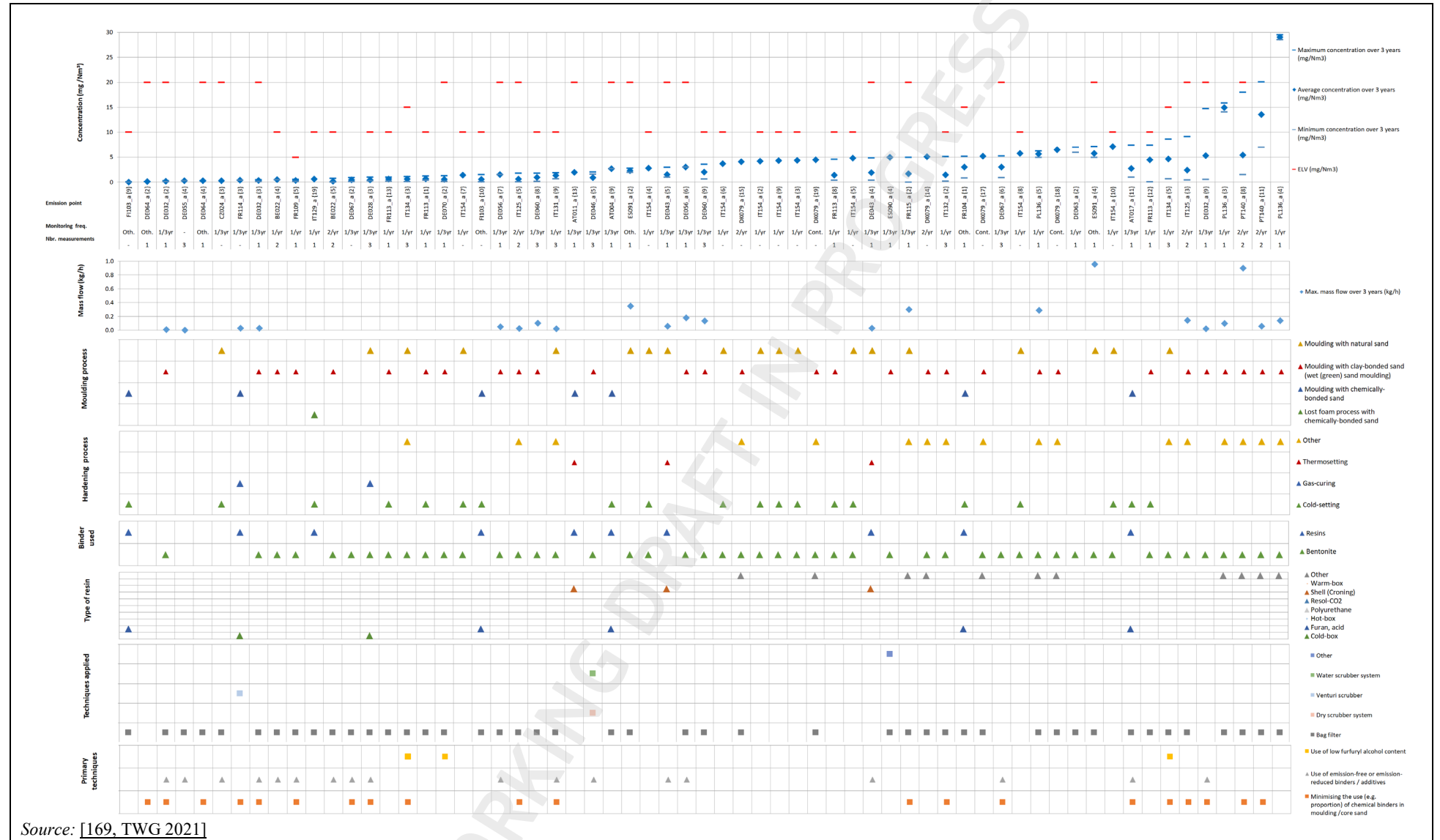
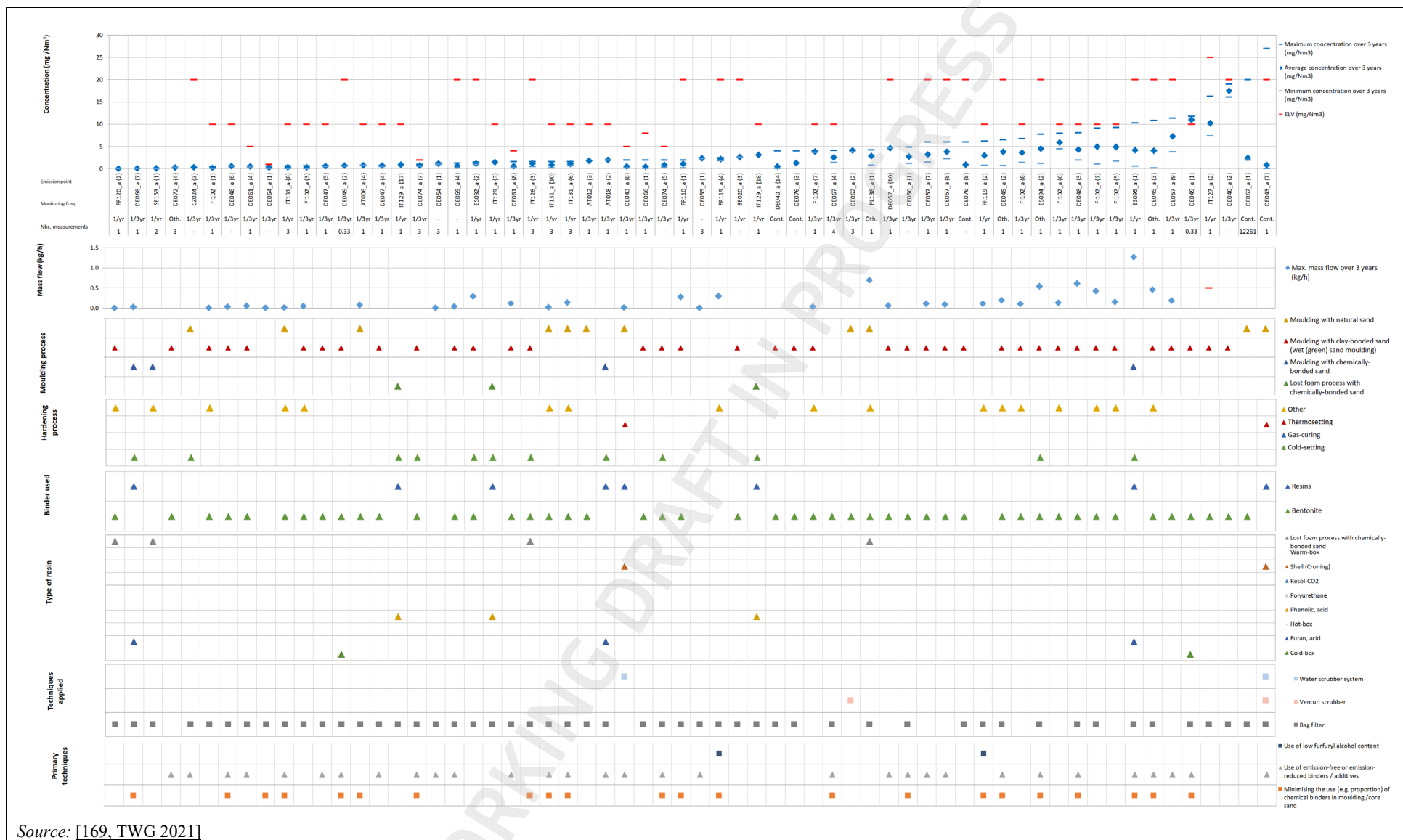


Figure 2.83: Dust emissions from moulding using lost moulds



Source: [169, TWG 2021]

Figure 2.84: Dust emissions from moulding using lost moulds and other processes

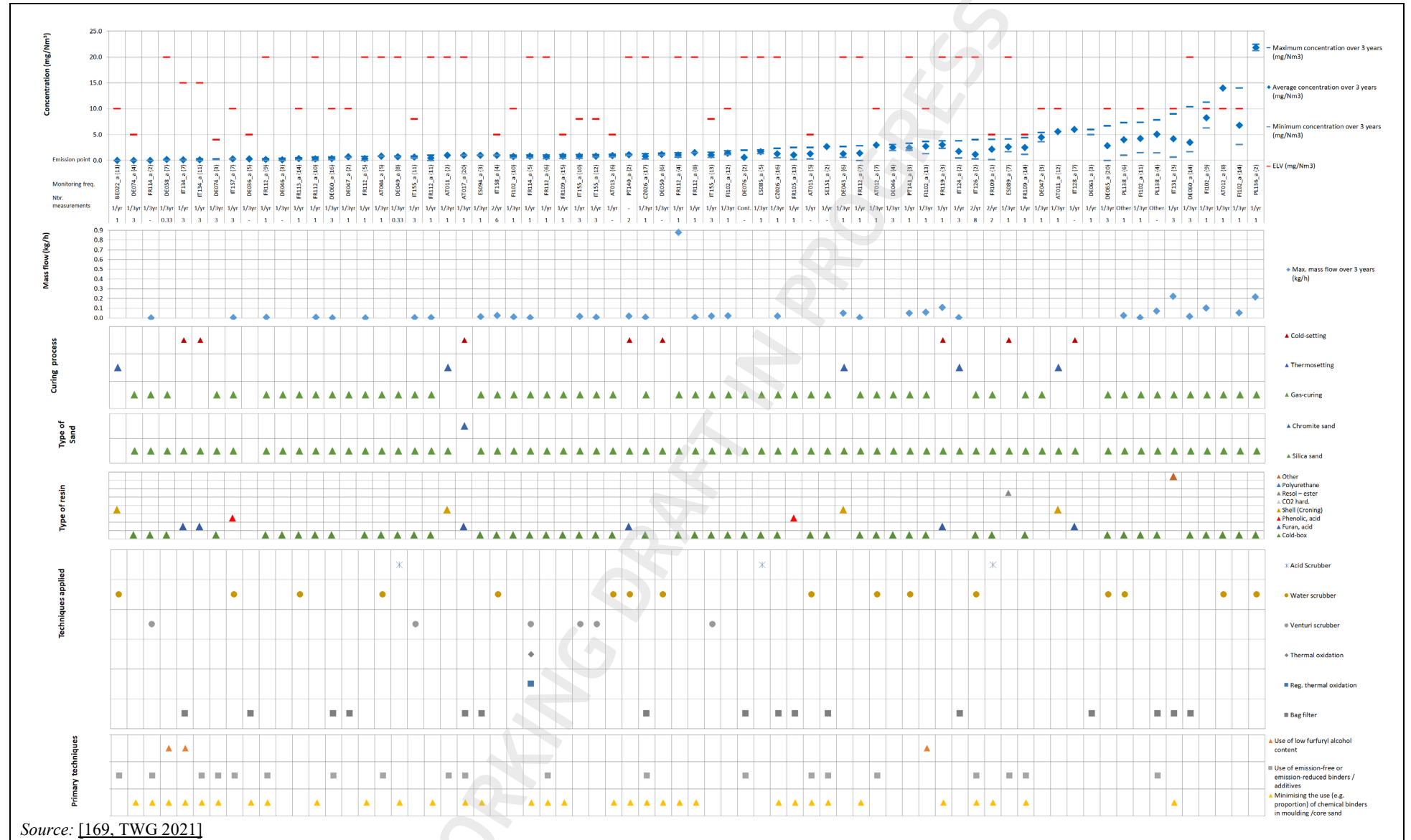


Figure 2.85: Dust emissions from core-making

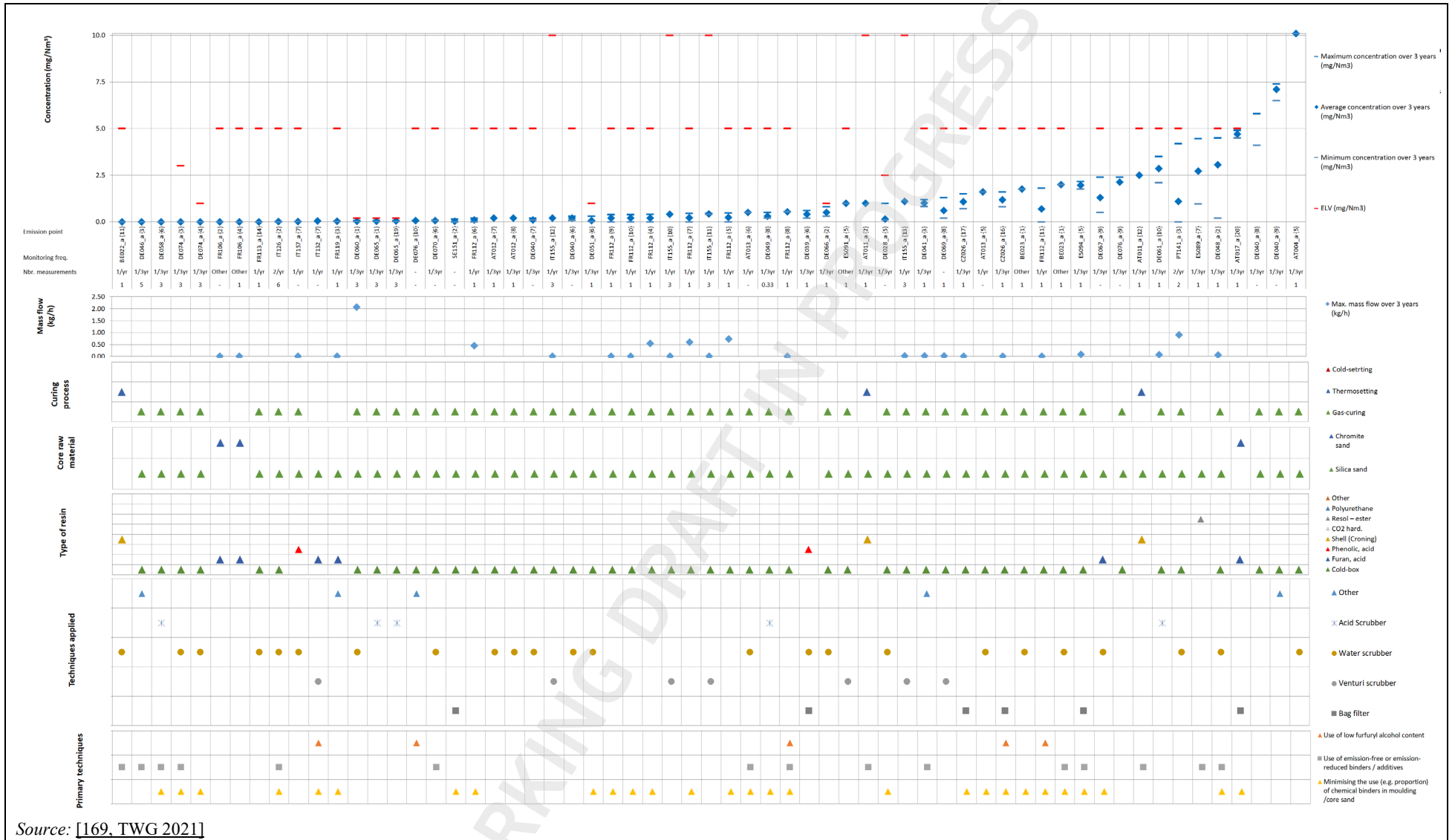


Figure 2.86: Amines emissions from core-making

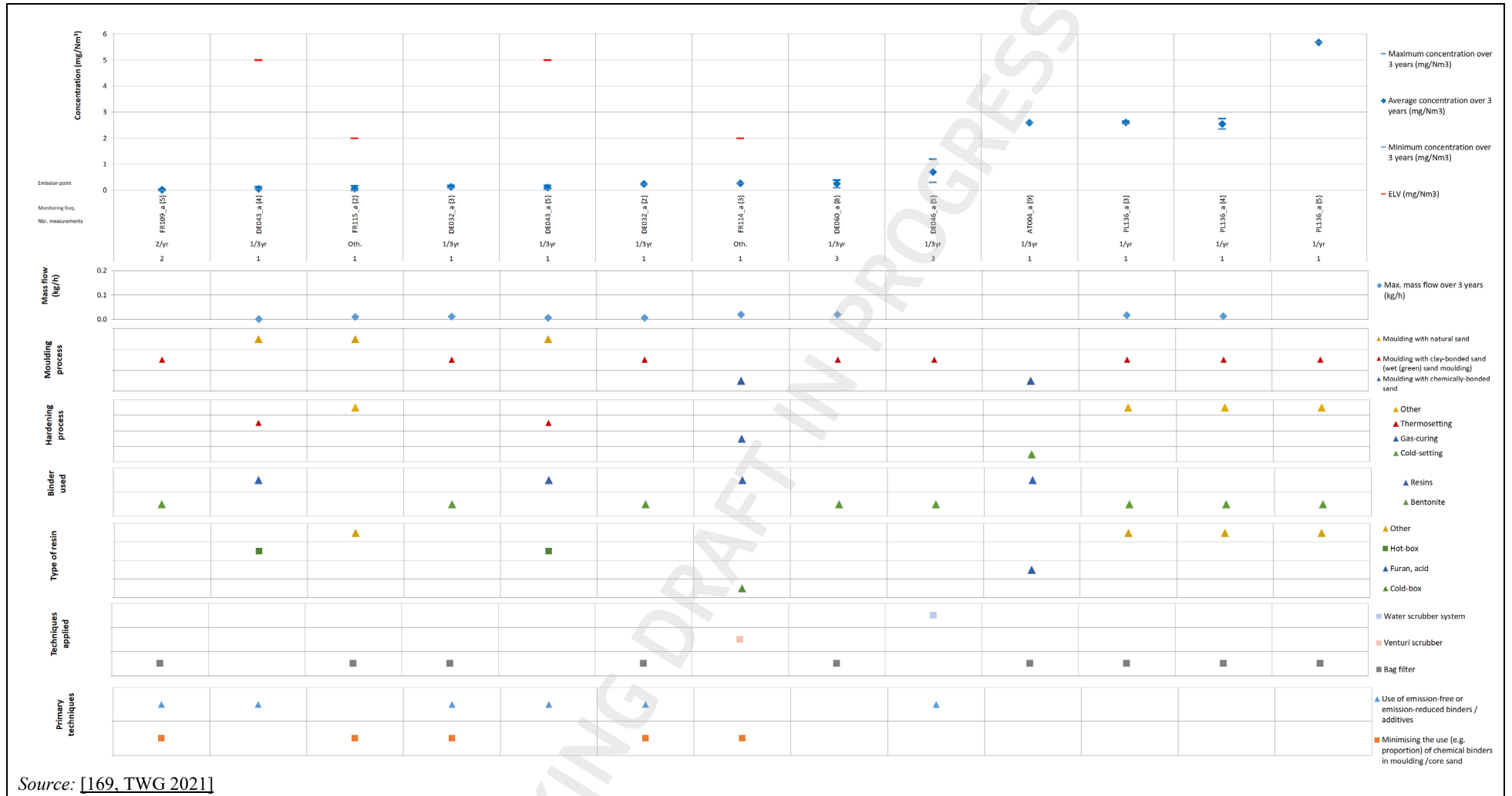


Figure 2.87: Formaldehyde emissions from moulding using lost moulds

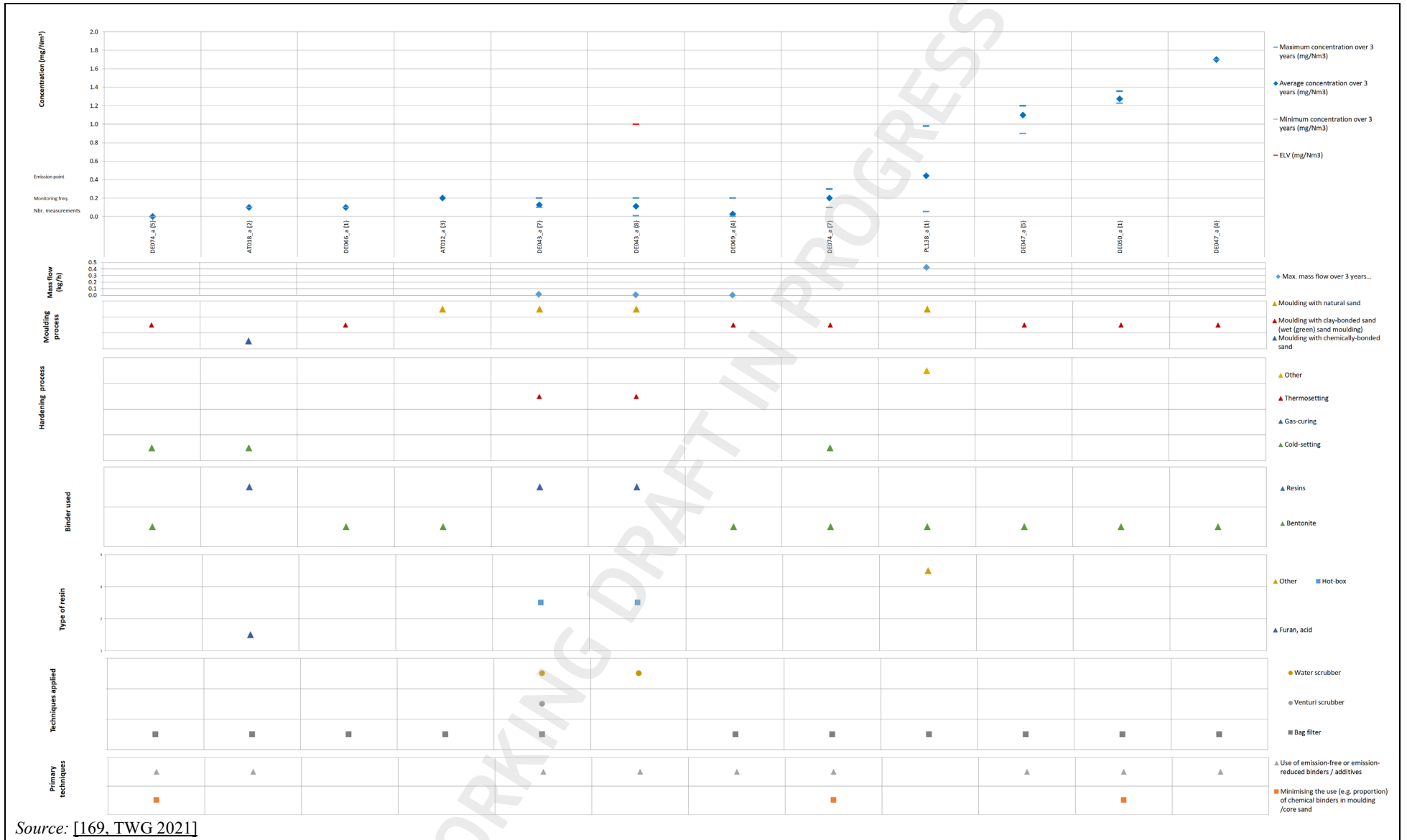


Figure 2.88: Formaldehyde emissions from moulding using lost moulds and other processes

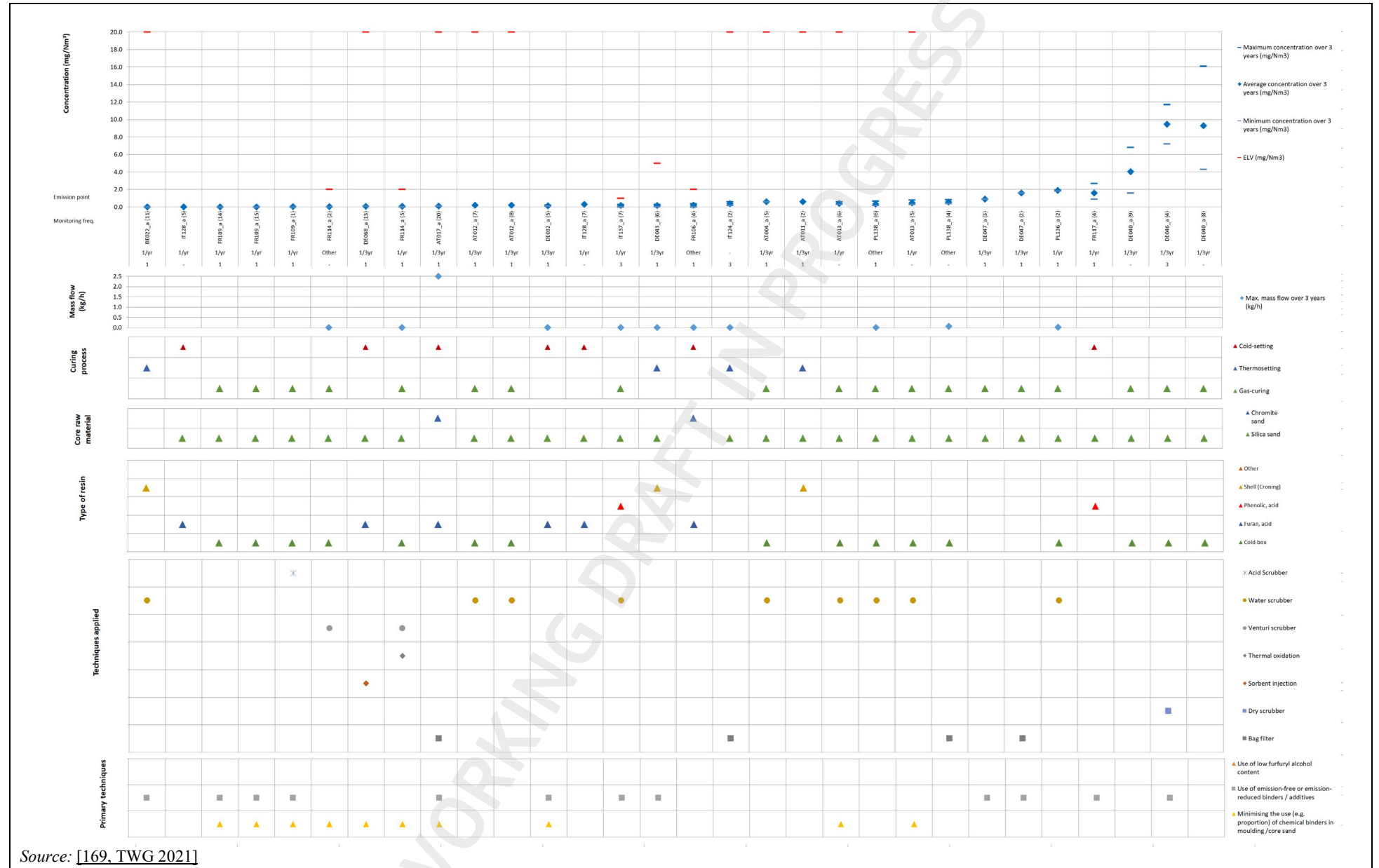


Figure 2.89: Formaldehyde emissions from core-making

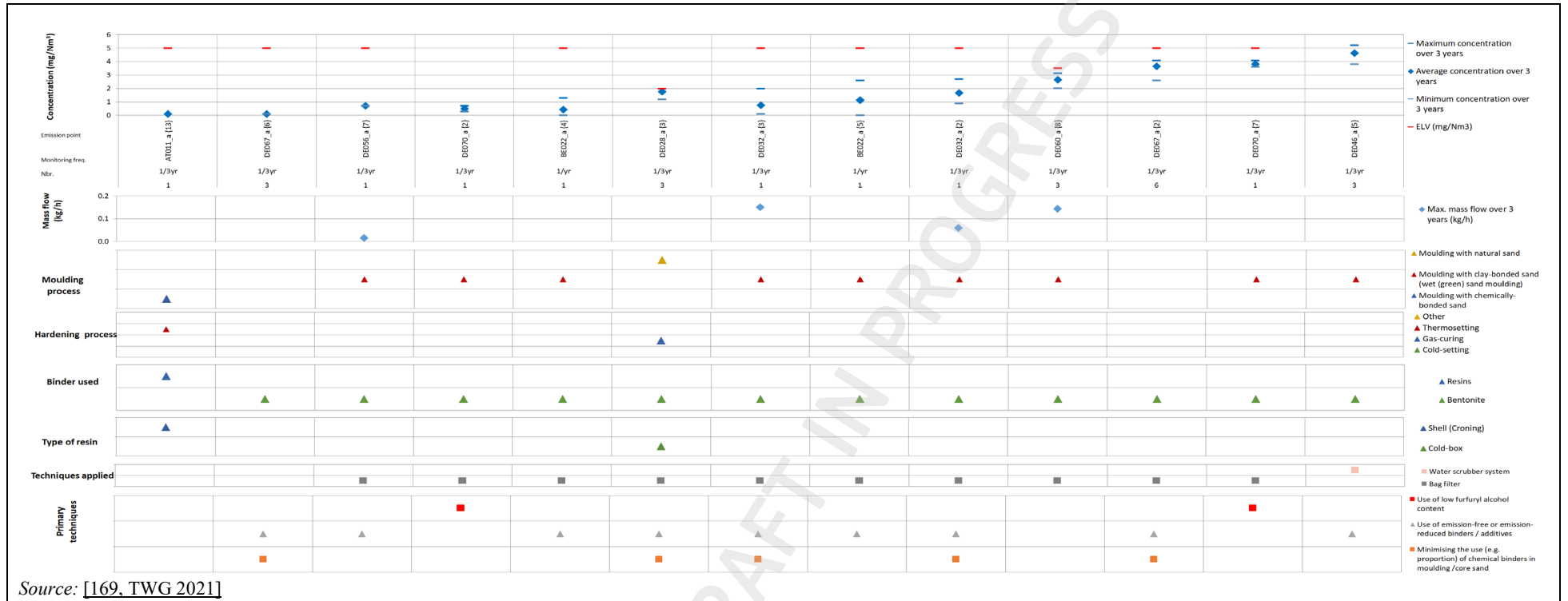


Figure 2.90: Benzene emissions from moulding using lost moulds

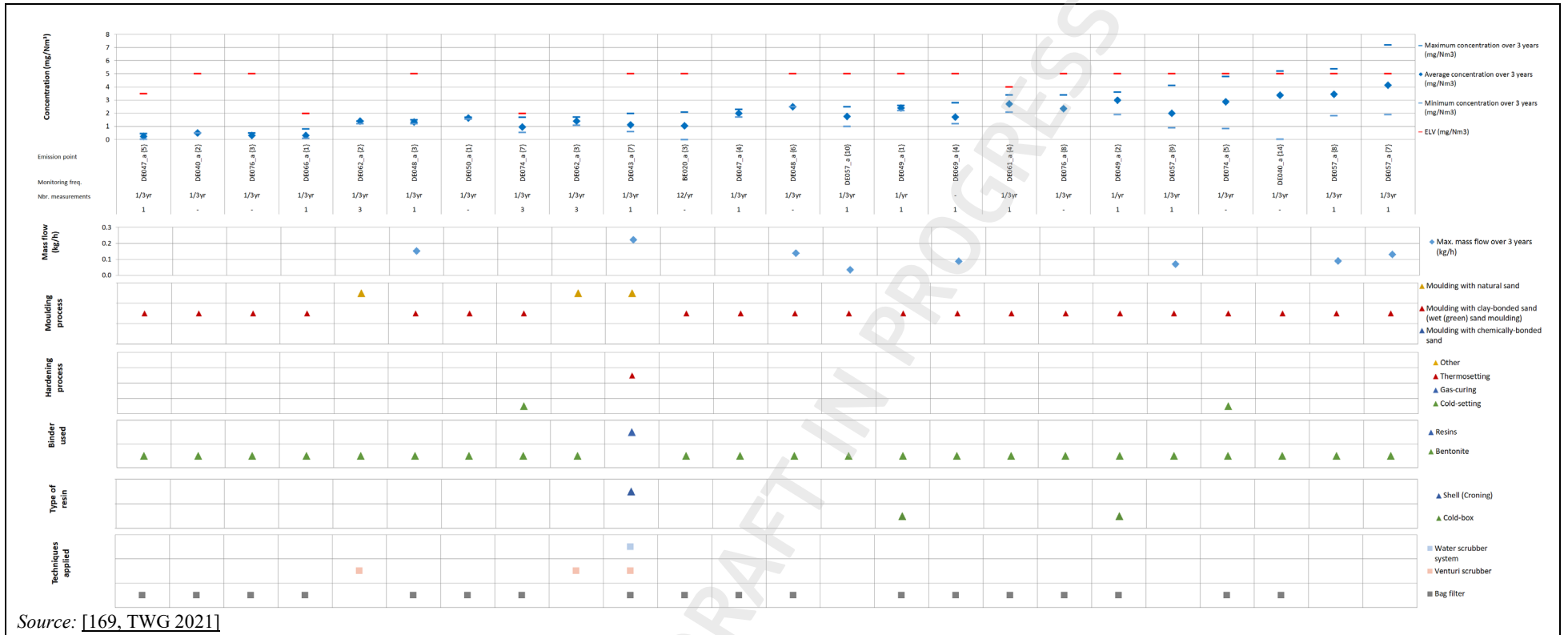


Figure 2.91: Benzene emissions from moulding using lost moulds and other processes

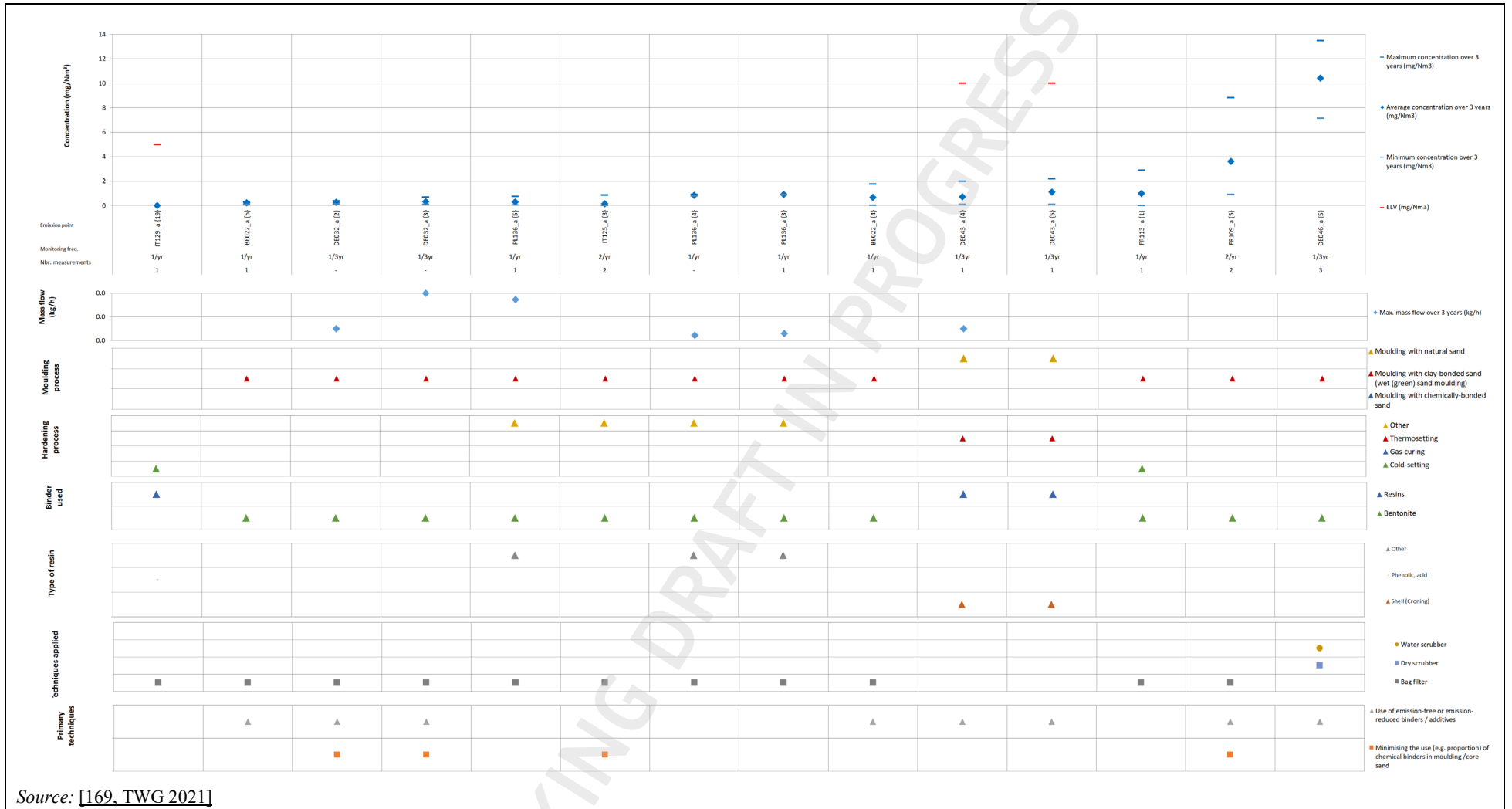


Figure 2.92: Phenol emissions from moulding using lost moulds

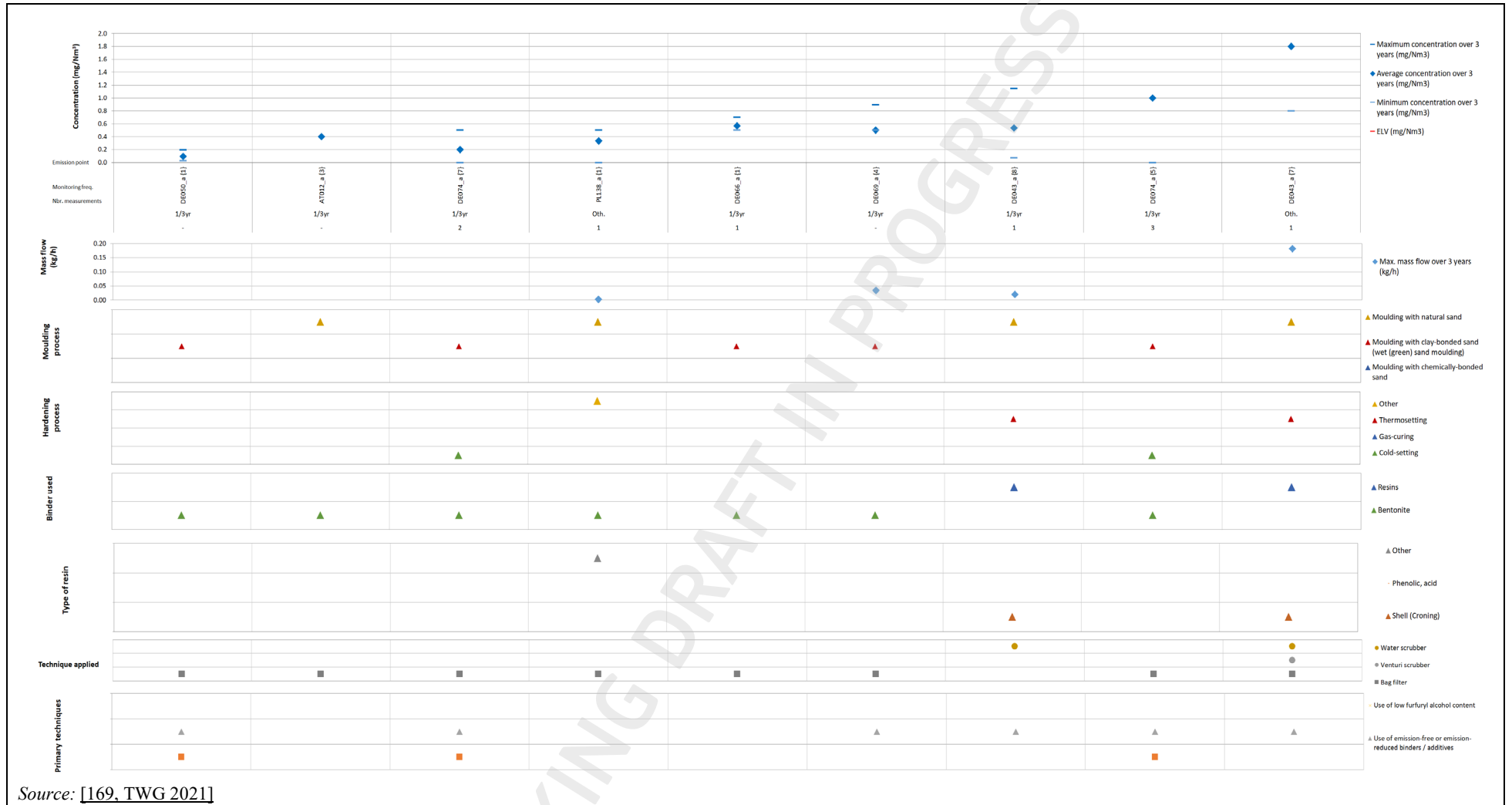


Figure 2.93: Phenol emissions from moulding using lost moulds and other processes

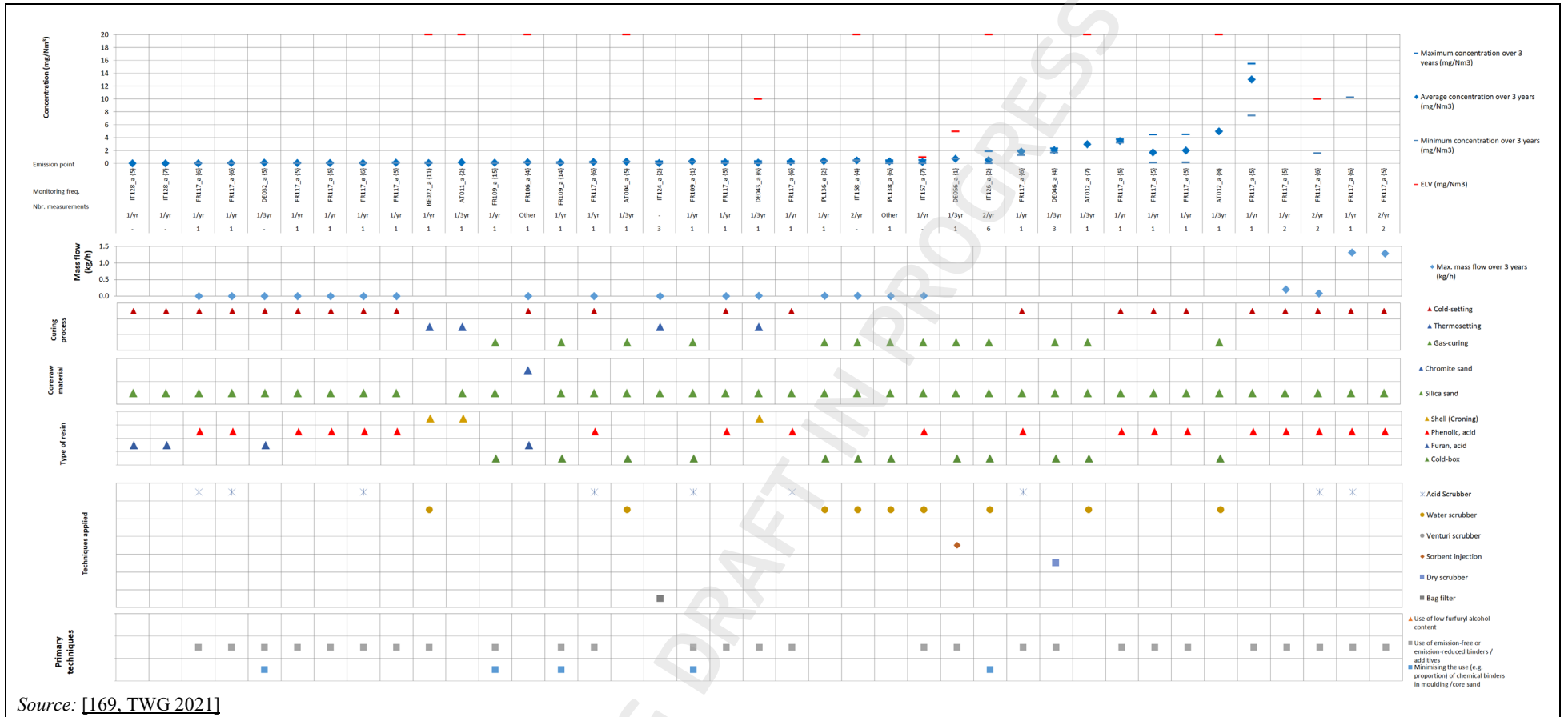


Figure 2.94: Phenol emissions from core-making

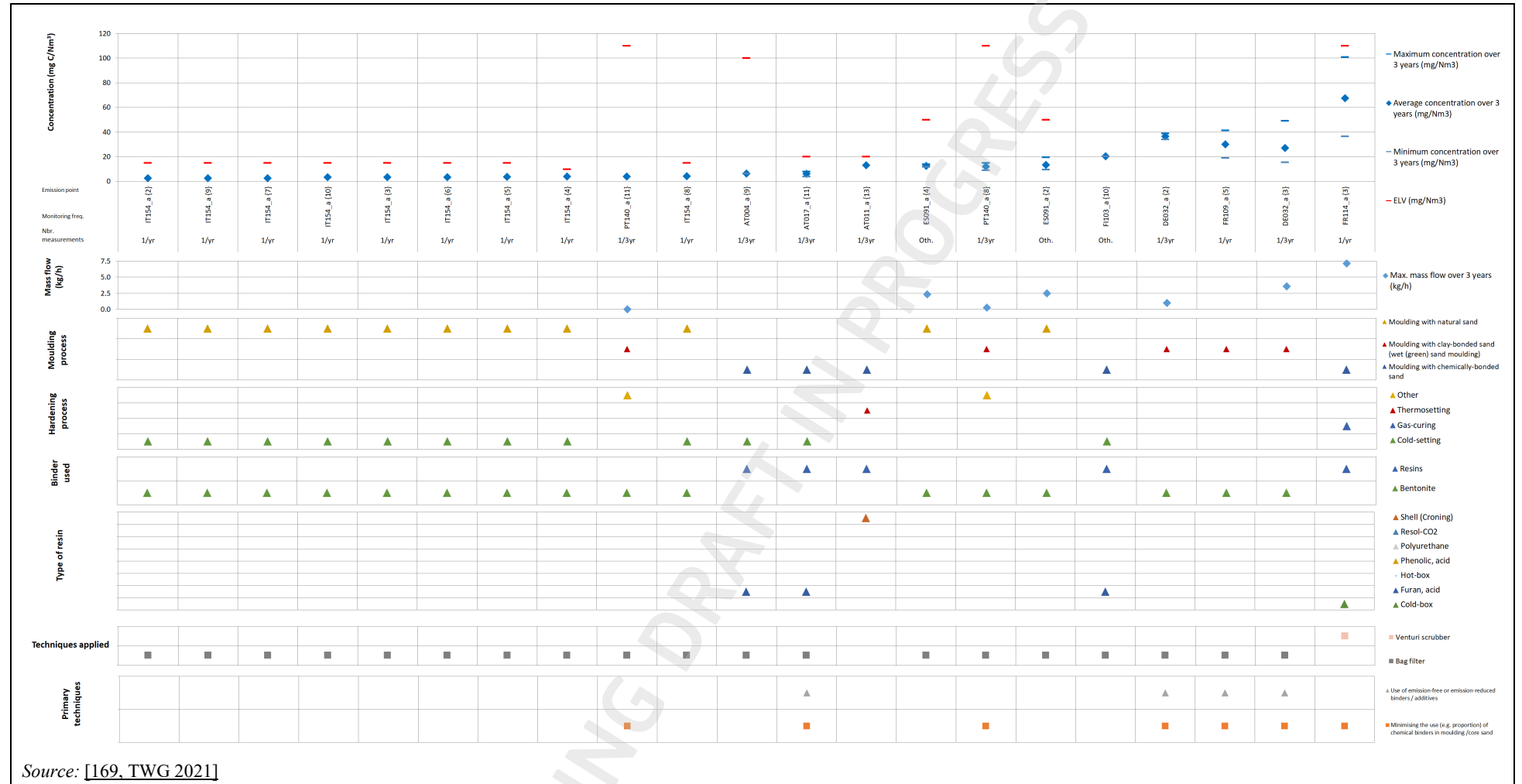


Figure 2.95: TVOC emissions from moulding using lost moulds

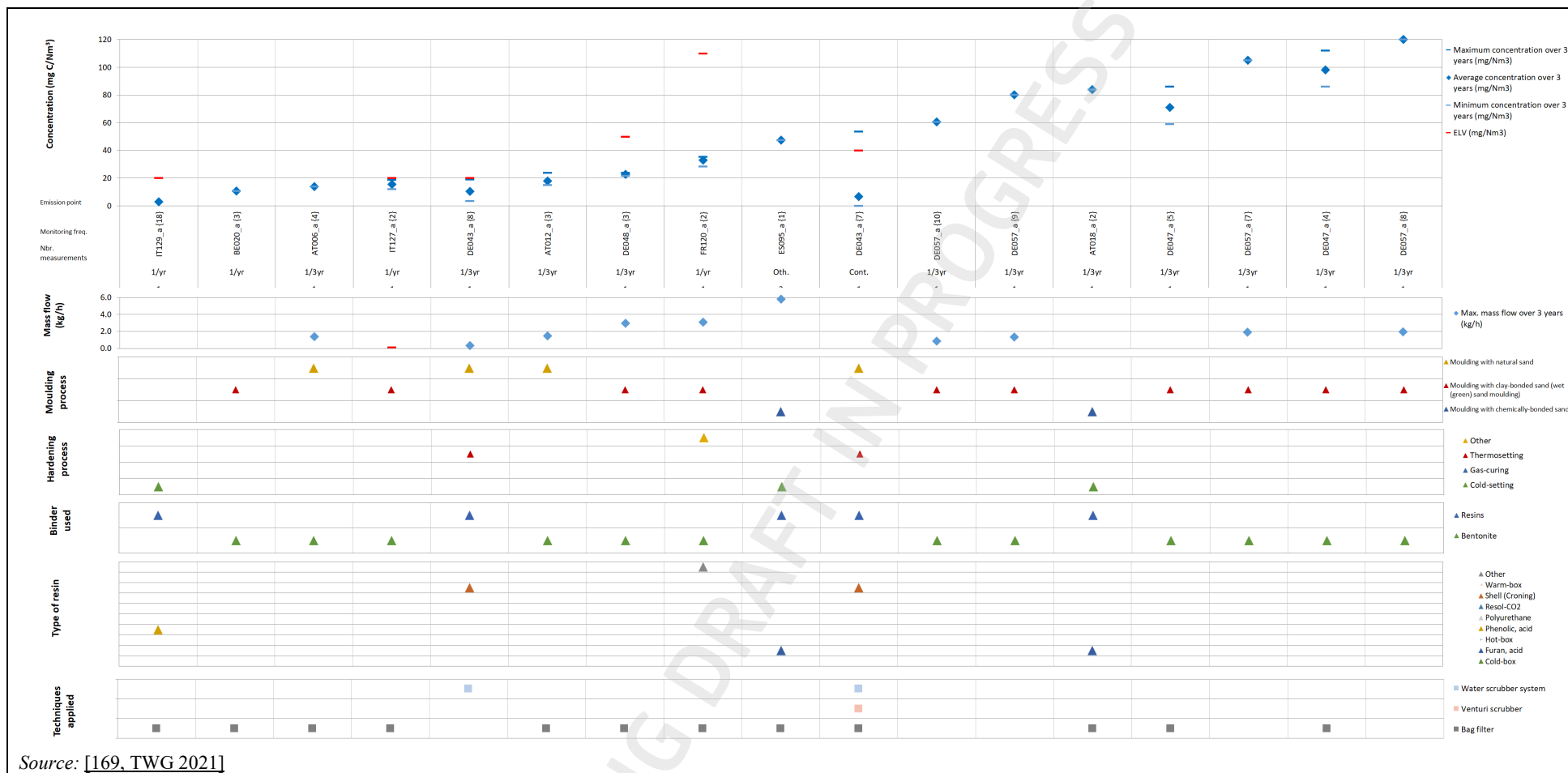


Figure 2.96: TVOC emissions from moulding using lost moulds and other processes

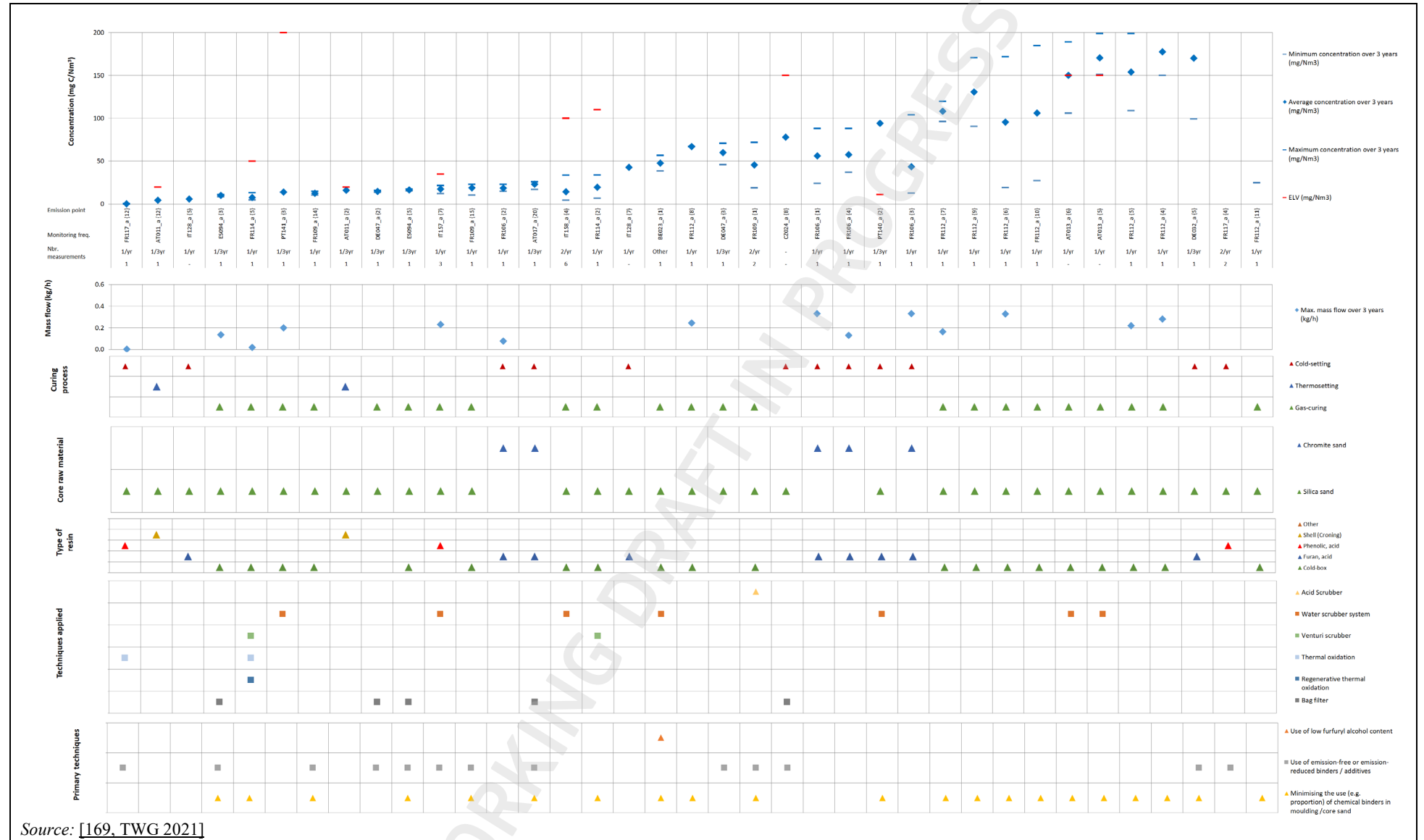


Figure 2.97: TVOC emissions from core-making

2.3.2.8 Coating of moulds and cores

The inputs/outputs for the processes of coating of chemically bonded moulds and cores are presented in the following table.

Input	Output
<ul style="list-style-type: none"> – Coatings ready to use or mass to be diluted with water or alcohol – Heat for solvent evaporation 	<ul style="list-style-type: none"> – VOCs (alcohol-based)

2.3.2.8.1 Dust and TVOC emissions

Some statistical data on the reported dust and TVOC emission data are presented in the following table.

Table 2.58: Statistical evaluation of the reported dust and TVOC emission data

Parameter	Number of data	Number of EPs	Number of plants	90 th percentile	Average	Median	10 th percentile
				mg/Nm ³			
Dust	9	6	4	-	1.96	2.00	-
TVOC	14	7	4	327.60	98.96	20.41	2.79

NB: The data above refer to EPs that are only associated with the coating process.
Source: [169, TWG 2021]

2.3.2.9 Casting, cooling and shake-out using lost moulds

The inputs/outputs for the casting, cooling and shake-out processes are presented in the following table.

Input	Output
<ul style="list-style-type: none"> – Finished moulds – Molten metal 	<ul style="list-style-type: none"> – Castings – Used sand – Combustion products (from preheating of pouring ladles) – Organic pollutants from pyrolysis and thermal degradation of binder, blackening moulds, etc. (phenol, formaldehyde, amine, hydrogen cyanide, PAH, benzene, VOC) – Odour – Waste from exhaust air cleaning (dry/sludge) – Dust from shake-out

Whilst **preheating** ladles, combustion gases are generated as a result of using natural gas as the common energy source.

The following emission types can occur during **pouring**:

- Thermally degradable components, such as exothermic sleeves, react releasing fumes and/or vapours.
- Chemical compounds from the binder and some blacking systems which can be released as a result of thermal degradation and/or volatilisation, e.g. combustion gases, water vapour, and volatile organic compounds. Some of the degradation products can be odorous.

Experience shows that the maximum emissions (related to total-C) only occur 10 minutes or more after pouring. CO is the main component, with the level of CO being indicative of the release of other compounds. [38, Vito 2001]

During **cooling and shake-out**, the thermal decomposition processes proceed and volatile compounds are generated, mainly controlled by diffusion and evaporation rates.

The removal (shake-out) of the sand moulds and cores from castings is a dust-intensive procedure, as the moulds, at least partially, have to be crushed.

The **second cooling step** releases nothing except water vapour from those plants where water spray is used as a cooling aid. [14, CAEF 1997]

The type of emissions during casting are dependent on the binder type used. Emissions are comparable to those during the mixing stage, with the addition of pyrolysis products occurring upon contact with the hot metal. Table 2.59 gives the results from a qualitative survey of the emissions associated with the various binder types.

Table 2.59: Environmental impact from binder systems upon pouring, shake-out and cooling

System name and binder constituents	Emissions to air during casting	Comments
GREEN SAND Clay Coal dust or substitute Water	Particulate matter- soot from coal burning Carbon monoxide and carbon dioxide Benzene Toluene Xylene	Potential odour (may be associated with the sulphur content of the coal)
SHELL SAND Phenol – Formaldehyde (Novalak) Resin	Particulate matter – soot from the incomplete combustion of carbon based resins Carbon oxides Phenol*, cresols* and xylenols* Ammonia Aldehydes Benzene PAH	Odour problems more prevalent – treatment may be necessary although dispersion may suffice
ALKALINE PHENOLIC Resol – Alkaline phenol Formaldehyde resin 1. Gas hardened 2. Self-setting	Particulate matter – soot from the incomplete combustion of carbon based resins Carbon oxides Formaldehyde Phenol, cresols and xylenols Aromatics	Odour may be a problem
PHENOLIC URETHANE 1. Gas hardened e.g. Cold-box 2. Self-setting (phenolic urethane no-bake)	Particulate matter – soot from the incomplete combustion of the carbon based resins Carbon oxides Nitrogen oxides Monoisocyanates Formaldehyde Phenol, cresols and xylenols Aromatics (inc. polycyclics) Anilines Naphthalenes Ammonia	Odour may be a problem

System name and binder constituents	Emissions to air during casting	Comments
FURAN Combination resins of: Phenol Urea Furfuryl alcohol Formaldehyde	Particulate matter – soot from the incomplete combustion of the carbon based resins Carbon oxides Phenol, cresols and xylenols Formaldehyde Aromatics (inc. polycyclics) Sulphur dioxide Ammonia Aniline Isocyanic acid* Methyl isocyanate*	Odour may occasionally be a problem
HOT-BOX Combination resins of: Phenol Urea Furfuryl alcohol Formaldehyde	Particulate matter – soot from the incomplete combustion of carbon based resins Carbon oxides Nitrogen oxides Formaldehyde Phenol, cresols and xylenols Aromatics (inc. polycyclics) Aniline Ammonia Isocyanic acid* Methyl isocyanate*	
OIL SAND Linseed oil and starch	Particulate matter – soot from the incomplete combustion of carbon based resins Carbon oxides Butadiene Ketones Acrolein	Odour may be a problem
CO₂ PROCESS Sodium silicate	Carbon oxides	
SILICATE ESTER Sodium silicate	Carbon oxides Alkanes Acetone Acetic acid Acrolein	
* For resin containing nitrogen (urea). Source: [62, UK Environment Agency 2002]		

2.3.2.9.1 Dust emissions

The reported levels of dust emissions to air from casting, cooling and shake-out processes using lost moulds are presented in Figure 2.98 and Figure 2.99.

Some statistical data on the reported dust emission data are presented in the following table.

Table 2.60: Statistical evaluation of the reported dust emission data

Parameter/ process	Number of data	Number of EPs	Number of plants	90 th percentile	Average	Median	10 th percentile
				mg/Nm ³			
Casting	101	53	25	5.93	2.68	1.99	0.56
Cooling	43	22	16	18.81	6.10	2.67	0.71
Shake-out	81	33	27	11.91	4.22	1.87	0.29
NB: The data above refer to EPs that are associated with only the process of casting, cooling or shake-out. Source: [169, TWG 2021]							

2.3.2.9.2 Amines emissions

Some statistical data on the reported amines emission data are presented in the following table.

Table 2.61: Statistical evaluation of the reported amines emission data

Parameter/ process	Number of data	Number of EPs	Number of plants	90 th percentile	Average	Median	10 th percentile
				mg/Nm ³			
Casting	2	2	1	-	0	-	-
Cooling	3	3	3	-	0.2	-	-
Shake-out	2	1	1	-	0.43	-	-

NB: The data above refer to EPs that are associated with only the process of casting, cooling or shake-out.
Source: [169, TWG 2021]

2.3.2.9.3 Benzene emissions

The reported levels of benzene emissions to air from casting, cooling and shake-out processes using lost moulds are presented in Figure 2.100.

Some statistical data on the reported benzene emission data are presented in the following table.

Table 2.62: Statistical evaluation of the reported benzene emission data

Parameter/ process	Number of data	Number of EPs	Number of plants	90 th percentile	Average	Median	10 th percentile
				mg/Nm ³			
Casting	18	8	6	1.09	0.59	0.31	0.08
Cooling	16	10	8	7.09	3.18	2.20	0.39
Shake-out	4	2	2	-	2.95	-	-

NB: The data above refer to EPs that are associated with only the process of casting, cooling or shake-out.
Source: [169, TWG 2021]

2.3.2.9.4 Formaldehyde emissions

The reported levels of formaldehyde emissions to air from casting, cooling and shake-out processes using lost moulds are presented in Figure 2.101.

Some statistical data on the reported formaldehyde emission data are presented in the following table.

Table 2.63: Statistical evaluation of the reported formaldehyde emission data

Parameter/ process	Number of data	Number of EPs	Number of plants	90 th percentile	Average	Median	10 th percentile
				mg/Nm ³			
Casting	14	5	4	0.90	0.27	0.15	0.01
Cooling	10	4	2	0.14	0.05	0.03	0.01
Shake-out	7	4	3	-	0.36	0.25	-

NB: The data above refer to EPs that are associated with only the process of casting, cooling or shake-out.
Source: [169, TWG 2021]

2.3.2.9.5 Phenol emissions

The reported levels of phenol emissions to air from casting, cooling and shake-out processes using lost moulds are presented in Figure 2.102.

Some statistical data on the reported phenol emission data are presented in the following table.

Table 2.64: Statistical evaluation of the reported formaldehyde emission data

Parameter/ process	Number of data	Number of EPs	Number of plants	90 th percentile	Average	Median	10 th percentile
				mg/Nm ³			
Casting	9	3	3	-	0.06	0.02	-
Cooling	10	4	2	2.23	1.12	0.92	0.06
Shake-out	2	2	1	-	0.27	-	-

NB: The data above refer to EPs that are associated with only the process of casting, cooling or shake-out.
Source: [169, TWG 2021]

2.3.2.9.6 Chromium (Cr) emissions

Some statistical data on the reported Cr emission data are presented in the following table.

Table 2.65: Statistical evaluation of the reported Cr emission data

Parameter/ process	Number of data	Number of EPs	Number of plants	90 th percentile	Average	Median	10 th percentile
				mg/Nm ³			
Casting	5	3	3	-	0.006	-	-
Cooling	1	1	1	-	0.0007	-	-
Shake-out	10	5	4	0.0096	0.006	0.007	0.000057

NB: The data above refer to EPs that are associated with only the process of casting, cooling or shake-out.
Source: [169, TWG 2021]

2.3.2.9.7 Lead (Pb) emissions

Some statistical data on the reported Pb emission data are presented in the following table.

Table 2.66: Statistical evaluation of the reported Pb emission data

Parameter/ process	Number of data	Number of EPs	Number of plants	90 th percentile	Average	Median	10 th percentile
				mg/Nm ³			
Casting	13	12	5	0.16	0.078	0.07	0.0034
Cooling	-	-	-	-	-	-	-
Shake-out	12	6	5	0.0048	0.0017	0.0007	0.0

NB: The data above refer to EPs that are associated with only the process of casting, cooling or shake-out.
Source: [169, TWG 2021]

2.3.2.9.8 TVOC emissions

The reported levels of TVOC emissions to air from casting, cooling and shake-out processes using lost moulds are presented in Figure 2.103.

Some statistical data on the reported TVOC emission data are presented in the following table.

Table 2.67: Statistical evaluation of the reported TVOC emission data

Parameter/ process	Number of data	Number of EPs	Number of plants	90 th percentile	Average	Median	10 th percentile
				mg/Nm ³			
Casting	74	31	15	46.92	16.82	7.75	2.98
Cooling	27	10	5	84.60	36.92	24.50	5.28
Shake-out	21	9	7	60.40	29.46	19.17	6.76
NB: The data above refer to EPs that are associated with only the process of casting, cooling or shake-out. Source: [169, TWG 2021]							

2.3.2.9.9 Figures for emissions to air

The structure of the figures presented in this section is explained in Section 2.3.2.1.10.

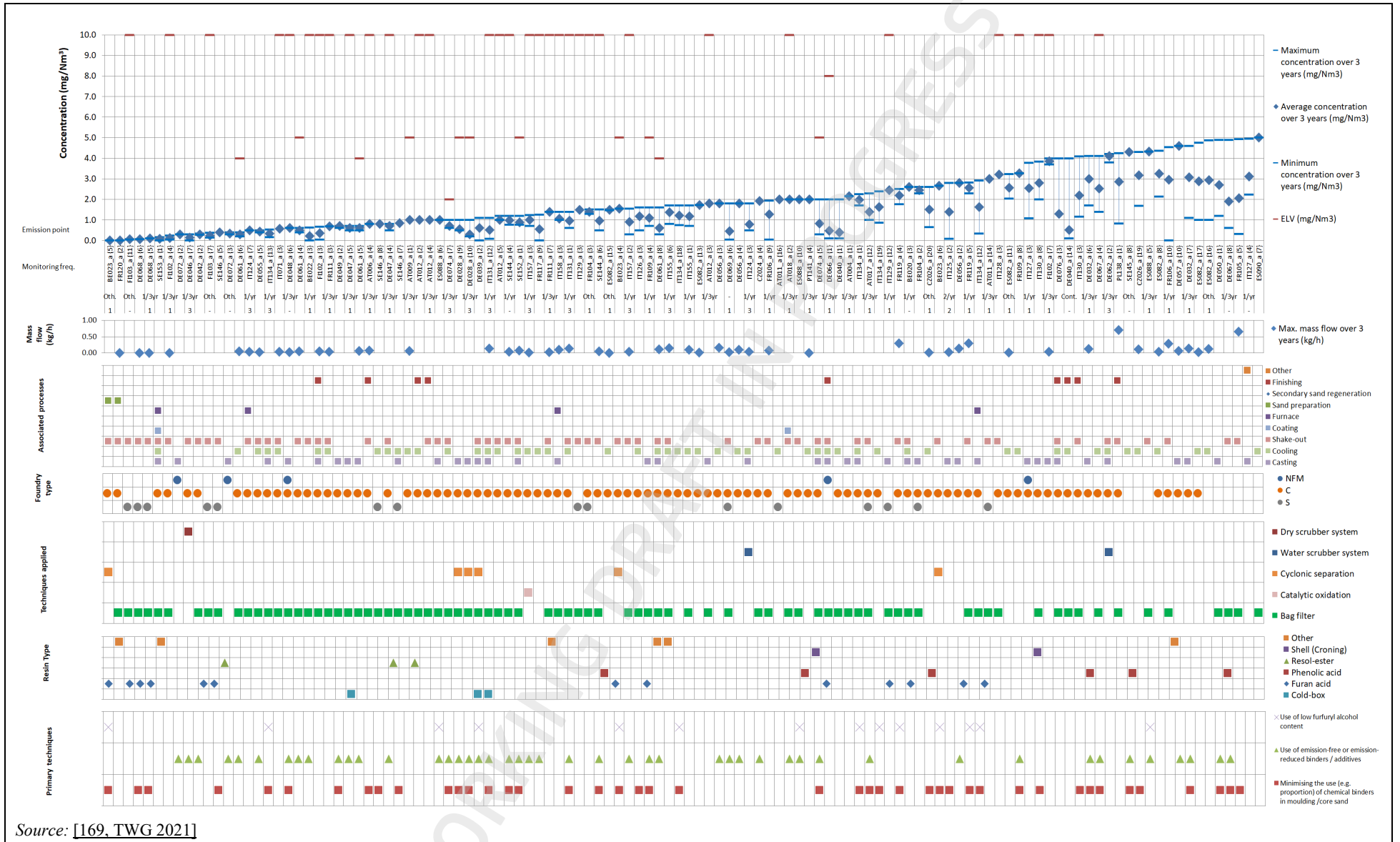


Figure 2.98: Dust emissions from casting, cooling and shake-out processes using lost moulds (1/2)

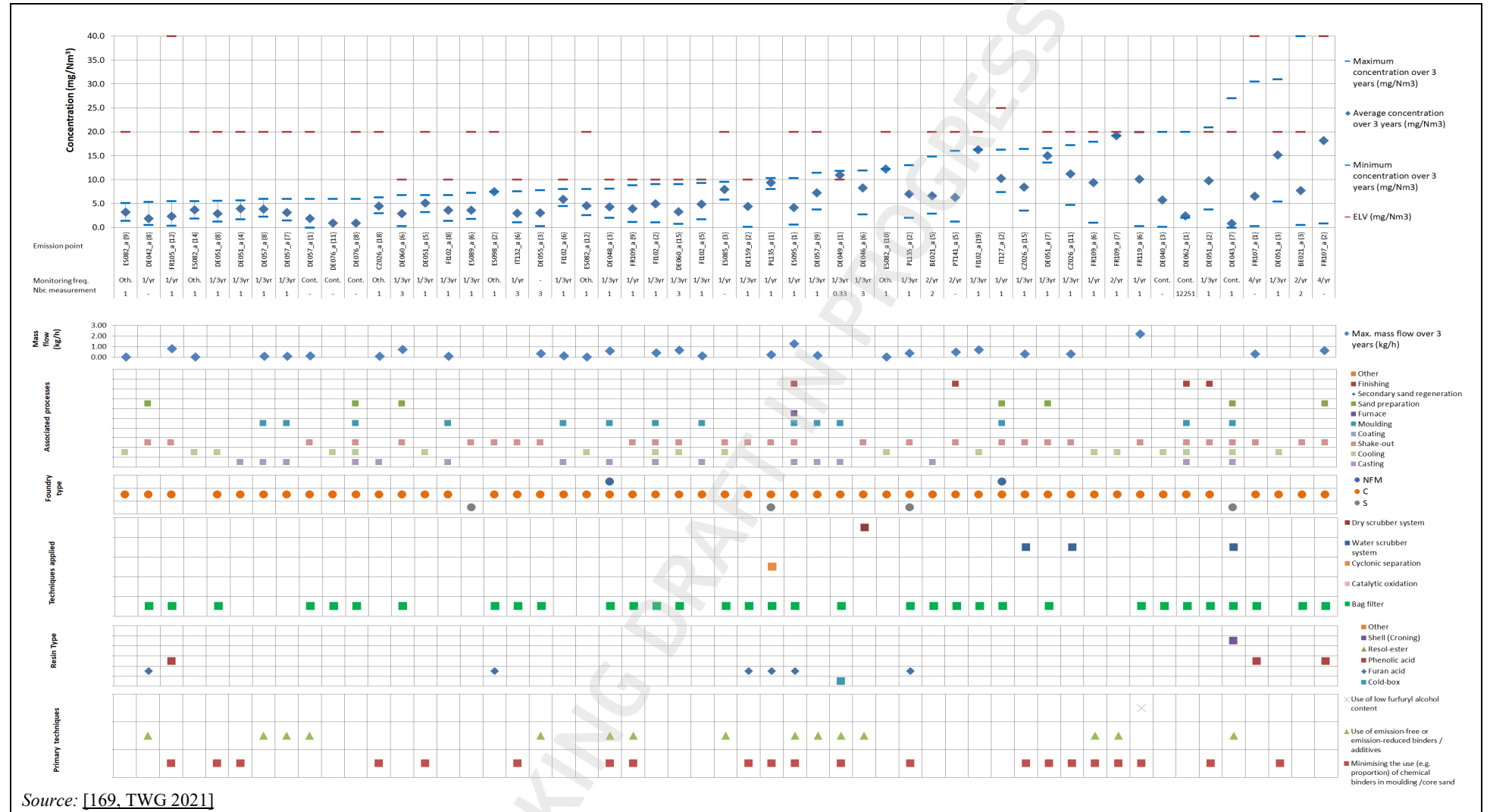


Figure 2.99: Dust emissions from casting, cooling and shake-out processes using lost moulds (2/2)

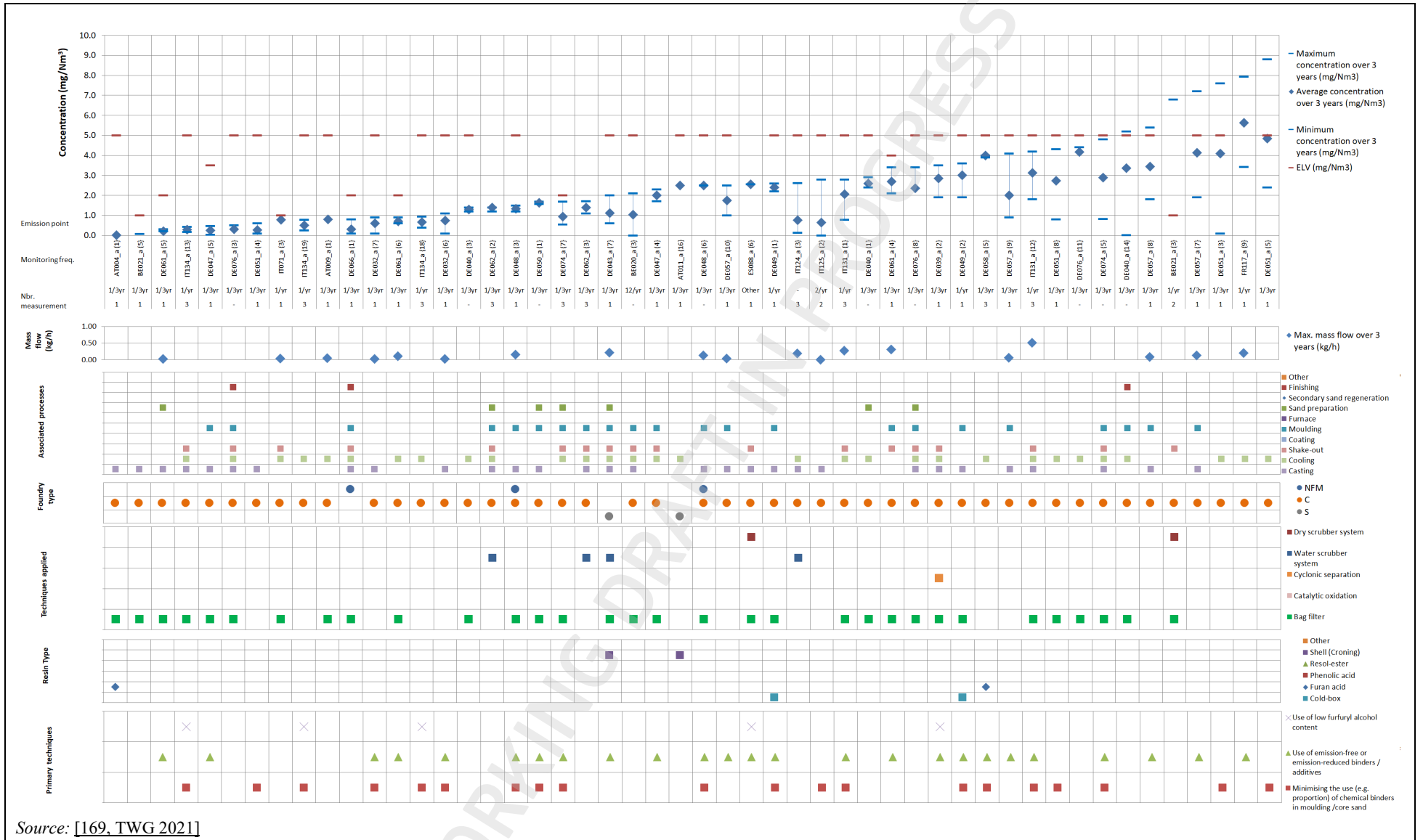


Figure 2.100: Benzene emissions from casting, cooling and shake-out processes using lost moulds

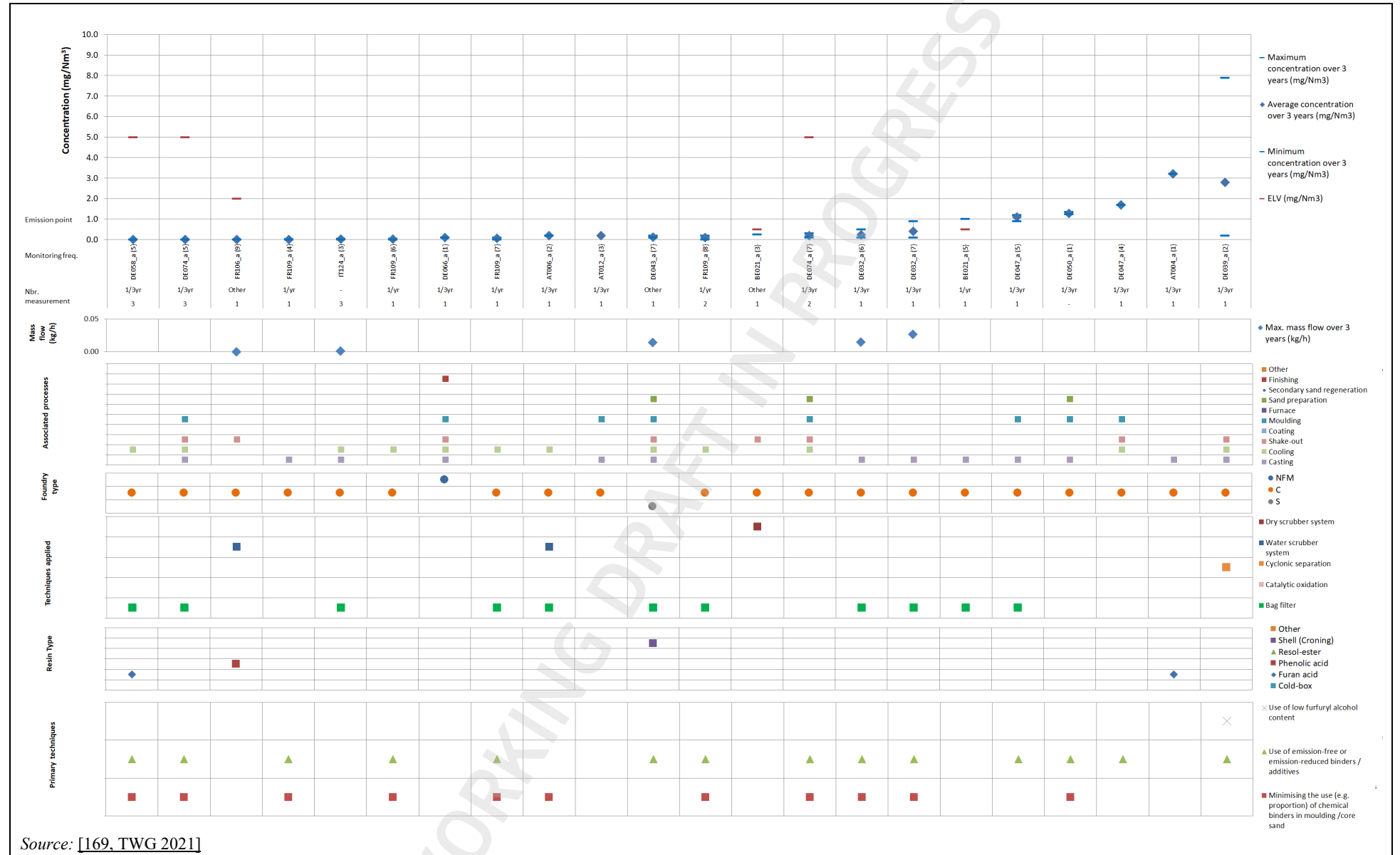


Figure 2.101: Formaldehyde emissions from casting, cooling and shake-out processes using lost moulds

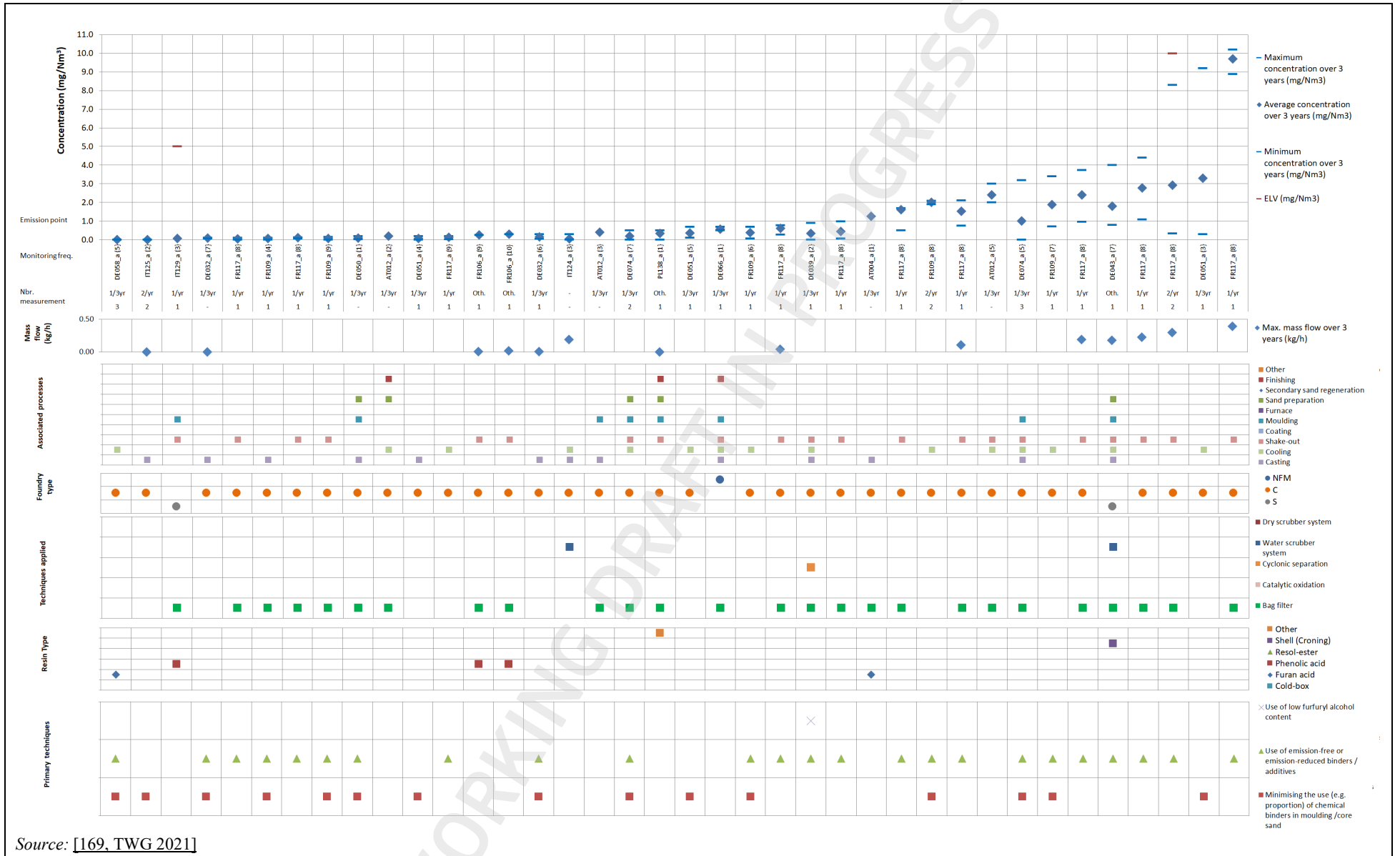


Figure 2.102: Phenol emissions from casting, cooling and shake-out processes using lost moulds

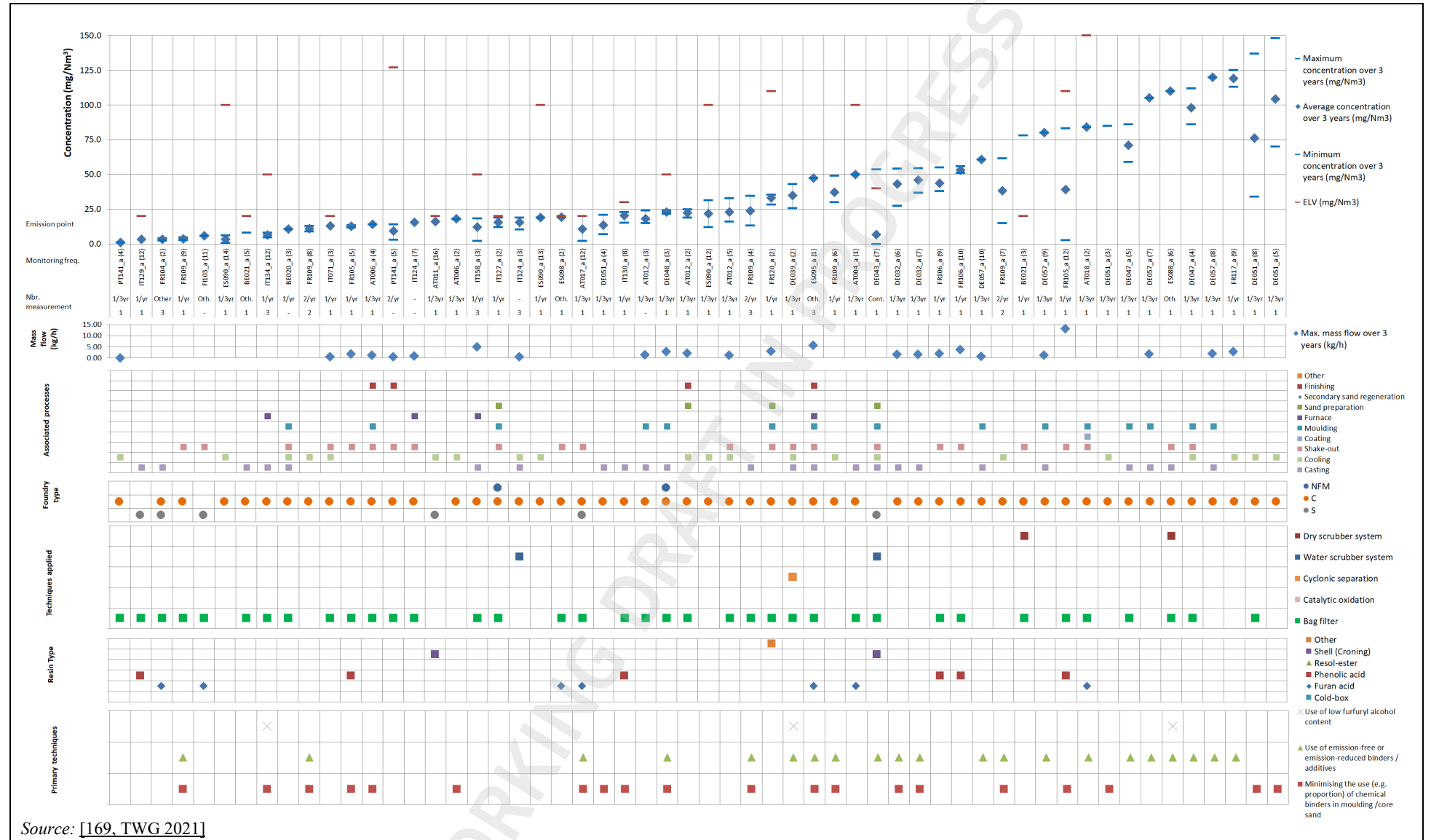


Figure 2.103: TVOC emissions from casting, cooling and shake-out processes using lost moulds

2.3.2.10 Alternative casting processes (i.e. lost foam, ceramic shell casting)

2.3.2.10.1 Unbonded sand – lost foam casting

The inputs/outputs for the lost-foam casting process using unbonded sand are presented in the following table.

Input	Output
– EPS granulate	– Sand moulds
– EPS glue	– EPS residues
– Refractory coating	– Products of pyrolysis and combustion
– Sand	– Dust

Emission data for organic compounds are given in Table 2.68. These apply to an aluminium lost foam foundry producing 1.5 t/h compared to a green sand foundry producing 1.2 t/h and using 1.9 t/h cold-box cores. The lost foam foundry was equipped with a bag house and a post-combustion unit. The green sand data apply to a unit with bag house filtration. The data show that the lost foam foundry, with the application of more intense flue-gas cleaning, emits higher levels of BTEX and formaldehyde, but a clearly lower level of organic carbon. Post-combustion of the casting off-gases is needed to decompose the products from EPS pyrolysis upon pouring.

Table 2.68: Stack emission data for lost foam and green sand aluminium foundries

Compound	Lost foam foundry	Green sand foundry
Benzene	35.33	8.5
Toluene, xylene, ethylbenzene, styrene	354.67	18.58
Unknown organic compounds	96.67	655.0
Total organic carbon	857.33	1283.33
PAH	1.45	1.43
Formaldehyde	18.00	2.08
Phenol	18.00	69.83

NB: All values in g/tonne molten aluminium.
Source: [35, Spillner, A. 1997]

The table below summarises the emissions data reported by four foundries (cast iron and aluminium foundries) using the lost foam casting process and the abatement techniques employed.

Table 2.69: Emissions data from cast iron and aluminium foundries using the lost foam casting process

Foundry type	Plant number / EP / Associated process	Abatement technique reported	Dust	TVOC	Benzene	Formaldehyde
			(mg /Nm ³)	(mg C/Nm ³)	(mg /Nm ³)	(mg /Nm ³)
Aluminium	FR115 / EP2 / Moulding line	Fabric filter	0.0 (2017)	25.1 (2017)	0.04 (2017)	0.04 (2017)
			0.0 (2018)	38.0 (2018)	0.04 (2018)	0.00 (2018)
			5.0 (2019)	26.0 (2019)	0.05 (2019)	0.17 (2019)
Aluminium	FR115 / EP4 / Shake out	Venturi scrubber + Regenerative thermal oxidation	1.42 (2017)	7.8 (2017)	0.00 (2017)	0.03 (2017)
			0.78 (2018)	11.7 (2019)		1.60 (2018)
			0.50 (2019)			0.34 (2019)
Aluminium	DE038 / EP2 / Casting	Fabric filter + Regenerative thermal oxidation	1.0 (2019)	No data reported	No data reported	No data reported

Foundry type	Plant number / EP / Associated process	Abatement technique reported	Dust	TVOC	Benzene	Formaldehyde
			(mg /Nm ³)	(mg C/Nm ³)	(mg /Nm ³)	(mg /Nm ³)
Cast iron	IT130 / EP8 / Casting	Fabric filter	2.58 (2017)	15.2 (2017)	No data reported	No data reported
			3.84 (2018)	22.7 (2018)		
			1.99 (2019)	22.8(2019)		

A recent study associates the use of the lost foam process with elevated emissions of BTEX, due to the thermal decomposition of expanded polystyrene resulting in benzene-toluene-styrene emissions. [181, Basque Government 2019]. As BTEX compounds are aromatic in nature and, therefore, have a characteristic odour, they are likely to result in odour nuisance in the surrounding area. The reported ambient benzene concentrations were in the range from 1 µg/Nm³ to 2.8 µg/Nm³ while the reported emission levels were of the order:

- benzene: 290 – 4 140 µg/Nm³;
- toluene: 280 – 7 600 µg/Nm³;
- styrene: 560 – 3 730 µg/Nm³;
- isopropanol: 350 – 2 330 µg/Nm³.

It is noted that the above emission levels are associated with no application of any abatement technique.

2.3.2.10.2 Chemically bonded sand – full mould

The inputs/outputs for the full mould casting processes are presented in the following table.

Input	Output
– EPS granulate	– Sand moulds
– EPS glue	– EPS residues
– Refractory coating	– Products of pyrolysis and combustion
– Sand	– Dust
– Binders	

The mass flow of emissions from full mould and hollow mould casting processes are to be considered as similar. This can be seen from Figure 2.104 which shows the mass flow of organic carbon as a function of time upon pouring. Time '0:00' corresponds to the starting of the pouring. The data were collected using furan-bonded sands, both for full and hollow mould making.

The full mould process shows a high emission upon pouring and an initial peak emission immediately after pouring which levels off within 1 hour. The hollow mould process shows a lower initial emission, but the levelling off goes slower and takes up to 2 hours. Therefore, the total organic carbon emission over the whole cooling step is equal for both processes. Additional measurements showed that the same profile applies for benzene, ethylbenzene, phenol and furfuryl alcohol. The maximum emission for styrene and toluene occurs after 15-30 minutes. This is due to an initial condensation of the molecules on the colder parts of the mould. [113, Müller, G. 1996]

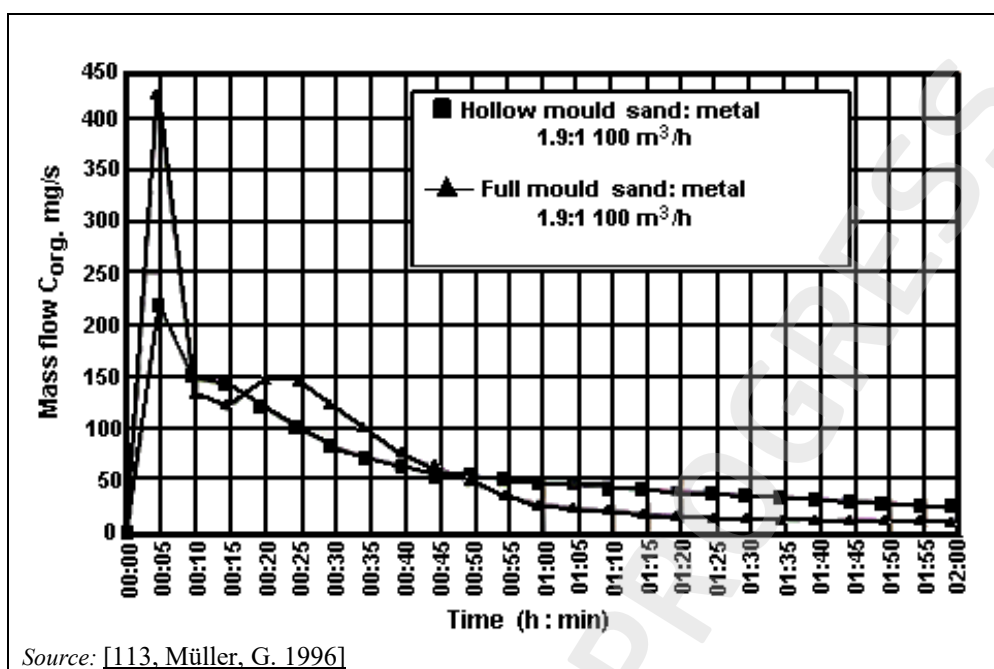


Figure 2.104: Waste gas load upon pouring in full and hollow moulds (cast alloy: lamellar iron; mould: furan-bonded sand; 1.9 tonne sand: 1 tonne Fe)

2.3.2.10.3 Ceramic shell casting

No plants in the SF data collection reported the use of the ceramic shell casting technique.

2.3.2.11 Casting in permanent moulds

The inputs/outputs for the casting process in permanent moulds are presented in the following table.

Input	Output
- Water-based release agent	- Casting
- Cooling water	- Oily mist from release agent spraying
- Molten metal	- Organic pollutants from thermal degradation of core binder
- Cores	- Metal oxide containing dusts from holding furnace
	- Dust from shake-out of cores
	- Waste water

Mass balance data for three different foundries using pressure die-casting of molten aluminium are given in Table 2.70.

Table 2.70: Mass balance data including inputs, exhaust gas and effluent compositions for three aluminium pressure die-casting foundries

	Foundry A	Foundry B	Foundry C
Input			
Water	802 l/tonne	935 l/tonne	1709 l/tonne
Release agent	16 l/tonne	8.26 l/tonne	1.12 l/tonne
Electricity	1 103 kWh/tonne	1 380 kWh/tonne	652 kWh/tonne
Output			
Waste water ¹		122 l/tonne	

	Foundry A	Foundry B	Foundry C
COD	18 000 mg/l		126 mg/l
pH	7.5		7.5
SS	1 300 mg/l		1 mg/l
Oil and grease	3 000 mg/l		1 mg/l (total hydrocarbons)
BOD ₅	2 000 mg/l		78 mg/l
Al	5 mg/l		0.6 mg/l
Exhaust gas			
NO _x		0.006 kg/tonne	
VOC		0.28 kg/tonne	0.14 – 0.27 kg/tonne
Dust		1.8 kg/tonne	0.030 – 0.16 kg/tonne
All values are expressed per tonne of good casting or in mg/l effluent. ¹ For foundry C, waste water quality after treatment consists in a distilling plant and cooling-evaporation towers. Source: [76, Silva Ribeiro, C. A. 2002], [100, TWG 2002]			

In die-casting, water-based release agents are sprayed on the open die, after dilution to a 1:50 – 1:200 ratio. Besides die coating, this spraying is used for die cooling. This explains the difference in water use displayed in the table. This practice causes a loss and spillage of water, and an up to 40 % water/agent leakage into the foundry waste water system.

Emission and consumption levels for permanent moulding processes depend on the type of alloy used, the surface area of the melt, the quantity of the sand cores which are inserted in the mould, and the surface/volume rate of the casting. The sand cores are the main sources of emissions. There is no important difference between the different casting techniques. Due to the wide variety of processes and applications, it is not possible to give average data. [100, TWG 2002]

Electricity consumption depends on process aspects, such as the closing force of the die, which are chosen on technical grounds.

Emission factors for the casting of bronze, brass and zamac as used in Belgium are given in Table 2.71.

Table 2.71: Indicative emission factors for casting of bronze, brass and zamac

Alloy	CuO	SnO	PbO	ZnO	Al ₂ O ₃	MnO
Bronze	0.06	0.04	2 – 20	625 – 6 250	n.a	n.a
Brass	0.01	n.a	0.007 – 1	125 – 21 500	n.a	n.a
Zamac	n.a	n.a	n.a	0.004	0.2	0.01
All data are expressed in g/tonne molten metal. Source: [38, Vito 2001]						

2.3.2.11.1 Dust emissions

The reported levels of dust emissions to air from casting in permanent moulds are presented in Figure 2.105.

Some statistical data on the reported dust emission data are presented in the following table.

Table 2.72: Statistical evaluation of the reported dust emission data

Parameter	Number of data	Number of EPs	Number of plants	90 th percentile	Average	Median	10 th percentile
				mg/Nm ³			
Dust	152	69	28	4.19	1.82	1.0	0.2
Source: [169, TWG 2021]							

2.3.2.11.2 TVOC emissions

Reported levels of TVOC emissions to air from casting in permanent moulds are presented in Figure 2.106.

Some statistical data of reported TVOC emission data are presented in the following table.

Table 2.73: Statistical evaluation of the reported TVOC emission data

Parameter	Number of data	Number of EPs	Number of plants	90 th percentile	Average	Median	10 th percentile
				mg/Nm ³			
TVOC	72	30	10	28.08	7.5	3.9	0.5
NB: The data above refer to EPs that are associated with the casting process in permanent moulds only. Source: [169, TWG 2021]							

2.3.2.11.3 Lead (Pb) emissions

Reported levels of Pb emissions to air from casting in permanent moulds are presented in Figure 2.107.

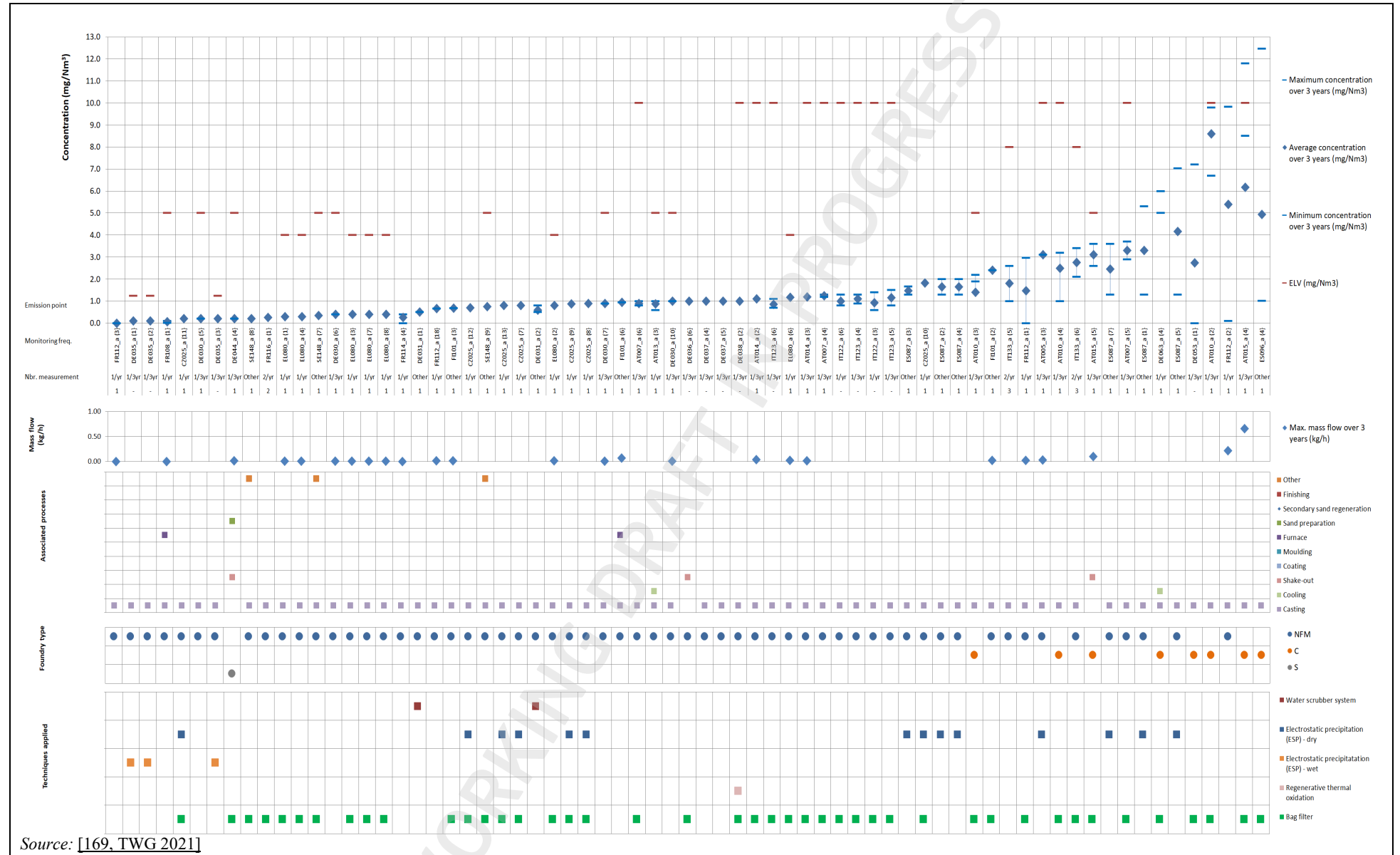
Some statistical data on the reported Pb emission data are presented in the following table.

Table 2.74: Statistical evaluation of the reported Pb emission data

Parameter	Number of data	Number of EPs	Number of plants	90 th percentile	Average	Median	10 th percentile
				mg/Nm ³			
Lead (Pb)	23	17	7	0.171	0.064	0.014	0.00005
Source: [169, TWG 2021]							

2.3.2.11.4 Figures for emissions to air

The structure of figures presented in this section is explained in Section 2.3.2.1.10.



Source: [169, TWG 2021]

Figure 2.105: Dust emissions from the casting process in permanent moulds

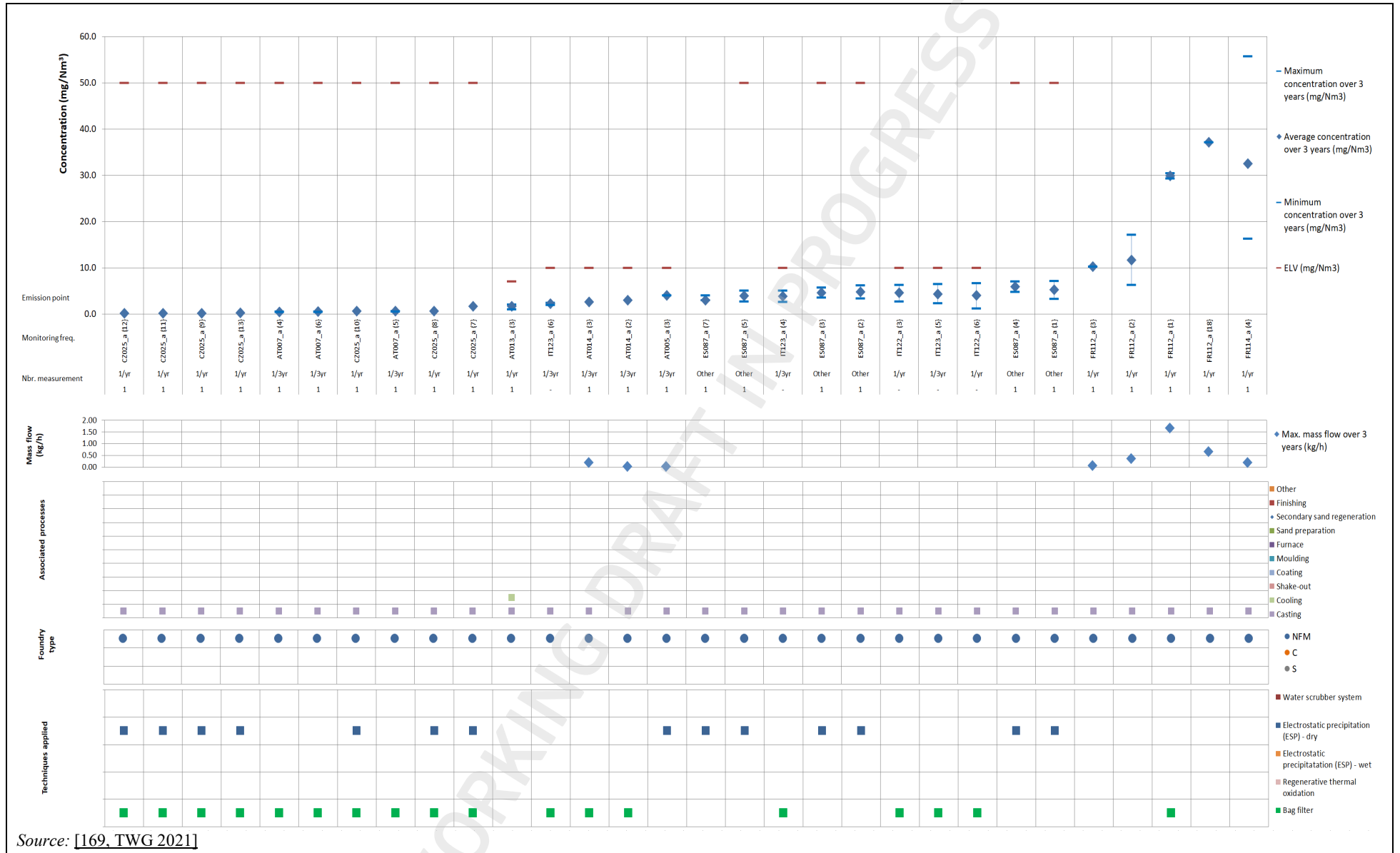


Figure 2.106: TVOC emissions from the casting process in permanent moulds

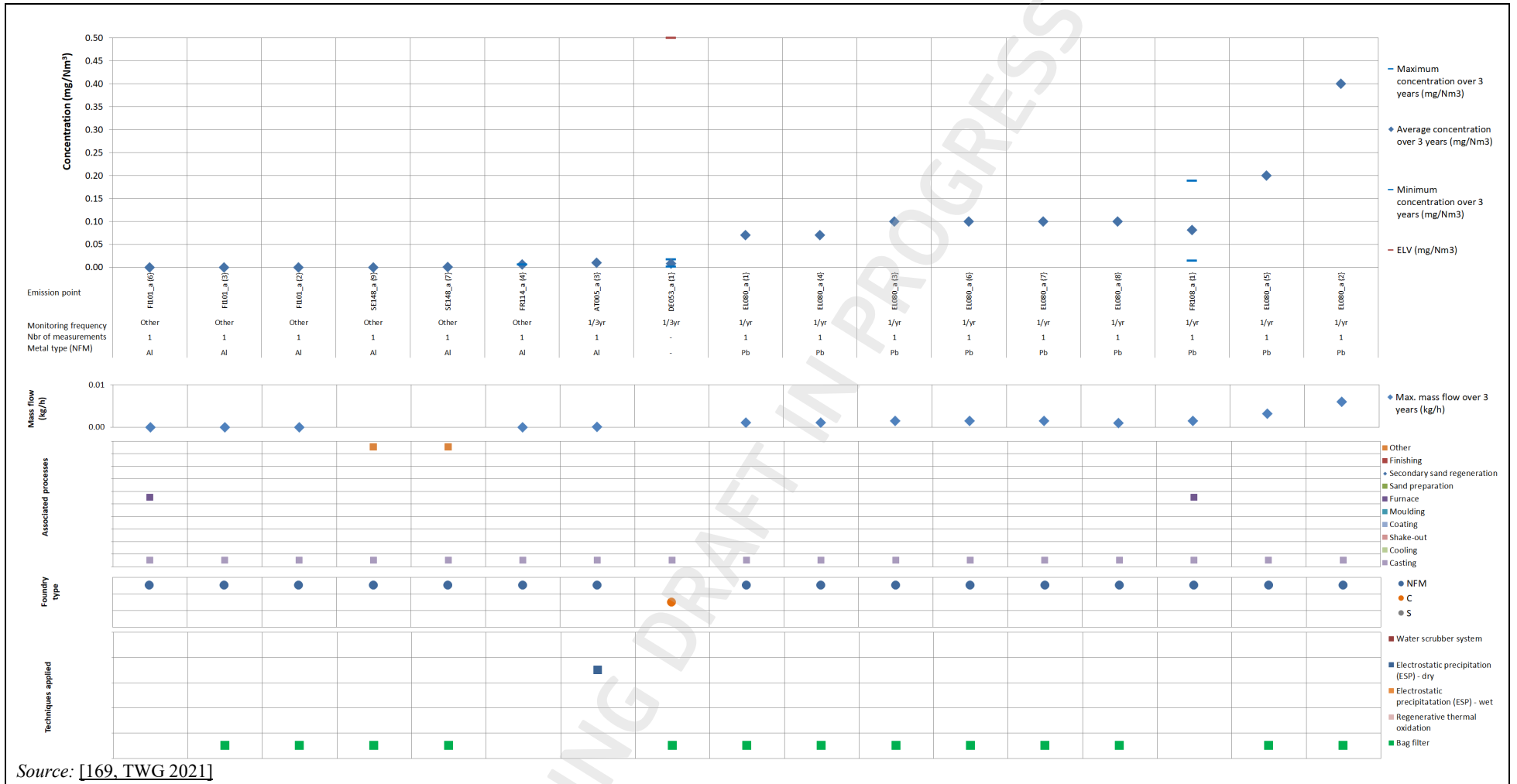


Figure 2.107: Pb emissions from the casting process in permanent moulds

2.3.2.12 Finishing

In foundries, finishing includes a number of mechanical operations carried out after the casting process including deburring, abrasive cutting, chiselling, needling, fettling, slide grinding, shot blasting and welding.

The inputs/outputs for the finishing process are presented in the following table.

Input	Output
- Unfinished castings	- Finished castings
- Abrasives	- Dust (<i>sand, metal particles</i>) from mechanical operations
- Water, soap	- Volatilised metals, combustion products from thermal operations
- Electricity	- Waste water

2.3.2.12.1 Dust emissions

The reported levels of dust emissions to air from finishing are presented in Figure 2.108, Figure 2.109, Figure 2.110 and Figure 2.111.

Some statistical data on the reported dust emission data are presented in the following table.

Table 2.75: Statistical evaluation of the reported dust emission data

Parameter	Number of data	Number of EPs	Number of plants	90 th percentile	Average	Median	10 th percentile
				mg/Nm ³			
Dust	427	199	78	10.75	2.77	1.22	0.20
NB: The data above refer to EPs that are associated with finishing only. Source: [169, TWG 2021]							

2.3.2.12.2 TVOC emissions

Some statistical data on the reported TVOC emission data are presented in the following table.

Table 2.76: Statistical evaluation of the reported TVOC emission data

Parameter	Number of data	Number of EPs	Number of plants	90 th percentile	Average	Median	10 th percentile
				mg/Nm ³			
TVOC	18	12	6	5.08	3.62	3.80	2.16
NB: The data above refer to EPs that are associated with finishing only. Source: [169, TWG 2021]							

2.3.2.12.3 Lead (Pb) emissions

Some statistical data on the reported Pb emission data are presented in the following table.

Table 2.77: Statistical evaluation of the reported Pb emission data

Parameter	Number of data	Number of EPs	Number of plants	90 th percentile	Average	Median	10 th percentile
				mg/Nm ³			
Lead (Pb)	29	18	7	0.009	0.0041	0.0018	0.00036
NB: The data above refer to EPs that are associated with finishing only. Source: [169, TWG 2021]							

2.3.2.12.4 Nickel (Ni) emissions

Some statistical data on the reported Ni emission data are presented in the following table.

Table 2.78: Statistical evaluation of the reported Ni emission data

Parameter	Number of data	Number of EPs	Number of plants	90 th percentile	Average	Median	10 th percentile
				mg/Nm ³			
Nickel (Ni)	44	23	10	0.01225	0.0047	0.0025	0.000643
NB: The data above refer to EPs that are associated with finishing only. Source: [169, TWG 2021]							

2.3.2.12.5 Cadmium (Cd) emissions

Some statistical data on the reported Cd emission data are presented in the following table.

Table 2.79: Statistical evaluation of the reported Cd emission data

Parameter	Number of data	Number of EPs	Number of plants	90 th percentile	Average	Median	10 th percentile
				mg/Nm ³			
Cadmium (Cd)	29	18	7	0.00134	0.0005	0.0002	0
NB: The data above refer to EPs that are associated with finishing only. Source: [169, TWG 2021]							

2.3.2.12.6 Chromium (Cr) emissions

Some statistical data on the reported Cr emission data are presented in the following table.

Table 2.80: Statistical evaluation of the reported Cr emission data

Parameter	Number of data	Number of EPs	Number of plants	90 th percentile	Average	Median	10 th percentile
				mg/Nm ³			
Chromium (Cr)	41	21	9	0.0743	0.0283	0.0134	0.001
NB: The data above refer to EPs that are associated with finishing only. Source: [169, TWG 2021]							

2.3.2.12.7 Figures for emissions to air

The structure of figures presented in this section is explained in Section 2.3.2.1.10.

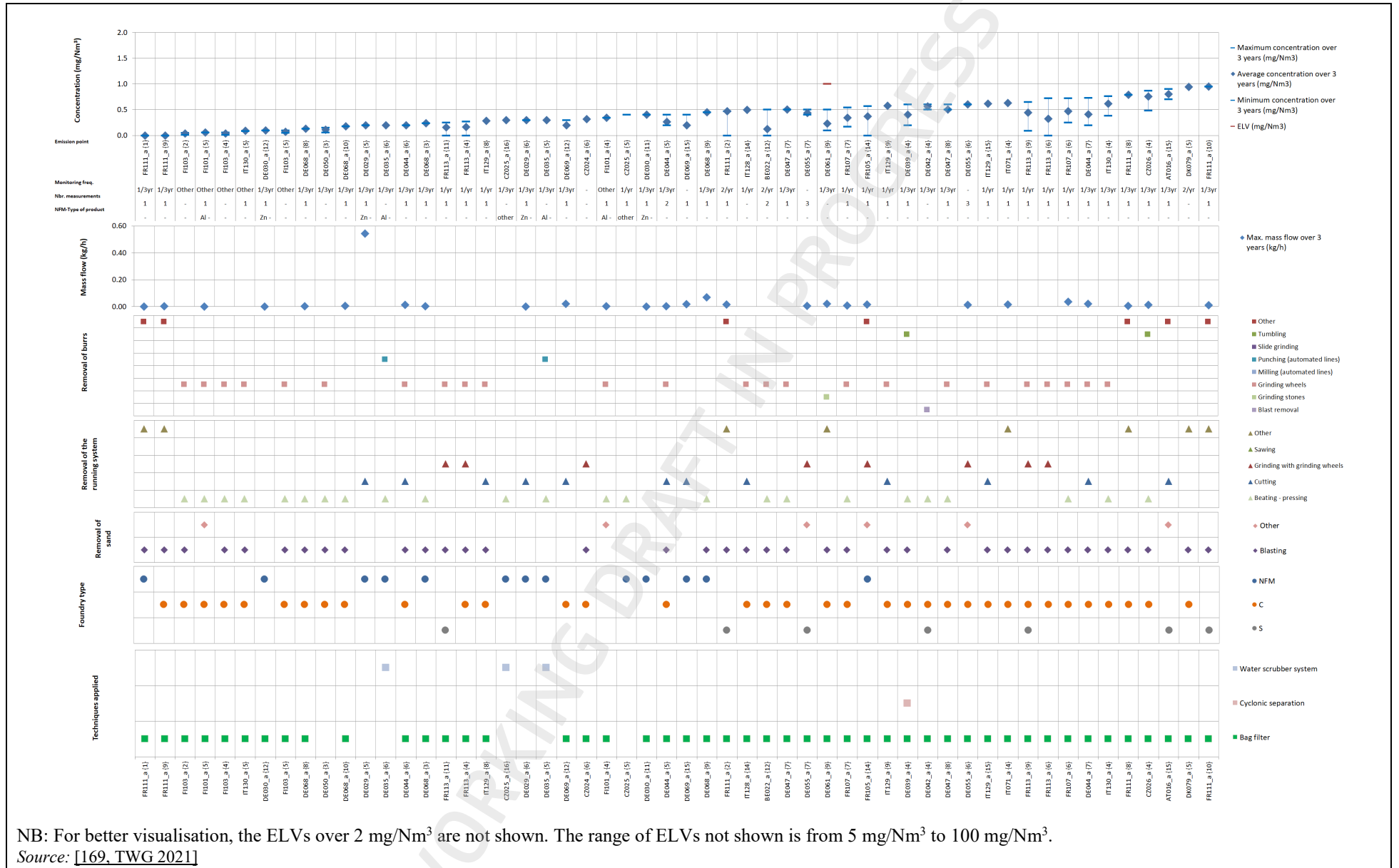


Figure 2.108: Dust emissions from finishing (1/4)

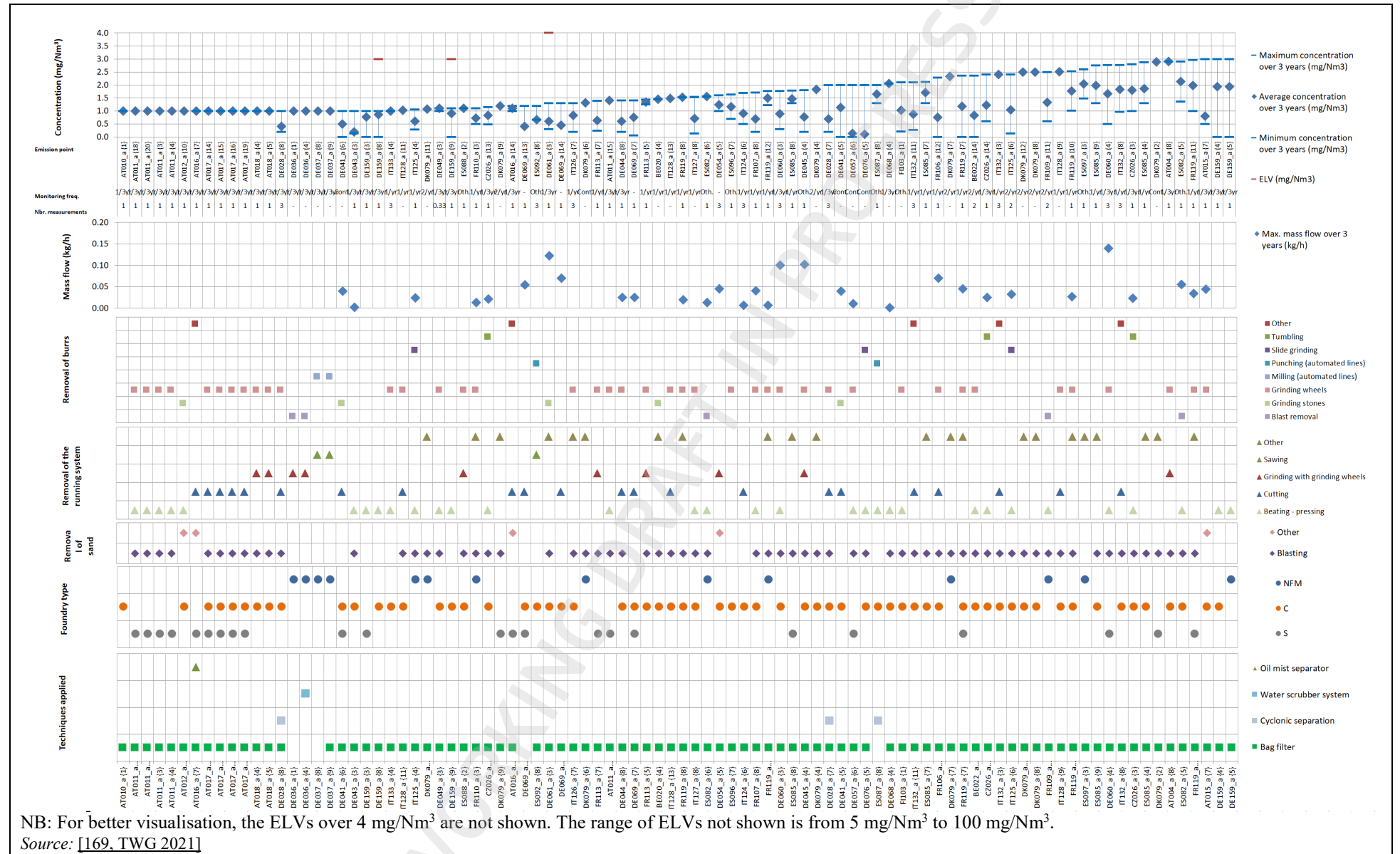


Figure 2.109: Dust emissions from finishing (2/4)

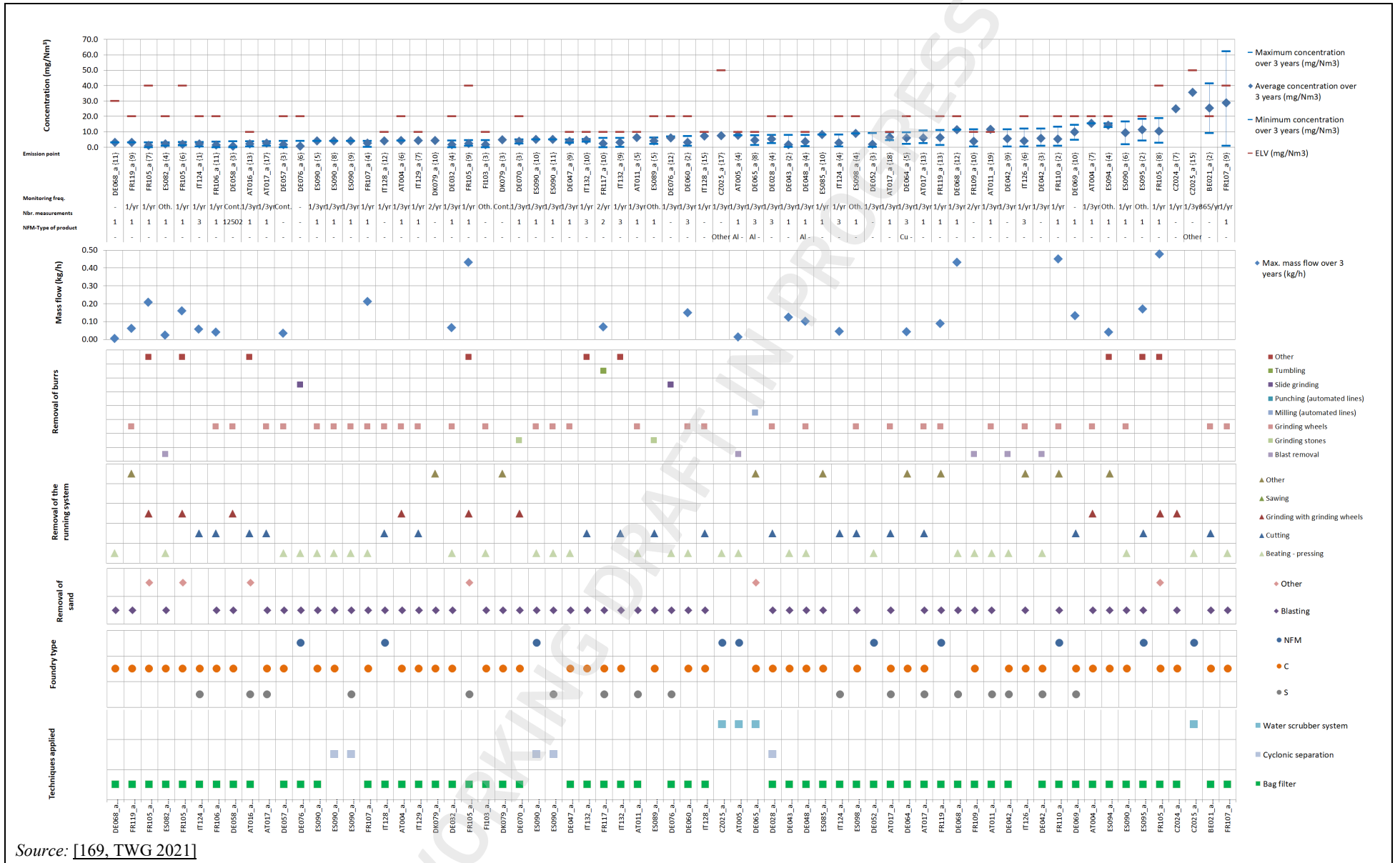
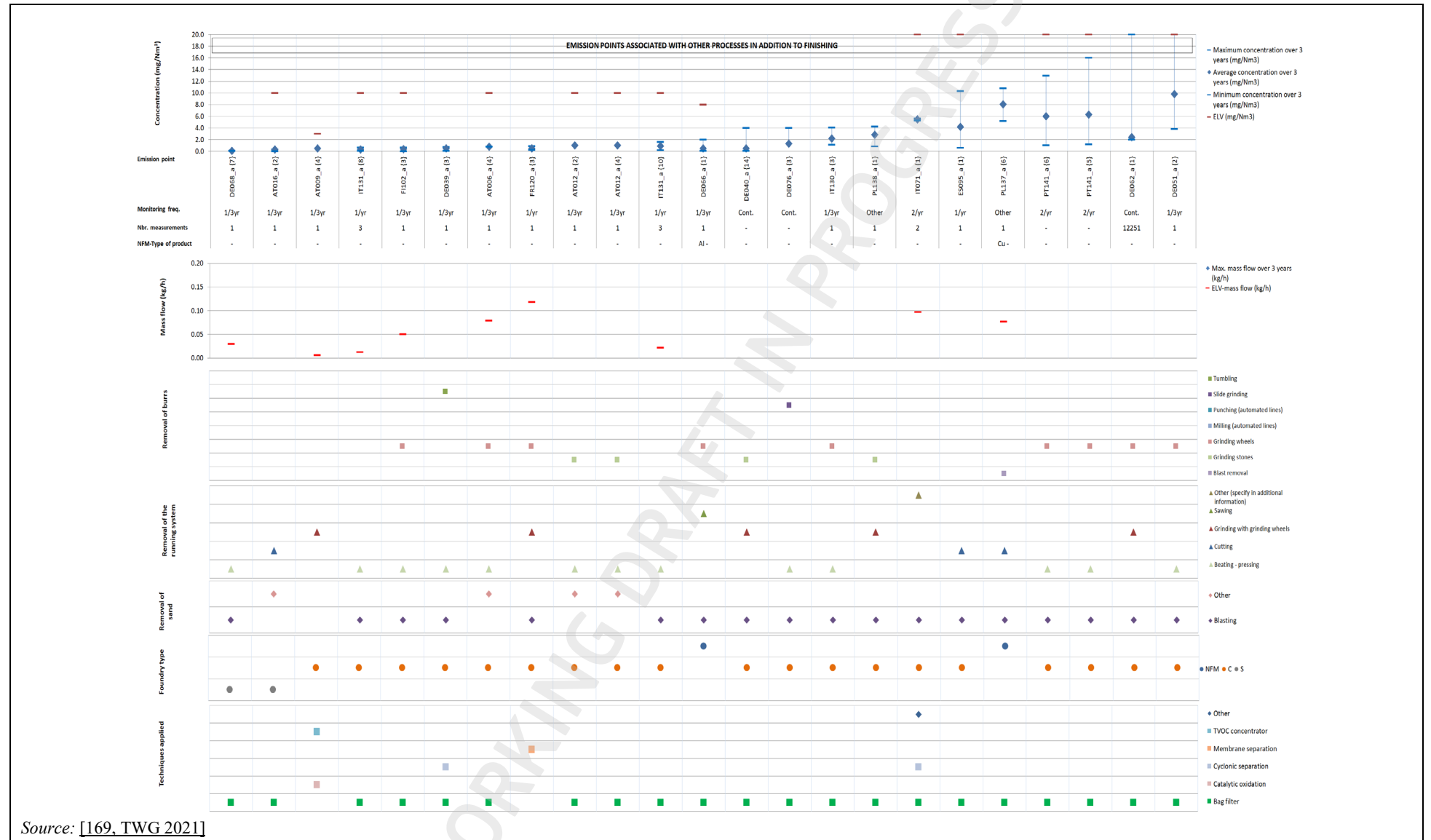


Figure 2.110: Dust emissions from finishing (3/4)



Source: [169, TWG 2021]

Figure 2.111: Dust emissions from finishing and other processes (4/4)

2.3.2.13 Sand reconditioning and regeneration

In the following sections, emission data for the sand reconditioning (preparation) and regeneration processes are presented.

In this document, sand reconditioning refers to any mechanical operation associated with the preparation and reconditioning of green and/or natural sand. This includes screening, removing tramp metal, separating and removing fines and oversized agglomerates. The sand is then cooled and sent to storage/reuse.

On the other hand, sand regeneration refers to any mechanical and/or thermal operation associated with the regeneration of chemically bonded sand in order to remove the residual binders. This includes an initial mechanical step (e.g. crushing, screening) followed by mechanical (e.g. grinding wheel, impact drum) and/or thermal (e.g. fluidised bed or rotary furnaces) processes.

2.3.2.13.1 Dust emissions

The reported levels of dust emissions to air from sand reconditioning and regeneration are presented in Figure 2.112 and Figure 2.113.

Some statistical data on the reported dust emission data are presented in the following table.

Table 2.81: Statistical evaluation of the reported dust emission data

Parameter	Number of data	Number of EPs	Number of plants	90 th percentile	Average	Median	10 th percentile
				mg/Nm ³			
Dust	214	89	58	11.93	4.26	1.83	0.29
NB: The data above refer to EPs that are associated with the sand reconditioning and regeneration processes only. Source: [169, TWG 2021]							

2.3.2.13.2 Benzene emissions

Some statistical data on the reported benzene emission data are presented in the following table.

Table 2.82: Statistical evaluation of the reported benzene emission data

Parameter	Number of data	Number of EPs	Number of plants	90 th percentile	Average	Median	10 th percentile
				mg/Nm ³			
Benzene	25	10	8	1.53	0.51	0.15	0.10
NB: The data above refer to EPs that are associated with the sand reconditioning and regeneration processes only. Source: [169, TWG 2021]							

2.3.2.13.3 Formaldehyde emissions

Some statistical data on the reported formaldehyde emission data are presented in the following table.

Table 2.83: Statistical evaluation of the reported formaldehyde emission data

Parameter	Number of data	Number of EPs	Number of plants	90 th percentile	Average	Median	10 th percentile
				mg/Nm ³			
Formaldehyde	23	10	10	1.11	0.50	0.11	0.03
NB: The data above refer to EPs that are associated with the sand reconditioning and regeneration processes only. Source: [169, TWG 2021]							

2.3.2.13.4 NO_x emissions

The reported levels of NO_x emissions to air from sand reconditioning and regeneration are presented in Figure 2.114.

Some statistical data on the reported NO_x emission data are presented in the following table.

Table 2.84: Statistical parameters of the reported NO_x emission data

Parameter	Number of data	Number of EPs	Number of plants	90 th percentile	Average	Median	10 th percentile
				mg/Nm ³			
NO _x	29	13	10	125	29	11.5	1.7
NB: The data above refer to EPs that are associated with the sand reconditioning and regeneration processes only. Source: [169, TWG 2021]							

2.3.2.13.5 SO₂ emissions

The reported levels of SO₂ emissions to air from sand reconditioning and regeneration are presented in Figure 2.115.

Some statistical data on the reported SO₂ emission data are presented in the following table.

Table 2.85: Statistical evaluation of the reported SO₂ emission data

Parameter	Number of data	Number of EPs	Number of plants	90 th percentile	Average	Median	10 th percentile
				mg/Nm ³			
SO ₂	19	7	6	335	100	1.7	0.1
NB: The data above refer to EPs that are associated with the sand reconditioning and regeneration processes only. Source: [169, TWG 2021]							

2.3.2.13.6 TVOC emissions

The reported levels of TVOC emissions to air from sand reconditioning and regeneration are presented in Figure 2.116.

Some statistical data on the reported TVOC emission data are presented in the following table.

Table 2.86: Statistical evaluation of the reported TVOC emission data

Parameter	Number of data	Number of EPs	Number of plants	90 th percentile	Average	Median	10 th percentile
				mg/Nm ³			
TVOC	32	16	13	61.73	31.79	7.90	1.06
NB: The data above refer to EPs that are associated with the sand reconditioning and regeneration processes only. Source: [169, TWG 2021]							

2.3.2.13.7 Figures for emissions to air

The structure of figures presented in this section is explained in Section 2.3.2.1.10.

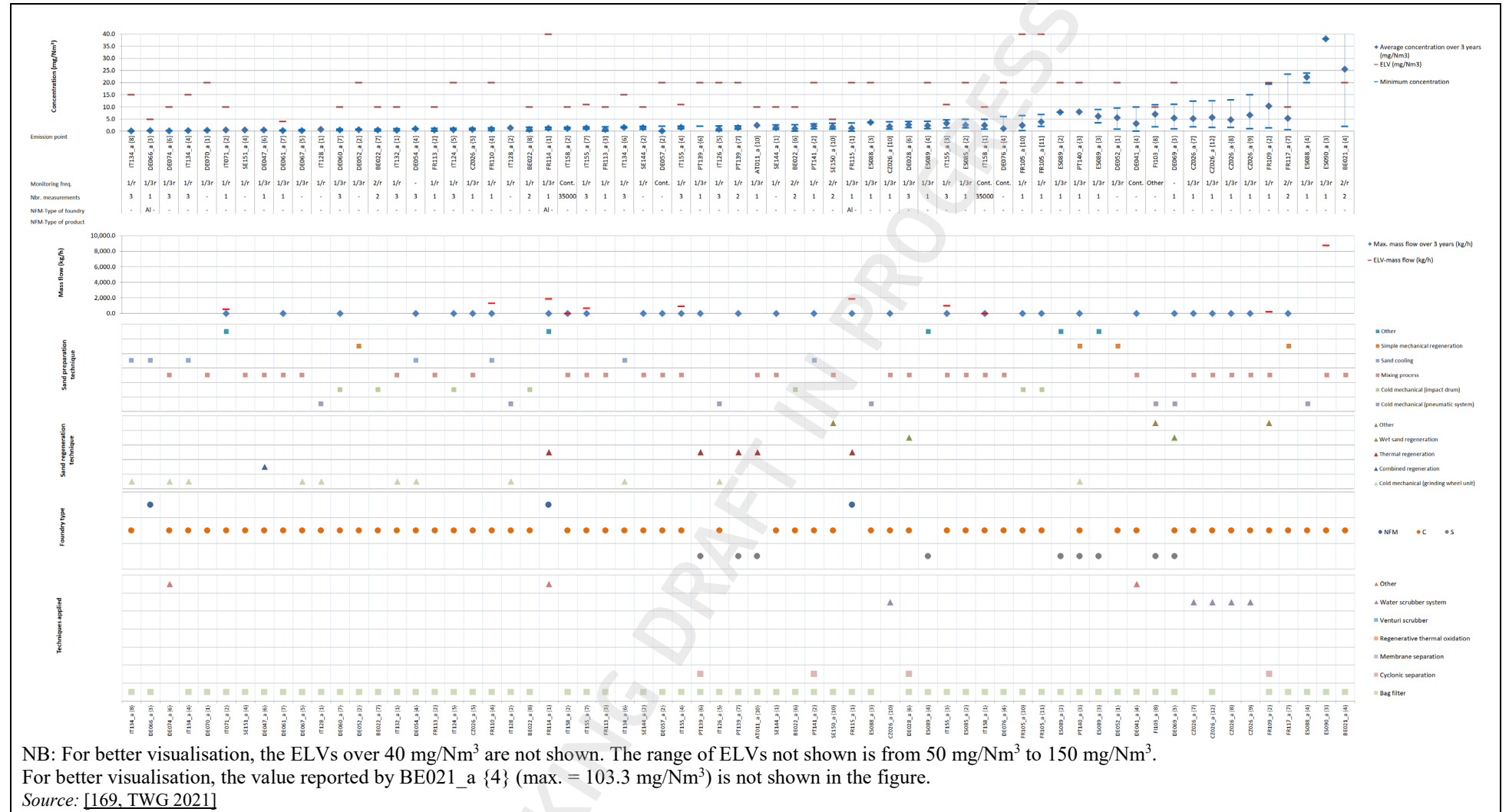


Figure 2.112: Dust emissions from sand reconditioning (1/2)

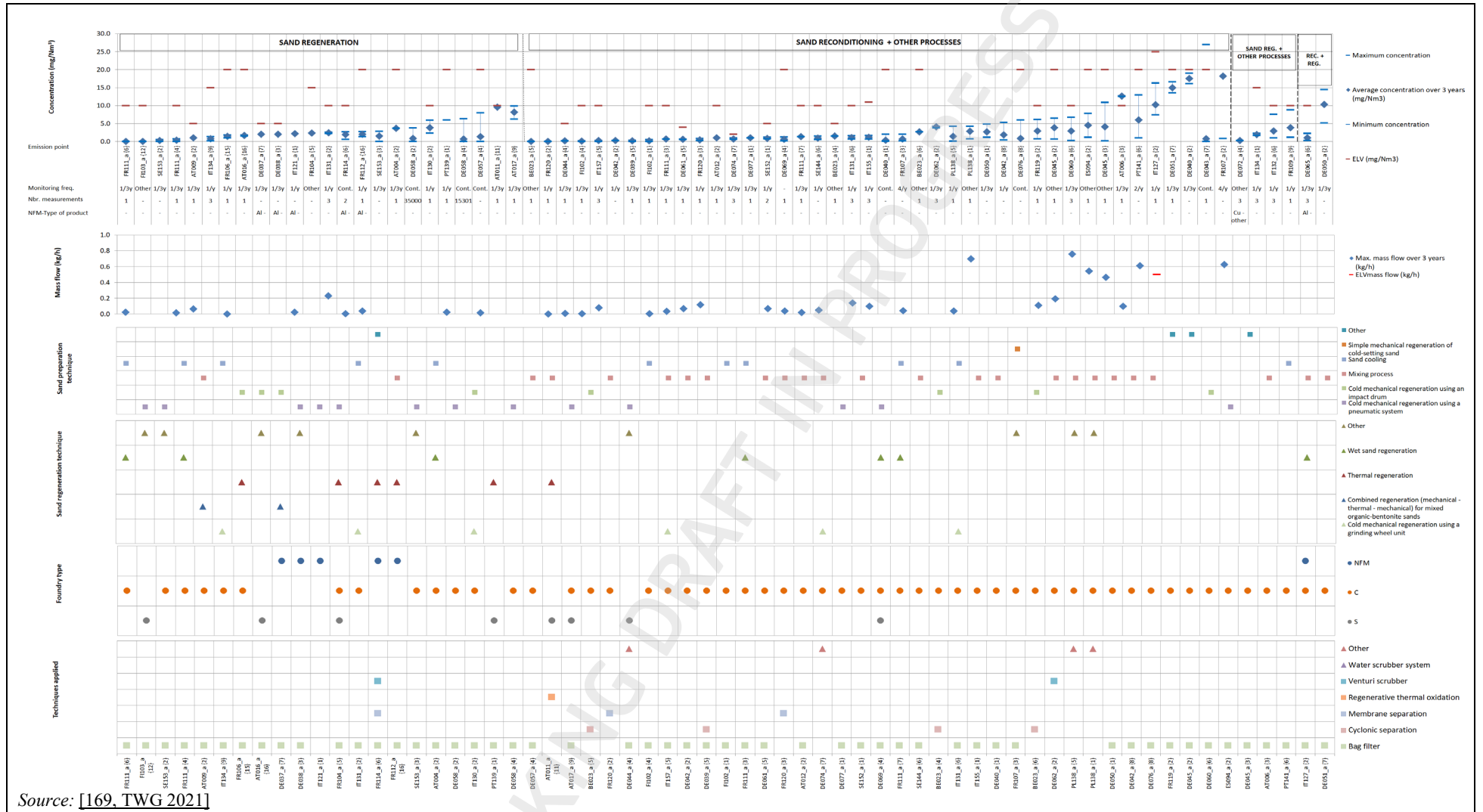


Figure 2.113: Dust emissions from sand reconditioning and regeneration (2/2)

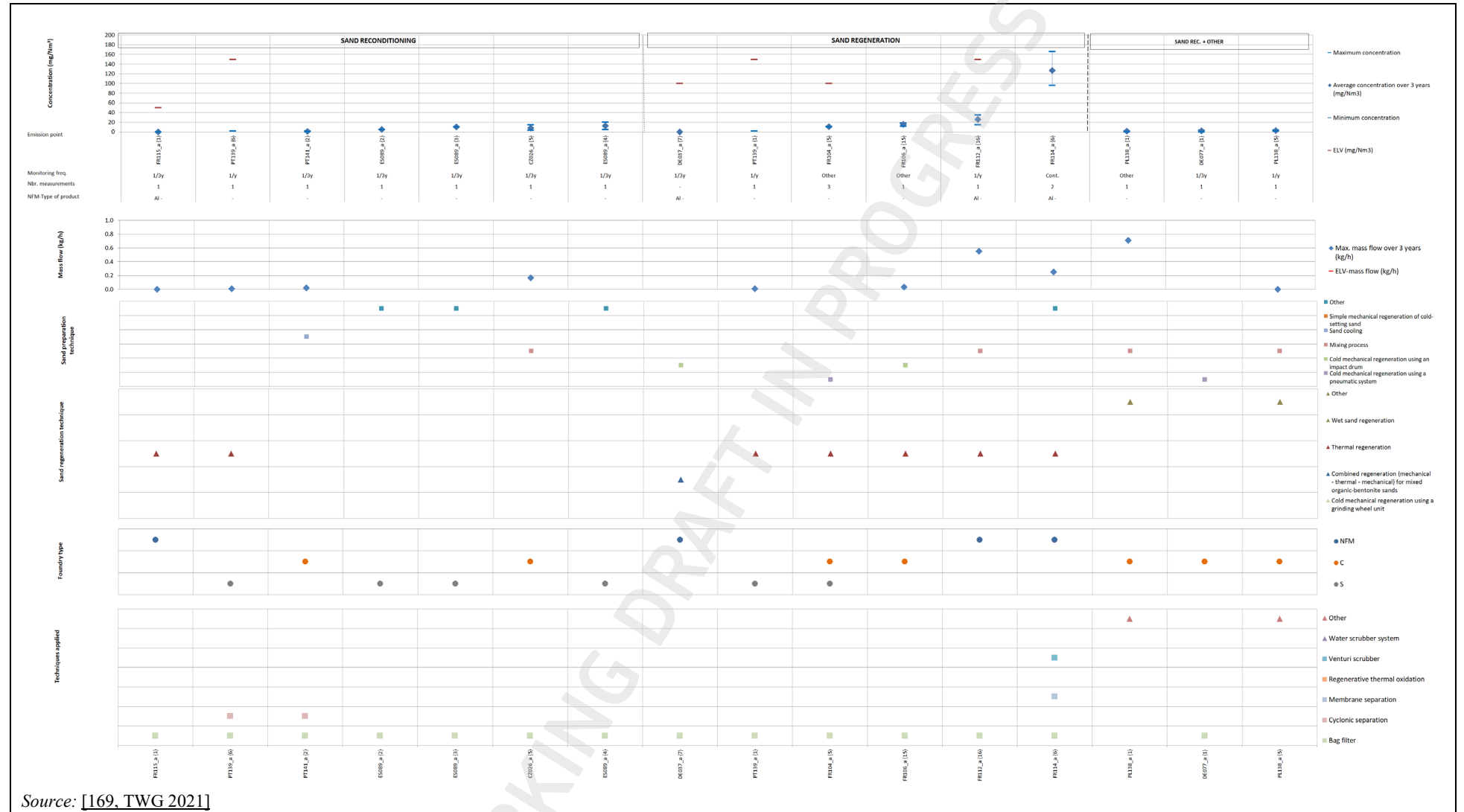


Figure 2.114: NO_x emissions from sand reconditioning and regeneration

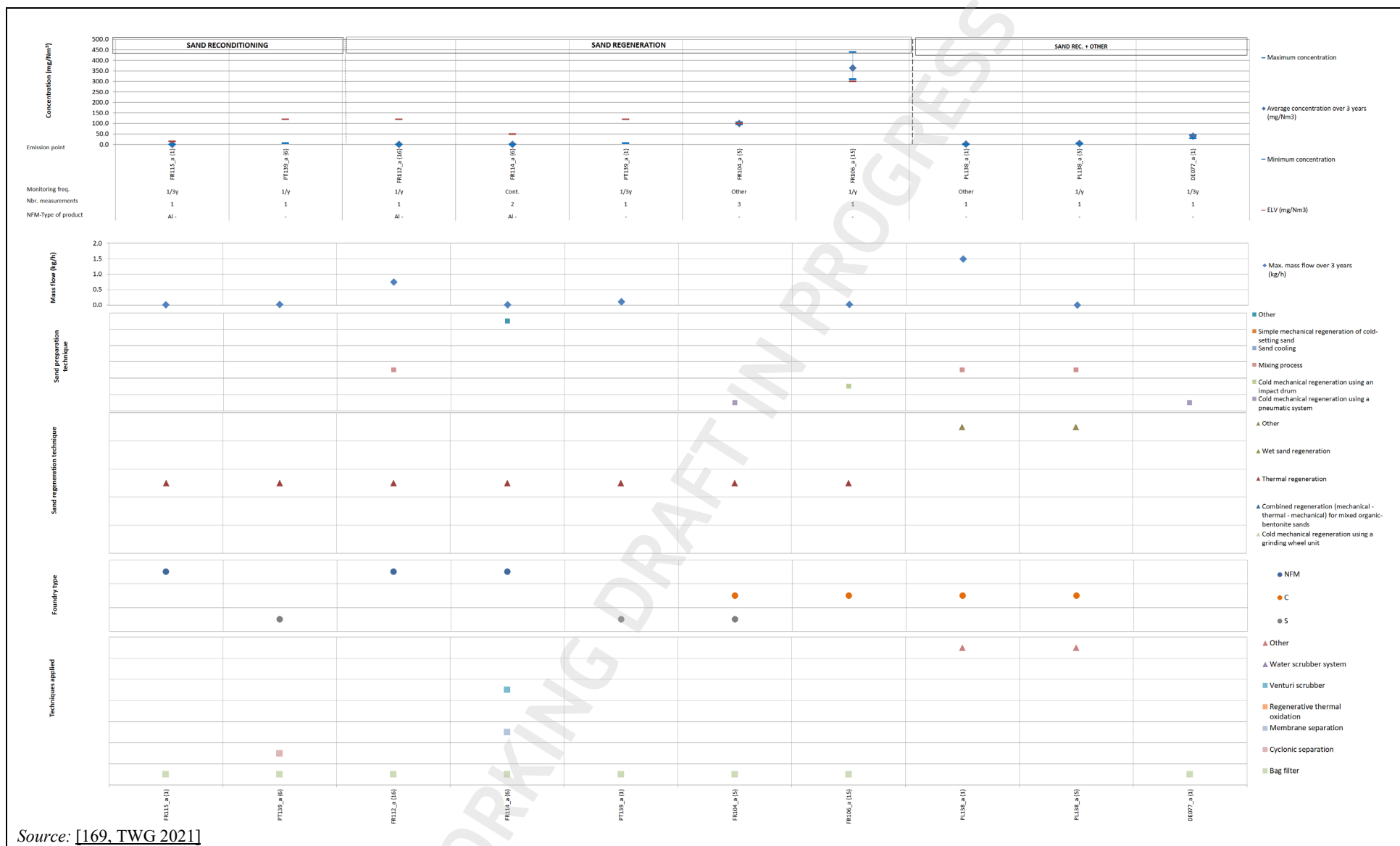


Figure 2.115: SO₂ emissions from sand reconditioning and regeneration

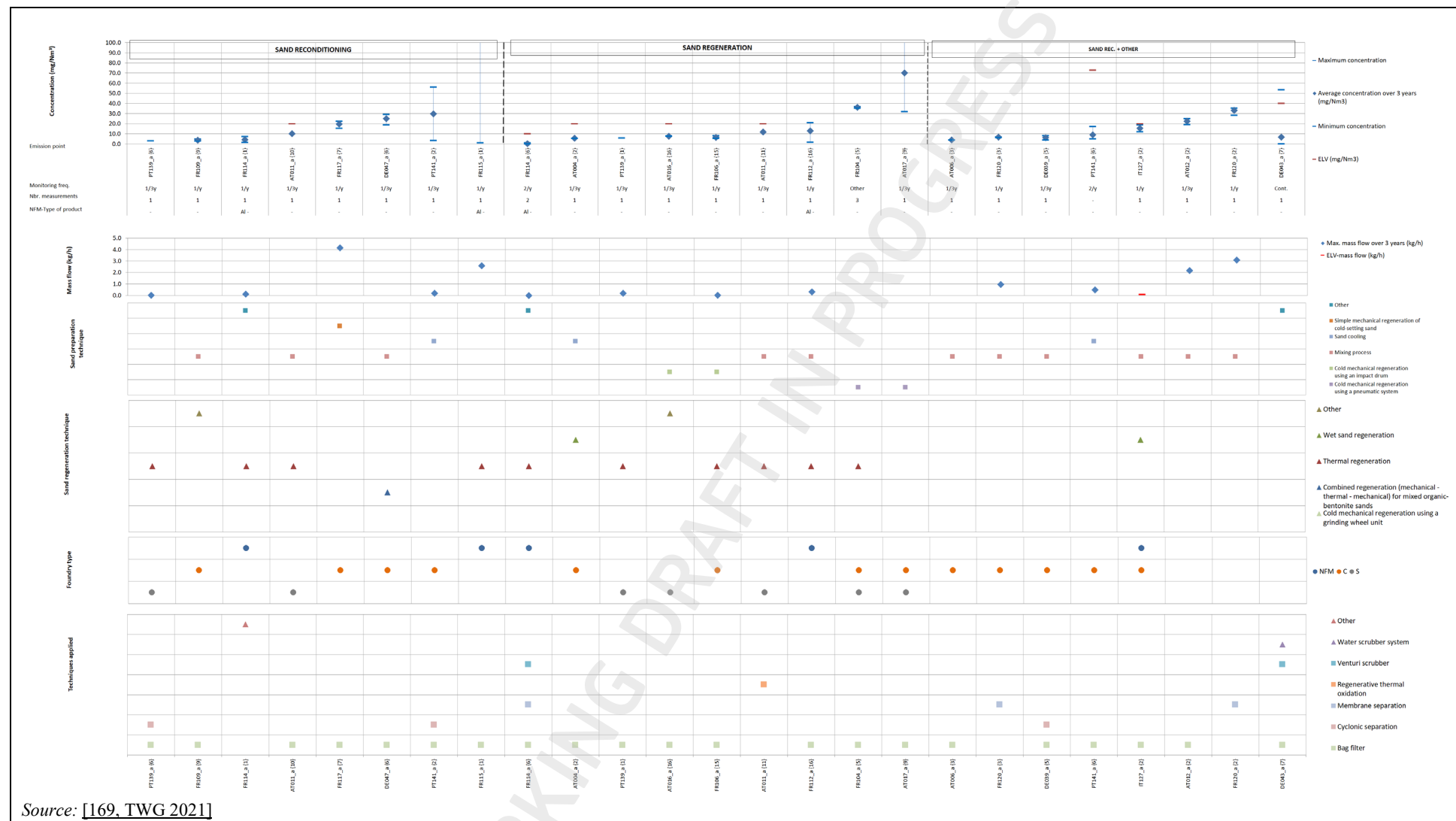


Figure 2.116: TVOC emissions from sand reconditioning and regeneration

2.3.3 Emissions to water

This section contains information on emissions to water from foundries (direct and indirect discharge to a receiving water body).

Figures for emissions to water consist of four sections:

- The upper part (section) shows the maximum concentration and the minimum of each of the 3 reporting years, and the average value obtained over the reporting period. Below the x-axis, information is included such as the point of release, the monitoring frequency and the number of measurements reported.
- The second part (section) shows the average mass flow values, either for the maximum concentration obtained over the reporting period or the average for the year when the maximum concentration was obtained.
- The third part (section) of the graph provides information on the processes associated with the generation of waste water.
- The fourth part (section) of the graph provides the information on the BAT candidates applied. All the figures are sorted in ascending order of the maximum concentration values for the 3 reporting years.

The following tables contain an overview of the reported data for emissions to water (direct and indirect discharges).

Table 2.87: Statistical evaluation of the reported emission data for direct discharge

Substance/ parameter	Number of emission points	Max. concentration	80 th percentile	Average	Median	20 th percentile
		mg/l				
COD	12	120	49	38.1	30	12
TSS	10	120	28.2	27.3	17.4	9.6
Zn	8	0.8	-	0.2	0.1	-
Fe	7	5.5	-	1.6	1.1	-
Ni	6	0.12	-	0.02	0.01	-
Total N	6	25.4	-	12.1	8.9	-
As	5	0.06	-	0.01	-	-
Cr	5	0.01	-	0.0033	0.0003	-
Cu	5	0.6	-	0.062	0.003	-
HOI	5	1.29	-	0.39	0.10	-
Cd	4	0.01	-	0.0011	0.004	-
Oils/total hydrocarbons	4	1.0	-	0.29	0.10	-
Pb	4	0.02	-	0.006	0.00004	-
Total P	4	1.0	-	0.39	0.3	-
Al	3	0.8	-	0.3	0.34	-
AOX	2	0.14	-	0.12	-	-
BOD5	2	14	-	12	-	-

Table 2.88: Statistical evaluation of the reported emission data for indirect discharge

Substance/ parameter	Number of emission points	Max. concentration	80 th percentile	Average	Median	20 th percentile
		mg/l				
COD	38	43 800	1 340	2 222	67	27.8
TSS	33	408	160	85.6	56.3	16
Zn	50	4.9	0.82	0.43	0.13	0.04
Fe	11	35	4.52	4.17	1.1	0.19
Ni	33	2.5	0.08	0.09	0.01	0.004
Total N	24	120	42.4	23.2	10.4	2.77
Fluoride	5	6.64	-	2.44	0.74	-
As	17	0.05	0.026	0.0086	0.005	0.0021
Cr	34	1.3	0.04	0.05	0.01	0.004
Cu	41	0.7	0.13	0.08	0.04	0.02
HOI	18	2 410	15	162.32	1.2	0.7
Cd	20	0.02	0.0047	0.0022	0.0008	0.0001
Oils/total hydrocarbons	24	25.30	9.33	4.42	10.4	0.16
Pb	38	0.35	0.05	0.034	0.01	0.003
Total P	9	1.3	0.04	0.05	0.01	0.002
Al	11					
AOX	23	4.8	1.6	0.72	0.22	0.05
Hg	11	0.0019	0.0012	0.0003	0.0002	0.0001
Phenols (Phenol index)	10	2.6	0.4	0.27	0.059	0.0058
Mn	6	0.51	-	0.13	0.05	-

2.3.3.1 Figures for emissions to water



Figure 2.117: Adsorbable organically bound halogens (AOX) emissions for direct and indirect discharges from wet scrubbing and slag granulation in cast iron foundries using cupola furnaces

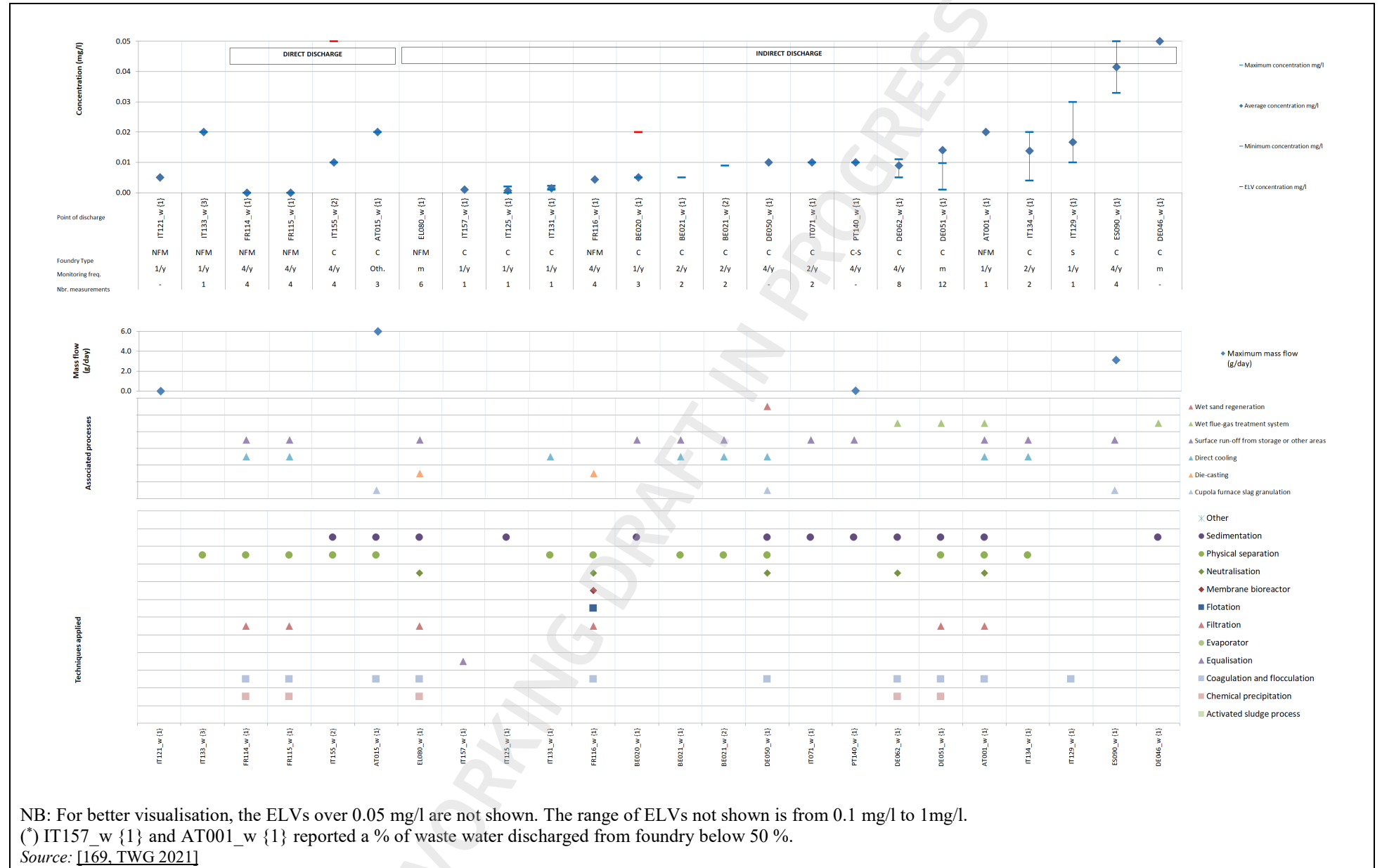
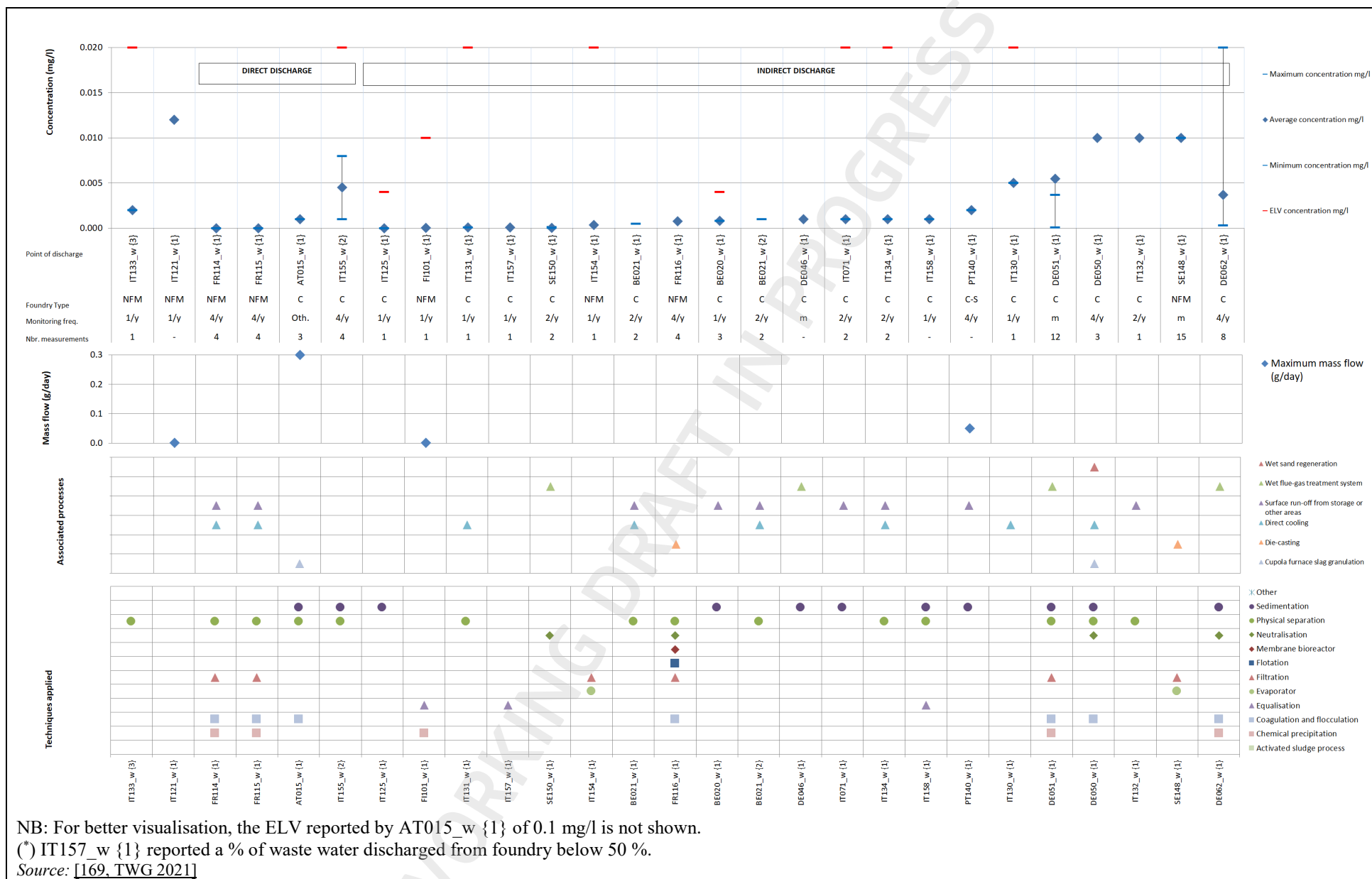


Figure 2.118: Arsenic (As) emissions for direct and indirect discharges



NB: For better visualisation, the ELV reported by AT015_w {1} of 0.1 mg/l is not shown.
 (*) IT157_w {1} reported a % of waste water discharged from foundry below 50 %.
 Source: [169, TWG 2021]

Figure 2.119: Cadmium (Cd) emissions for direct and indirect discharges

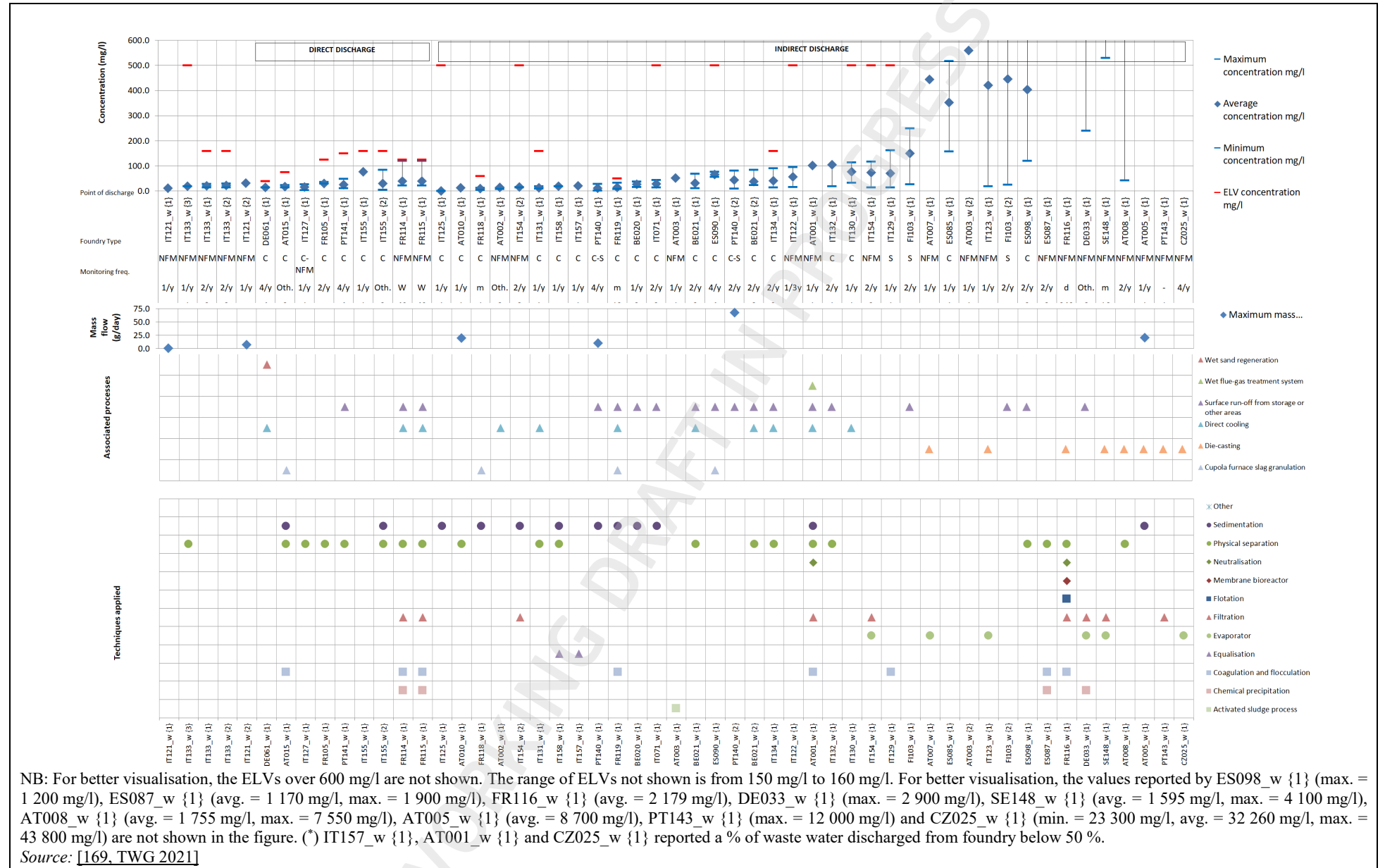
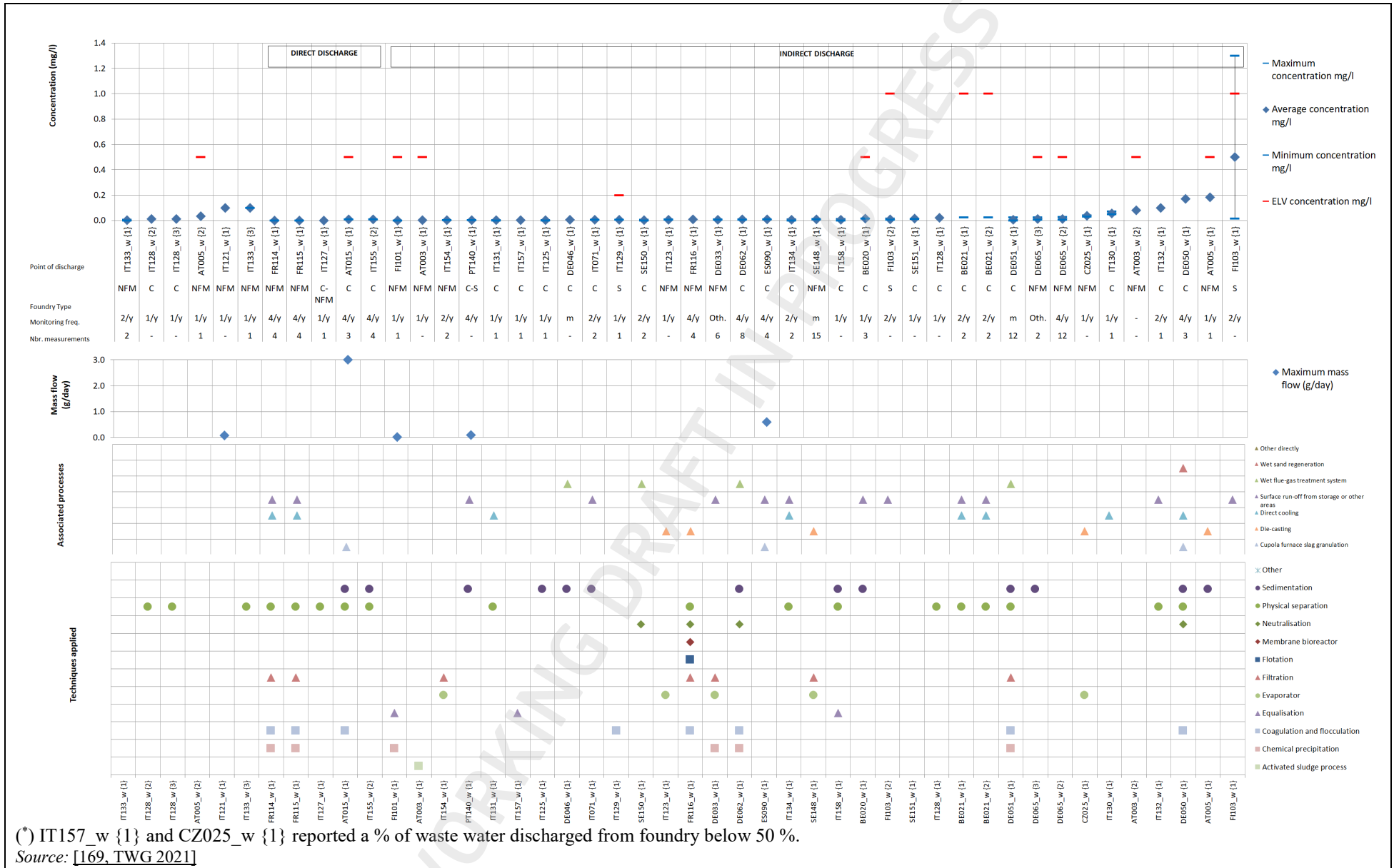


Figure 2.120: COD emissions for direct and indirect discharges



(*) IT157_w {1} and CZ025_w {1} reported a % of waste water discharged from foundry below 50 %.
 Source: [169, TWG 2021]

Figure 2.121: Chromium (Cr) emissions for direct and indirect discharges

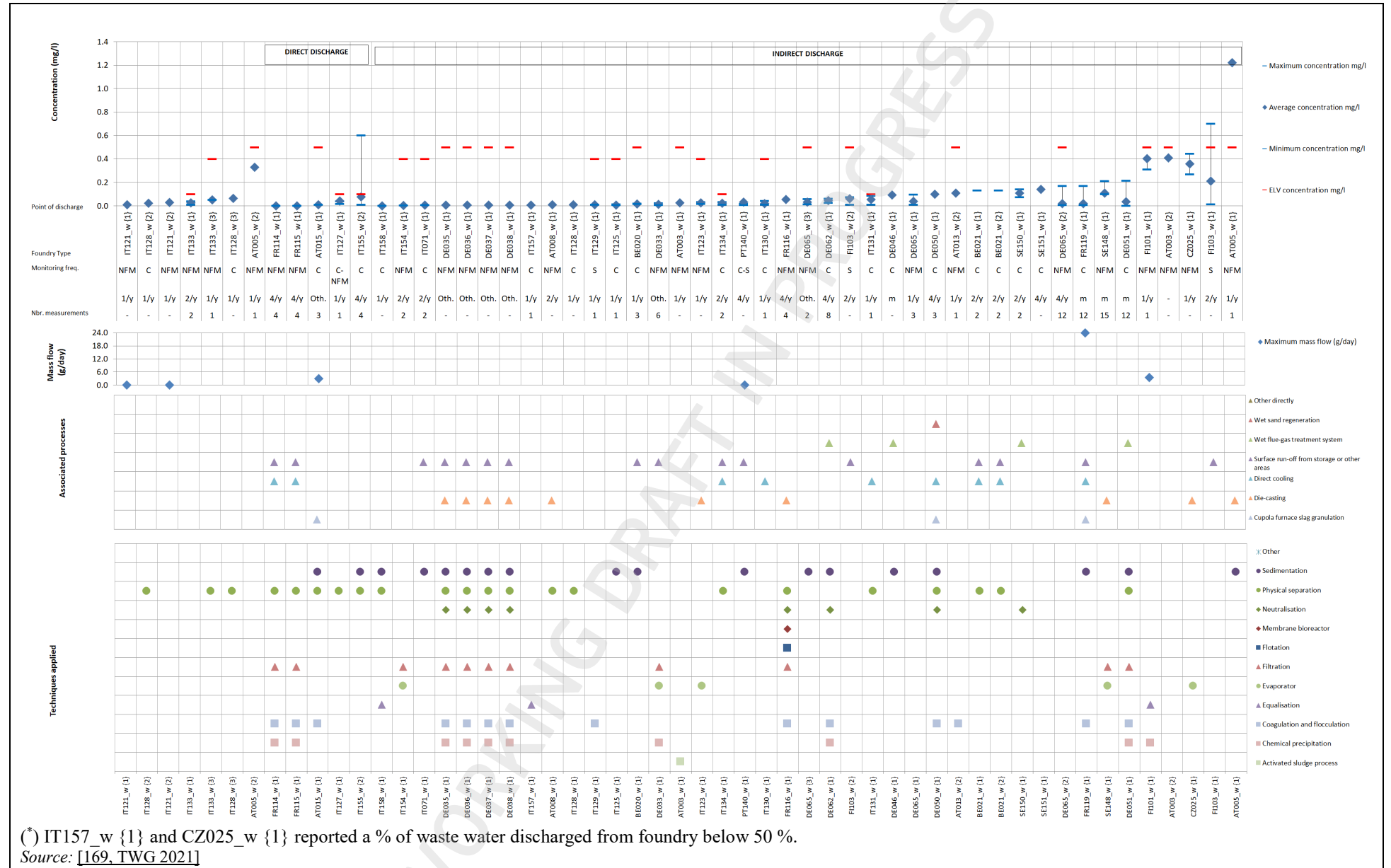


Figure 2.122: Copper (Cu) emissions for direct and indirect discharges

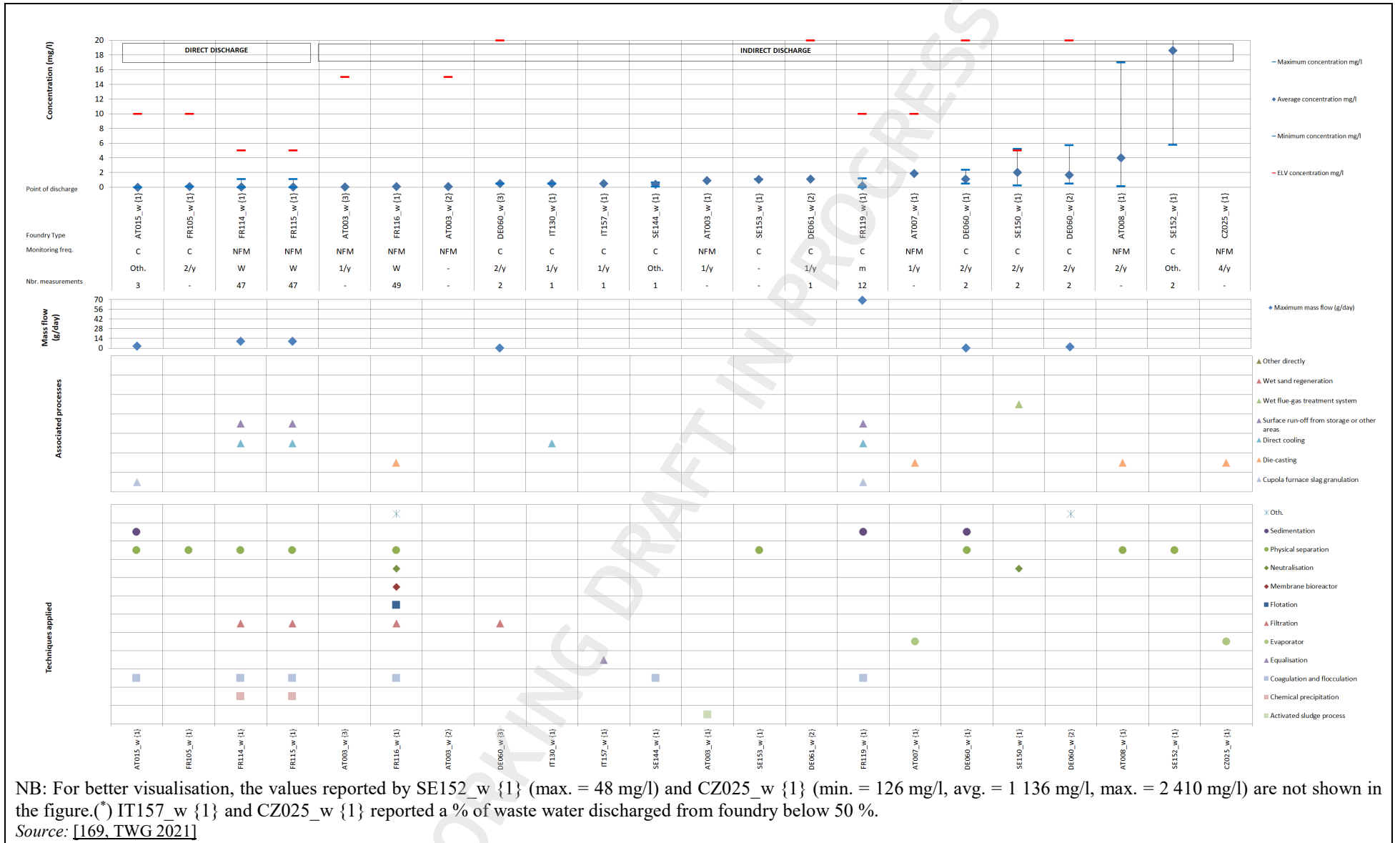


Figure 2.123: Hydrocarbon oil index (HOI) emissions for direct and indirect discharges

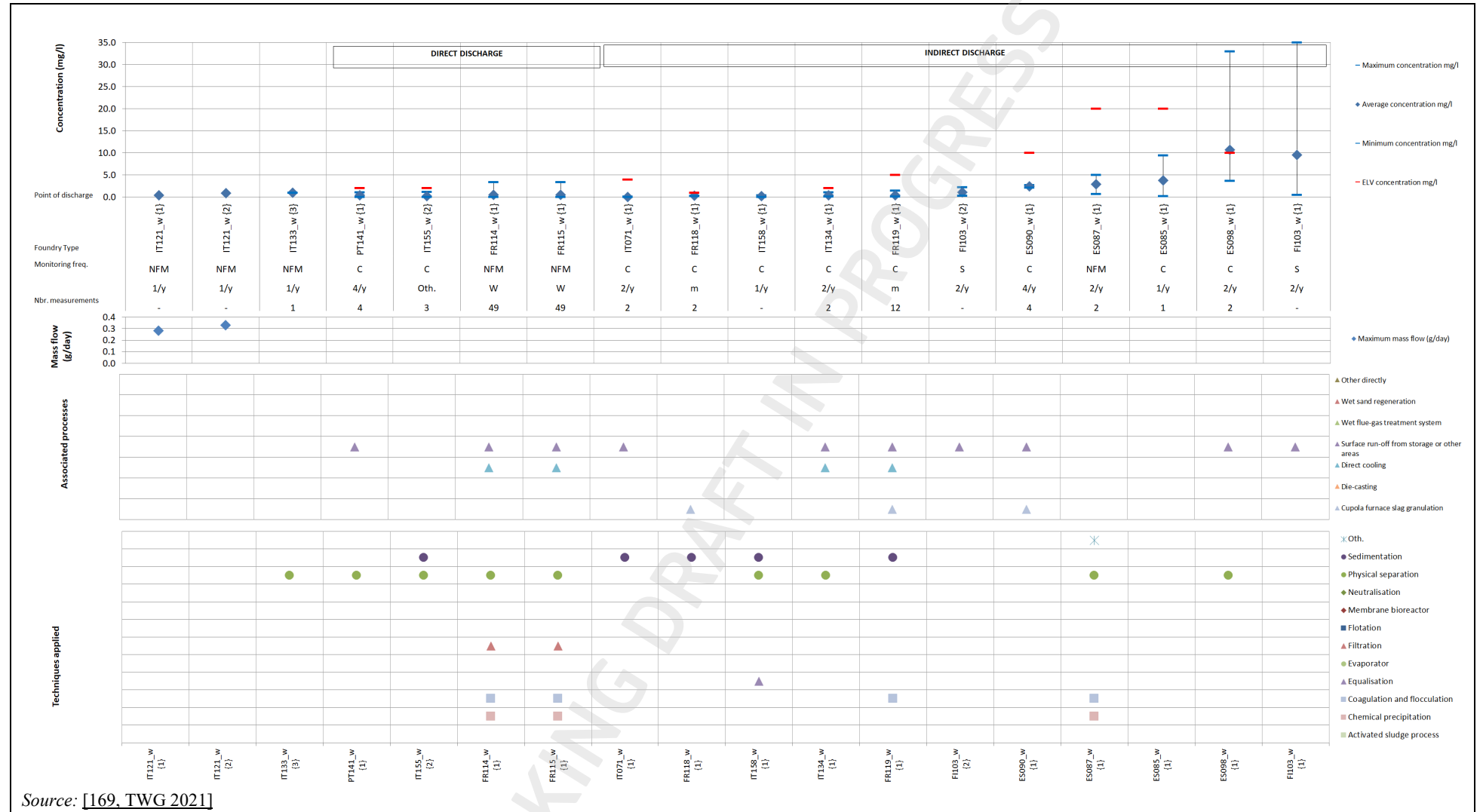


Figure 2.124: Iron (Fe) emissions for direct and indirect discharges

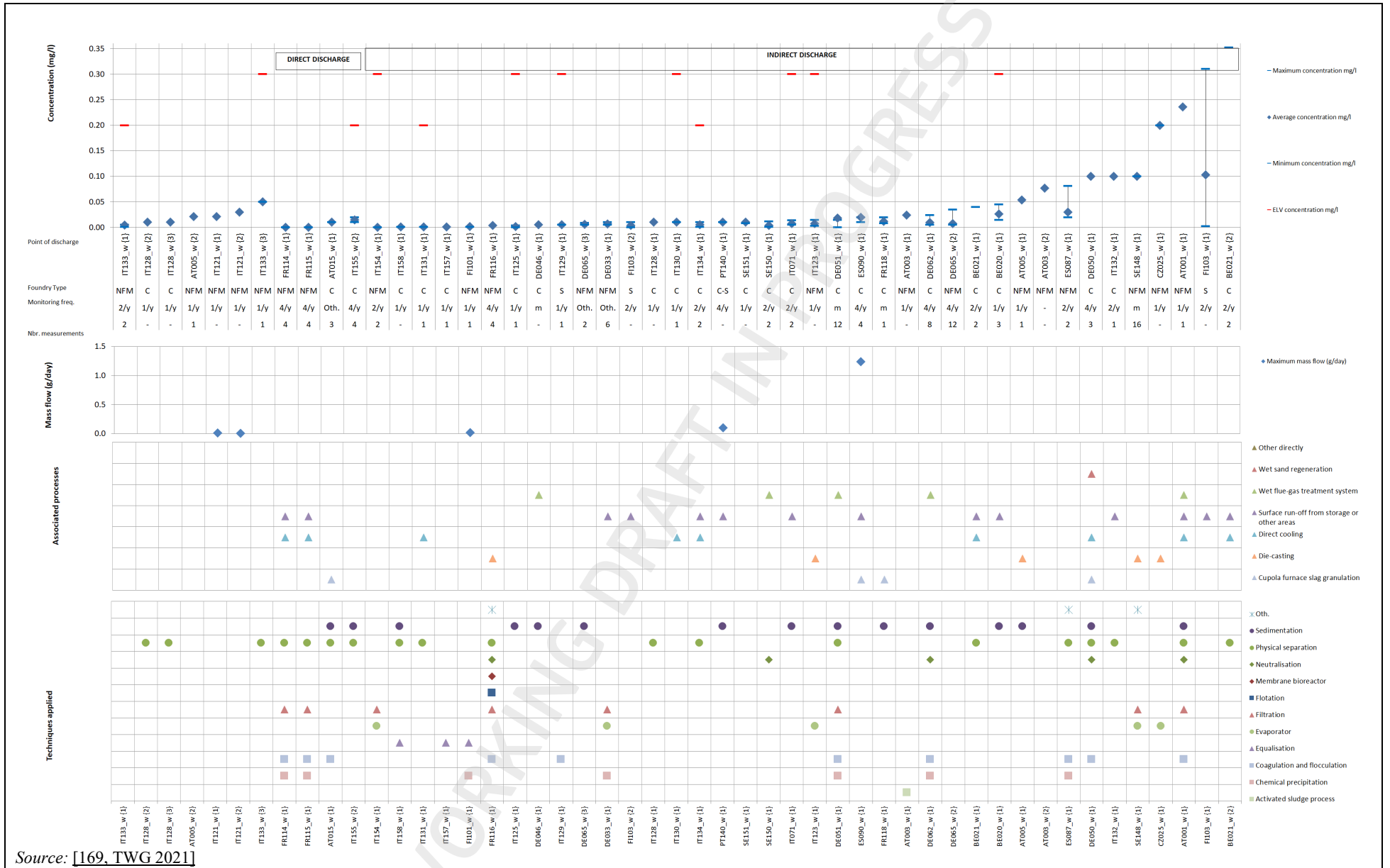
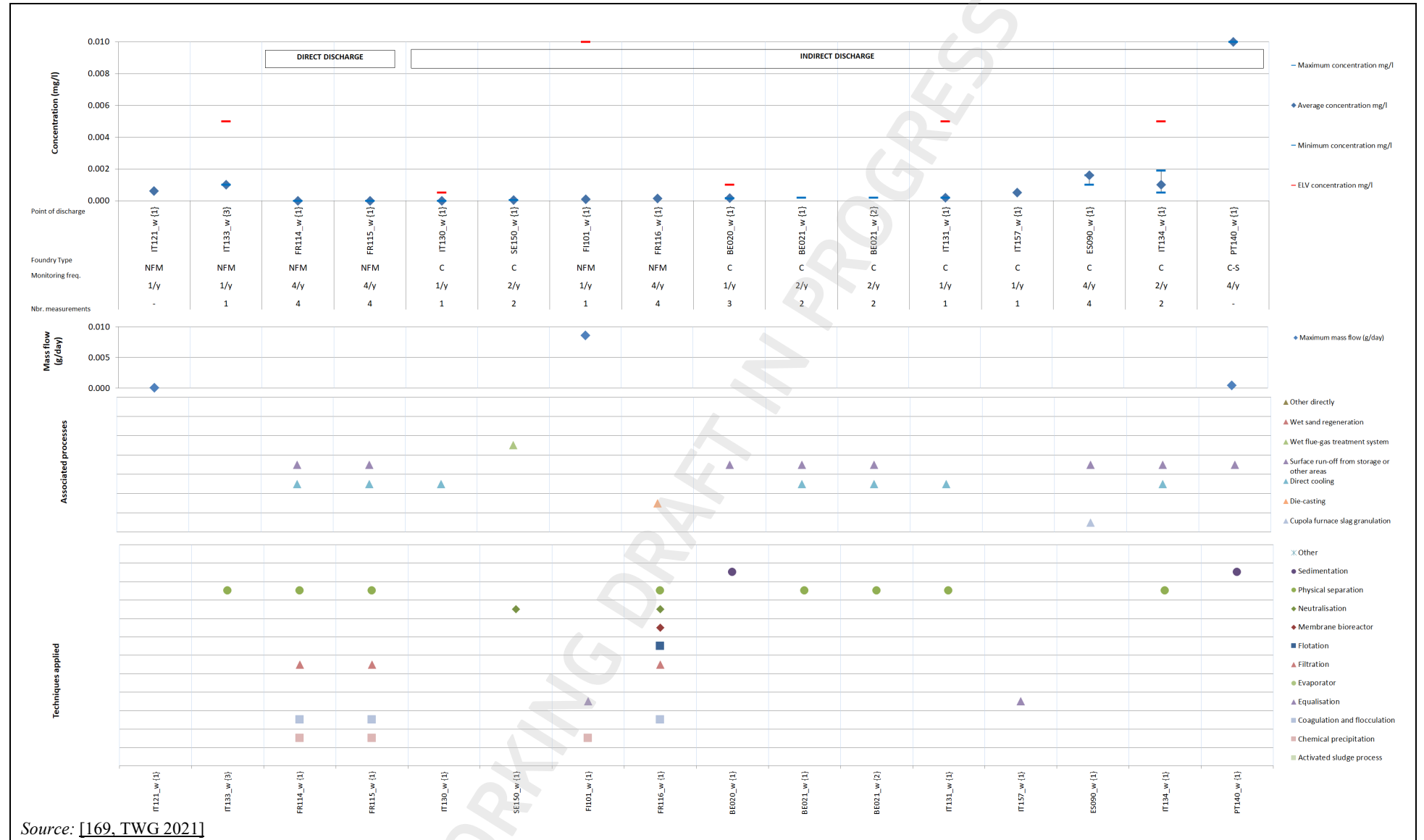


Figure 2.125: Lead (Pb) emissions for direct and indirect discharges



Source: [169, TWG 2021]

Figure 2.126: Mercury (Hg) emissions for indirect discharges

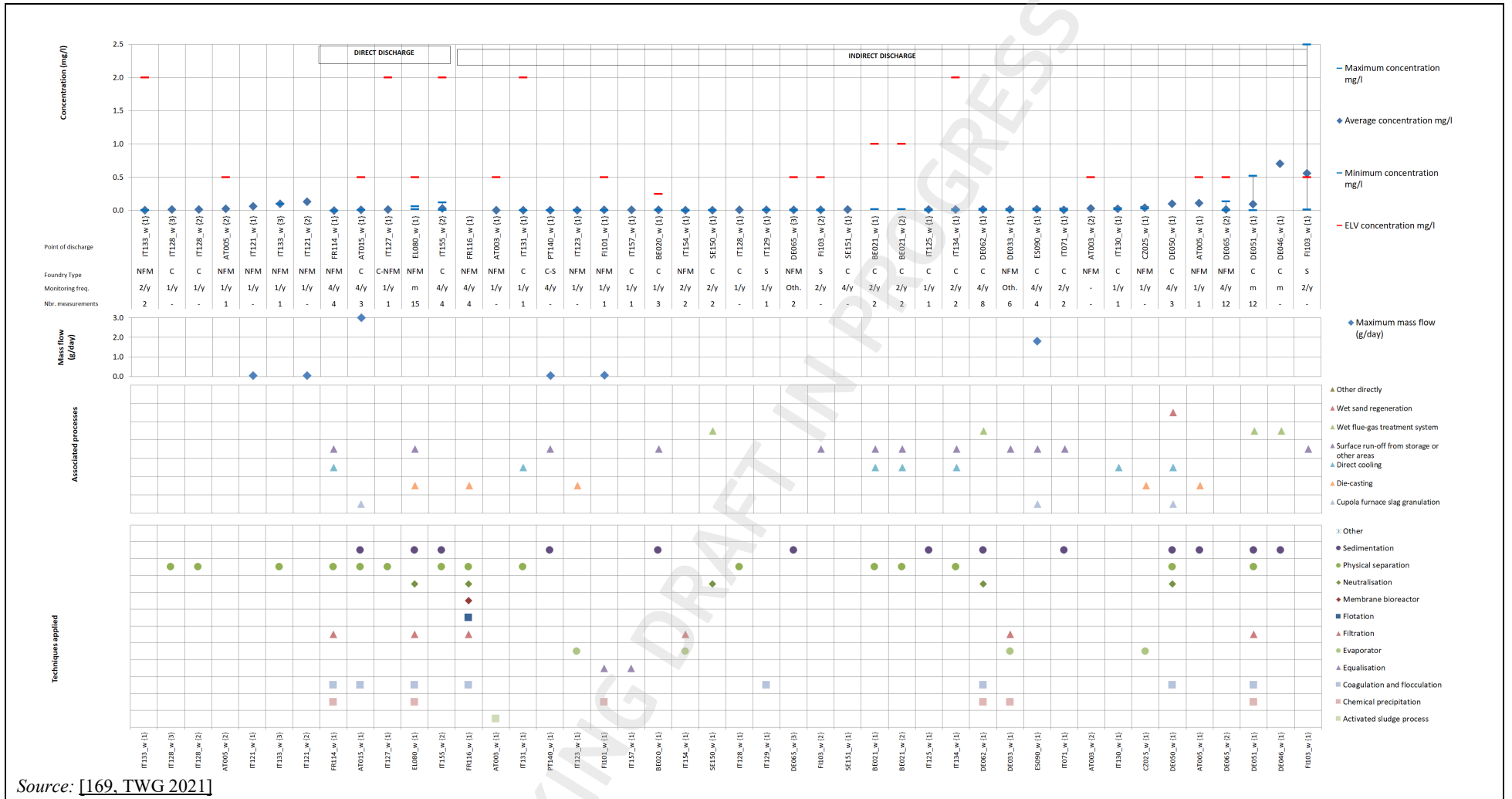


Figure 2.127: Nickel (Ni) emissions for direct and indirect discharges

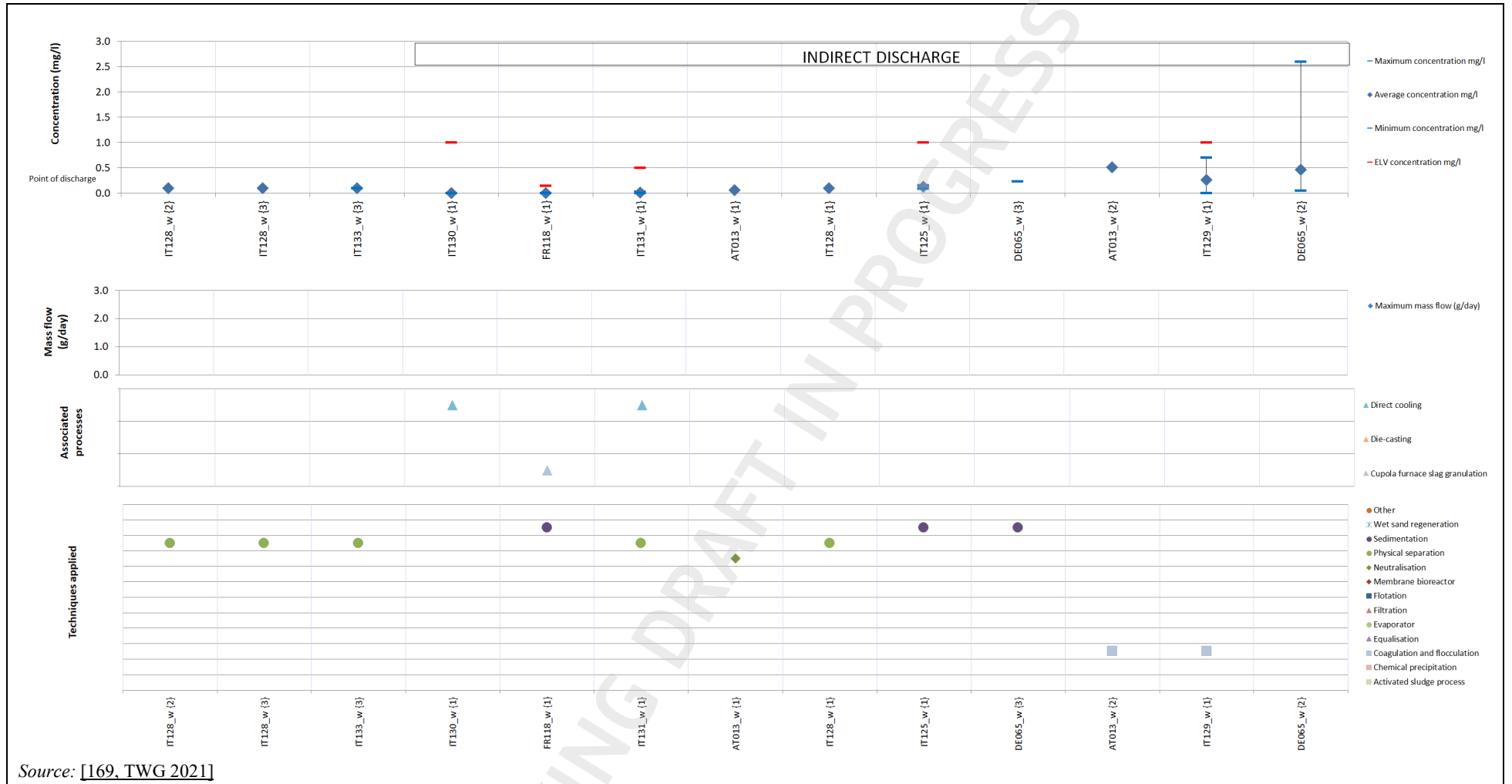


Figure 2.128: Phenol index (PI) emissions for indirect discharges

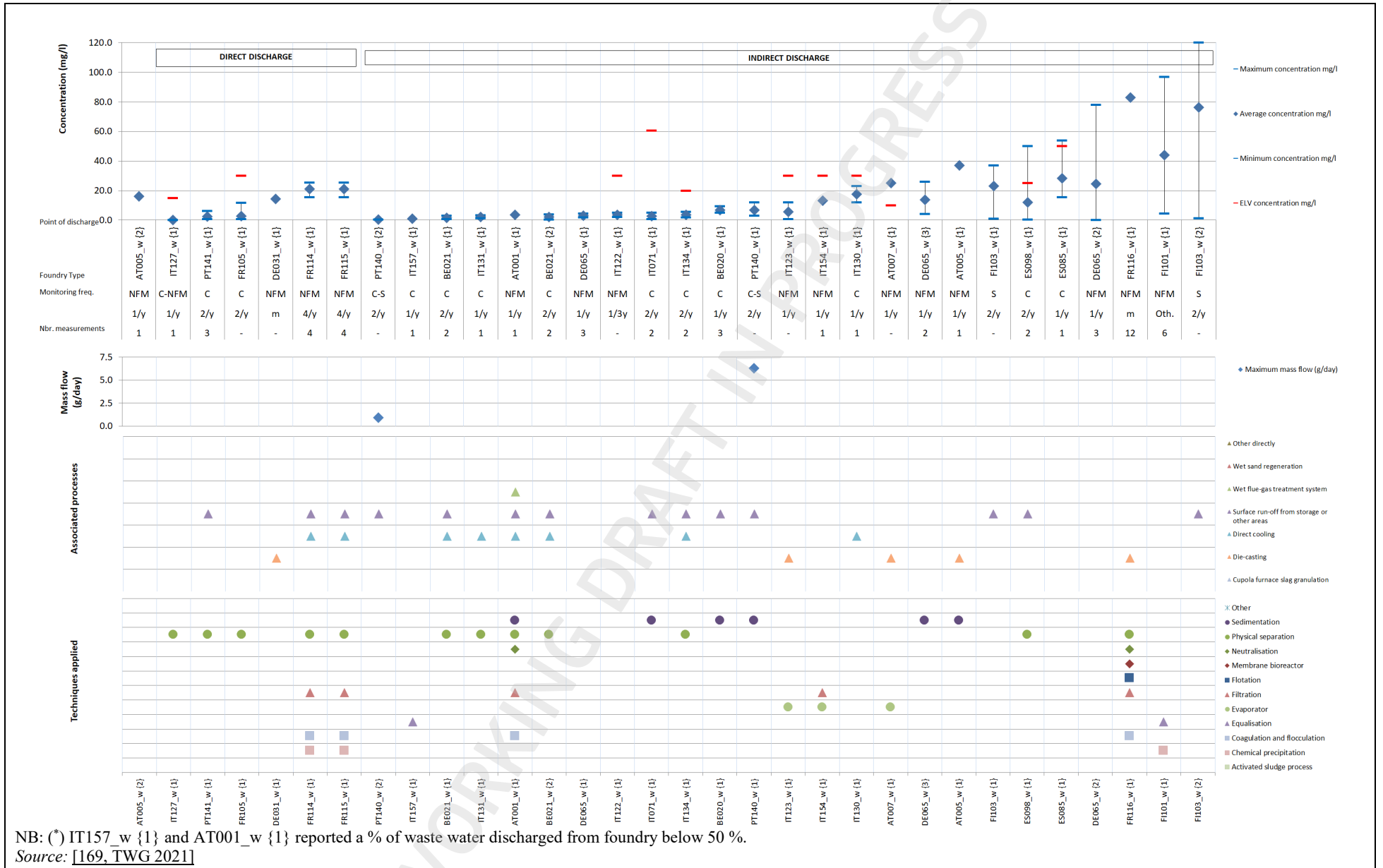


Figure 2.129: Total nitrogen (Total N) emissions for direct and indirect discharges

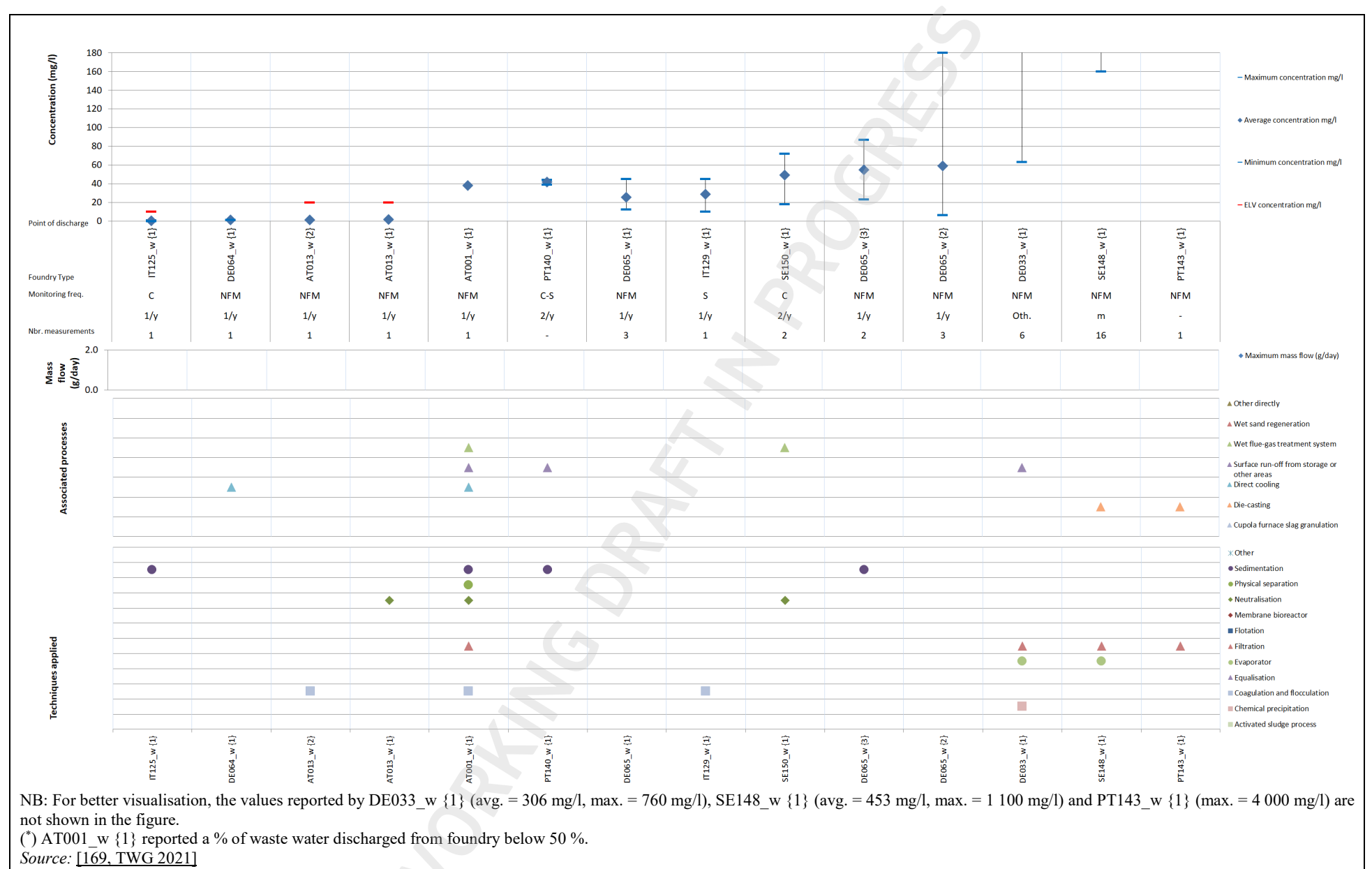
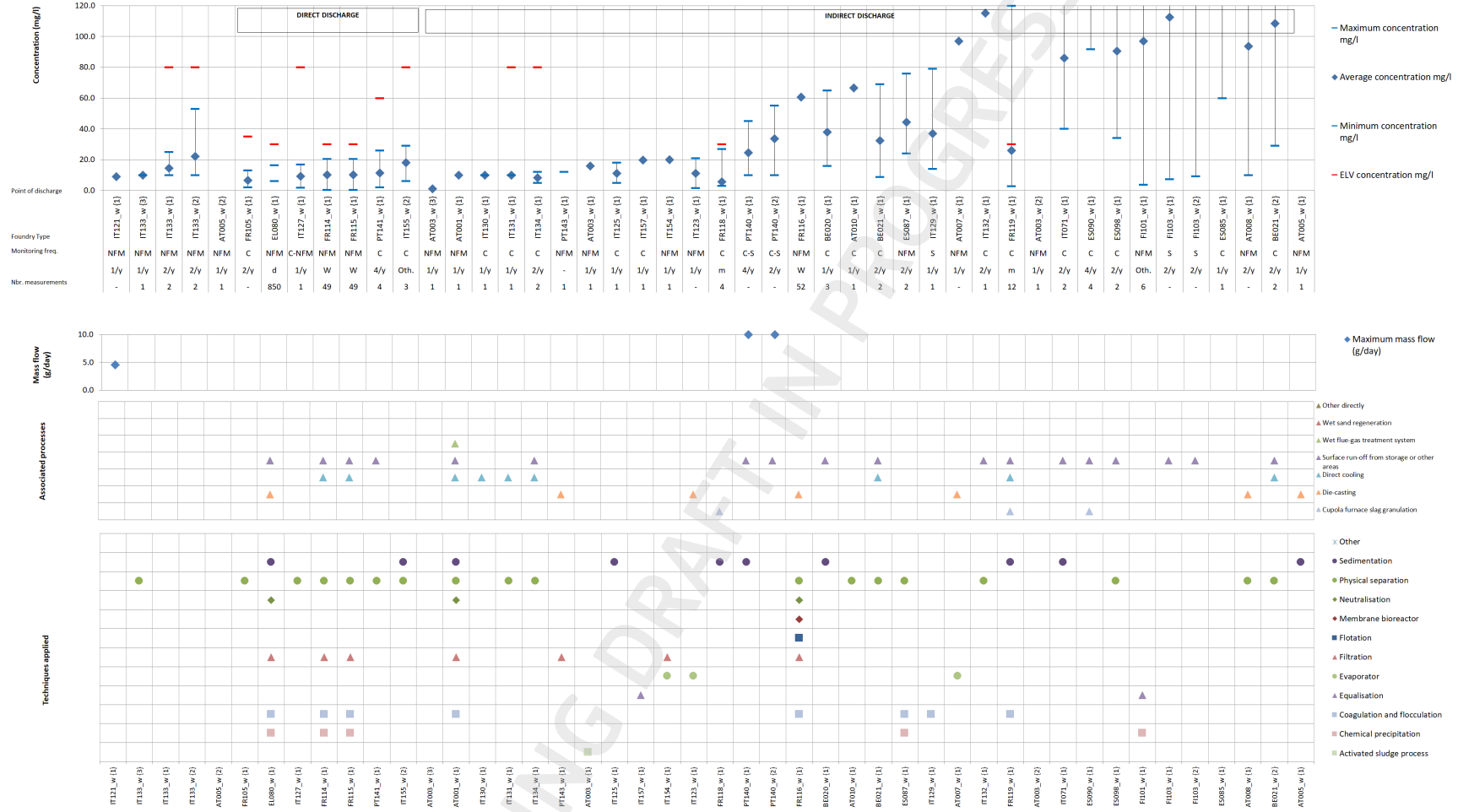


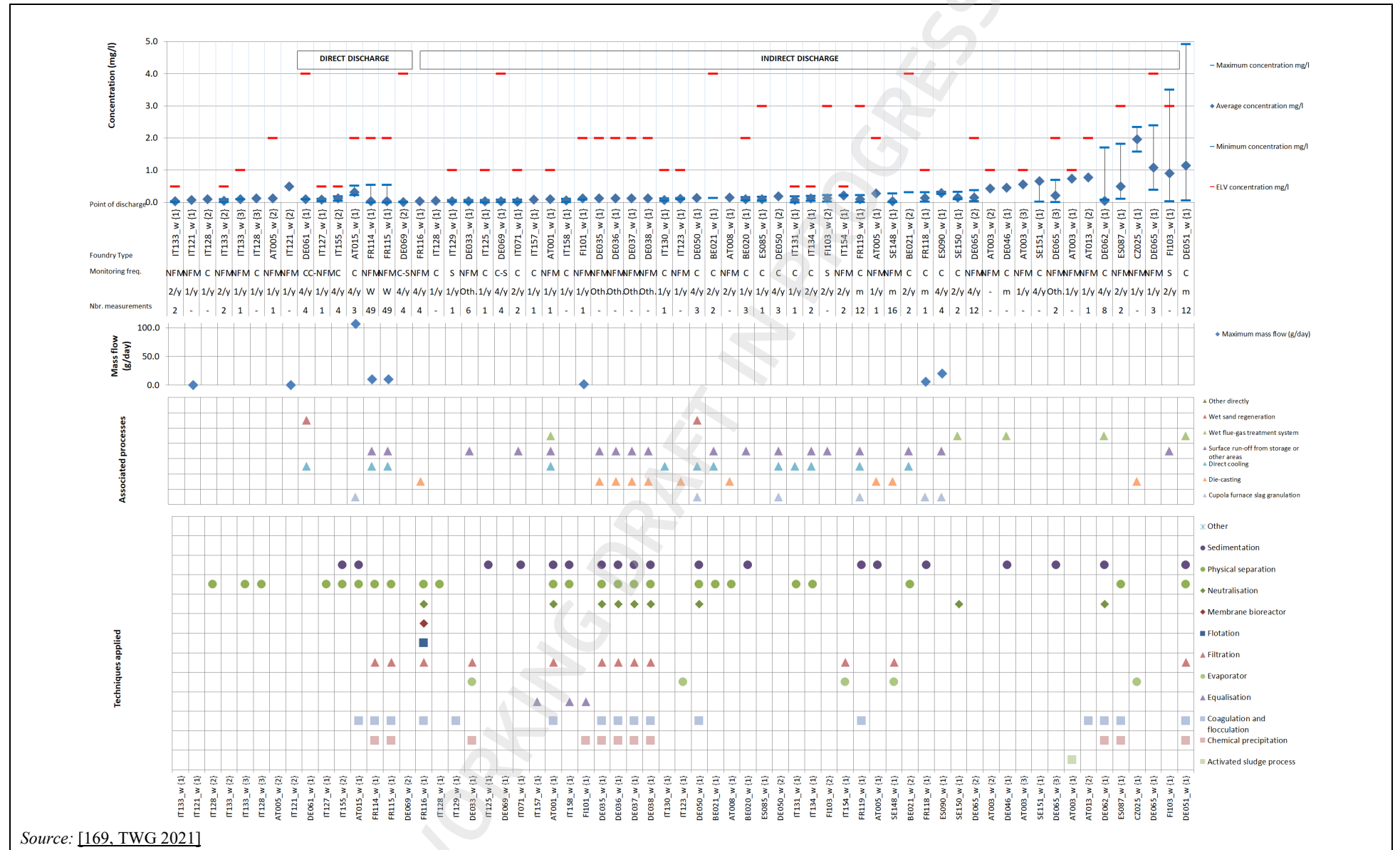
Figure 2.130: Total organic carbon (TOC) emissions for indirect discharges



EP	Average concentration (mg/l)	Maximum concentration (mg/l)	EP	Average concentration (mg/l)	Maximum concentration (mg/l)
AT005 w {2}	364		FI103 w {1}		250
AT003 w {2}	147		FI103 w {2}	158	270
IT071 w {1}		150	ES085 w {1}	177	386
ES090 w {1}	140	190	AT008 w {1}		390
ES098 w {1}		206	BE021 w {2}		408
FI101 w {1}		240	AT005 w {1}	880	

Source: [169, TWG 2021]

Figure 2.131: Total suspended solids (TSS) emissions for direct and indirect discharges



Source: [169, TWG 2021]

Figure 2.132: Zinc (Zn) emissions for direct and indirect discharges

2.3.4 Water consumption and waste water generation

2.3.4.1 Processes associated with water consumption

Table 2.89 below shows the number of plants that reported data for specific water consumption (expressed in m³ per tonne of liquid metal) for specific foundry processes. [169, TWG 2021]

Table 2.89: Number of plants which reported specific water consumption levels for specific foundry processes

Process	Number of plants which reported water consumption data
Moulding with wet sand	36
High-pressure die-casting	23
Wet treatment of used sand	12
Wet scrubbing for cold-box mould / core-making	10
Finishing process	5
Cooling	4
Wet scrubbing for core-making using the SO ₂ process	4
Cupola furnace wet scrubbing	3

The reported levels of specific water consumption at plant level, expressed in m³ per tonne of liquid metal, are presented in Figure 2.133, Figure 2.134 and Figure 2.135.

In Figure 2.136, the distribution of reported water consumption levels at process level, for specific foundry processes is presented.

2.3.4.2 Waste water generation from scrap storage

Scrap may have adhering soil, and external scrap typically exhibits production-specific impurities. The adhering impurities may be washed off when it rains and may then enter the soil and groundwater. An overview of the possible impurities is given in the following table.

Table 2.90: Possible impurities for specified scrap types

Scrap type	Adhering impurities
Swarf	Cutting oils, emulsions (may contain chlorine)
Punching scrap	Punching oils (may contain chlorine)
Broken machine castings, not conforming to specifications	Hydraulic oils, gear oils
Scrap from cold forming and smitheries	Phosphates, zinc soaps, graphite, forming oils
<i>Source: [93, UBA 2003]</i>	

If the adhering impurities are substances constituting a hazard to water (oils, emulsions), then requirements on the storage of substances constituting a hazard to water must be complied with.

2.3.4.3 Waste water generation from wet scrubbers used in cupola melting

Wet scrubbers are in use in melting shops to clean the cupola off-gases. Wet scrubbers use water to remove dust particles (average loading: 10 – 15 g/Nm³) and gases such as sulphur dioxide from cupola off-gases. In the settling tank, a large part of the solid particles are captured and thereby almost completely removed from the scrubbing water.

he partly acid gases washed out of the cupola off-gases, such as sulphur dioxide, accumulate in the scrubbing water, causing its salt concentration to increase (e.g. the formation of sodium sulphate) and its pH to decrease. This salt accumulation is supported by evaporation losses, so it is necessary to draw the water off from time to time.

Waste water from wet dedusting systems in melting shops mainly contains:

- solids such as oxides of silicon, iron and aluminium, calcium carbonates and cyanides;
- heavy metals, such as copper or zinc;
- organic pollutants, which can enter waste water via soiled scrap.

AOX (adsorbable organically bound halogens) levels in water used for the scrubbing of cupola off-gases can amount to several milligrams. Possible causes of AOX are scrap coatings and adhering chlorinated organic compounds entering the water during the gas scrubbing process. Chlorinated organic compounds can also reach the water via auxiliaries, such as commercial-grade hydrochloric acid or iron and aluminium chlorides, which are used as flocculants.

Table 2.91 gives an overview of the pollutant concentrations in filter effluent from the dewatering of sludge from the wet scrubbers of cupola furnaces.

Table 2.91: Pollutant concentrations in filter effluent from dewatering the sludge from the wet scrubbers of cupola furnaces

Analyte	Units	Value
pH value		7.2 – 9.9
El. conductivity	µS/cm	1 400 – 18 400
Lead	mg/l	<0.01 – 2.5
Cadmium	mg/l	<0.01 – 0.03
Chromium	mg/l	<0.01 – 0.13
Copper	mg/l	0.02 – 0.89
Nickel	mg/l	0.04 – 0.23
Mercury	mg/l	<0.001
Zinc	mg/l	1.8 – 27.9
Sulphate	mg/l	430 – 1 550
Chloride	mg/l	1 330 – 3 947
COD	mg/l	154 – 7 580
<i>Source: [93, UBA 2003]</i>		

2.3.4.4 Waste water generation from the casting, cooling and shake-out area and from mould production / sand preparation

In the casting, cooling and shake-out area and in mould production / sand preparation, insoluble fines from the moulding material are captured during dedusting, along with small organic proportions from the bonding agent used. If wet dedusting is applied, these compounds are found in the waste water flow. The inorganic solids are iron oxides and clays, which are in part finely dispersed and difficult to remove.

2.3.4.5 Waste water generation from core-making

In core-making shops, chemical scrubbers are in use. They use either acid (cold-box process) or basic (SO₂ process and Croning). The quantity of waste water discharged is dependent upon the accumulation of pollutants and salts in the circulating water. If pollution levels are too high, part of the polluted water must be drawn off.

Scrubbing solutions from cold-box and hot-box core-making contain readily biodegradable amines and phenols.

The treatment of amine-containing scrubbing solutions requires a nitrification/denitrification stage. These treatment steps can also be carried out in an external biological waste water treatment plant. An alternative to discharge is the recovery of the amines.

Following oxidation, scrubbing solutions from the SO₂ process mainly contain sodium sulphate. Since high sulphate concentrations (> 600 mg/l) can lead to damage to sewerage systems, a limit value is set by the respective competent authority according to local conditions (e.g. the presence of sulphate-resistant piping and dilution with other waste water).

[93, UBA 2003]

2.3.4.6 Data for specific water consumption levels

The figures related to specific water consumption which are presented in this section are composed of three parts (sections):

- The upper part (first section) of the figure always shows the maximum, average and minimum reported values of specific water consumption for the 3 reporting years and the average values obtained over the reporting period. Below the x-axis, additional contextual information is included such as the plant number and the type of foundry.
- In the second part (section) of the figure, information is given related to the recycled/reused water expressed as a percentage (%) (over the 3-year reporting period) of the fresh water consumed.
- The third section of the figure contains information on the applied techniques to reduce water consumption.

In addition to the three figures containing the reported data on specific water consumption at plant level, an additional figure presents the distribution of specific water consumption at process level. The relevant processes (according to the submitted data) are:

- high-pressure die casting;
- moulding with wet sand;
- wet treatment of used sand;
- wet scrubbing of cold-blast cupola off-gases;
- finishing processes (machining);
- wet scrubbing for core-making off-gases.

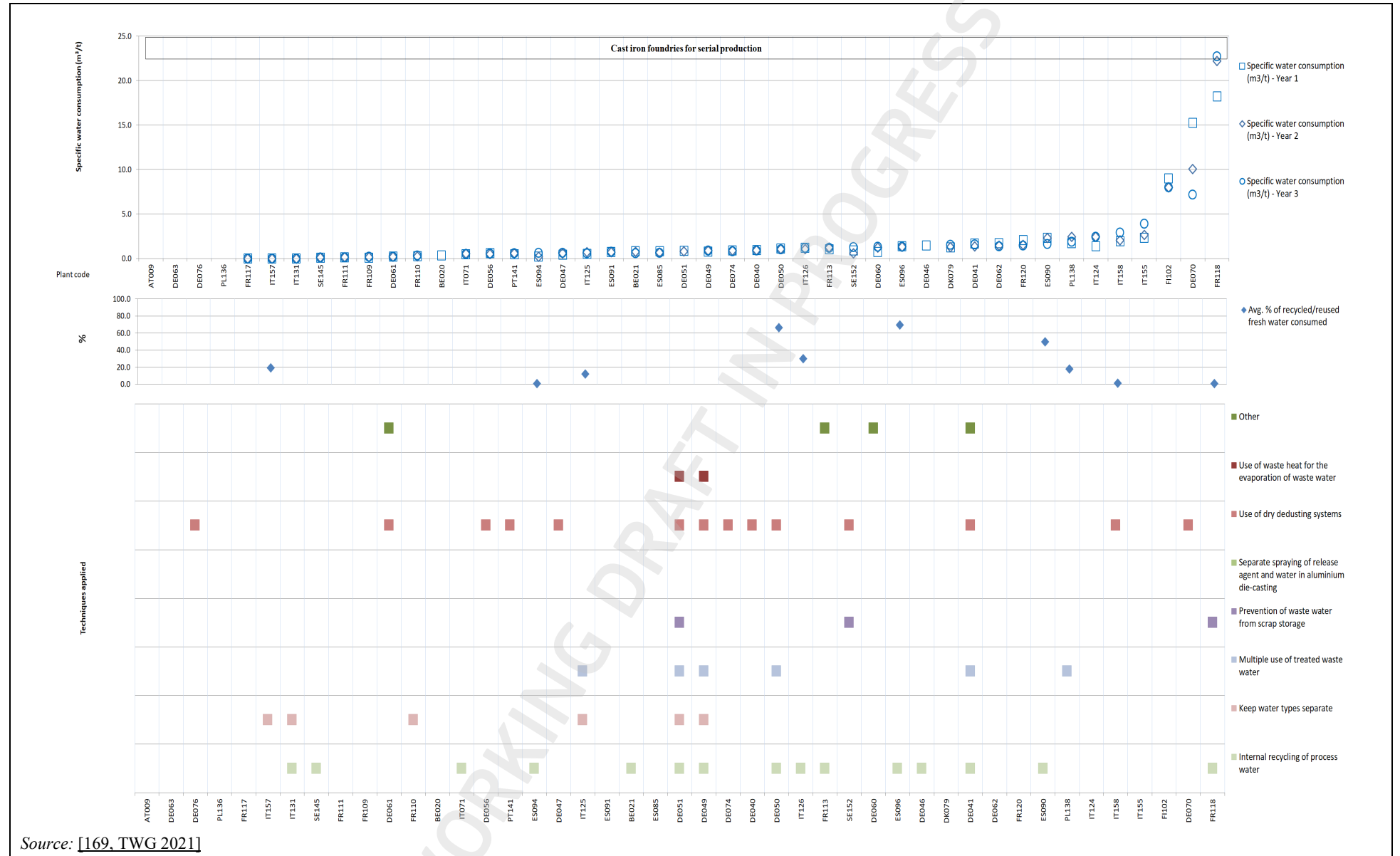


Figure 2.133: Specific water consumption (at plant level) (1/3)

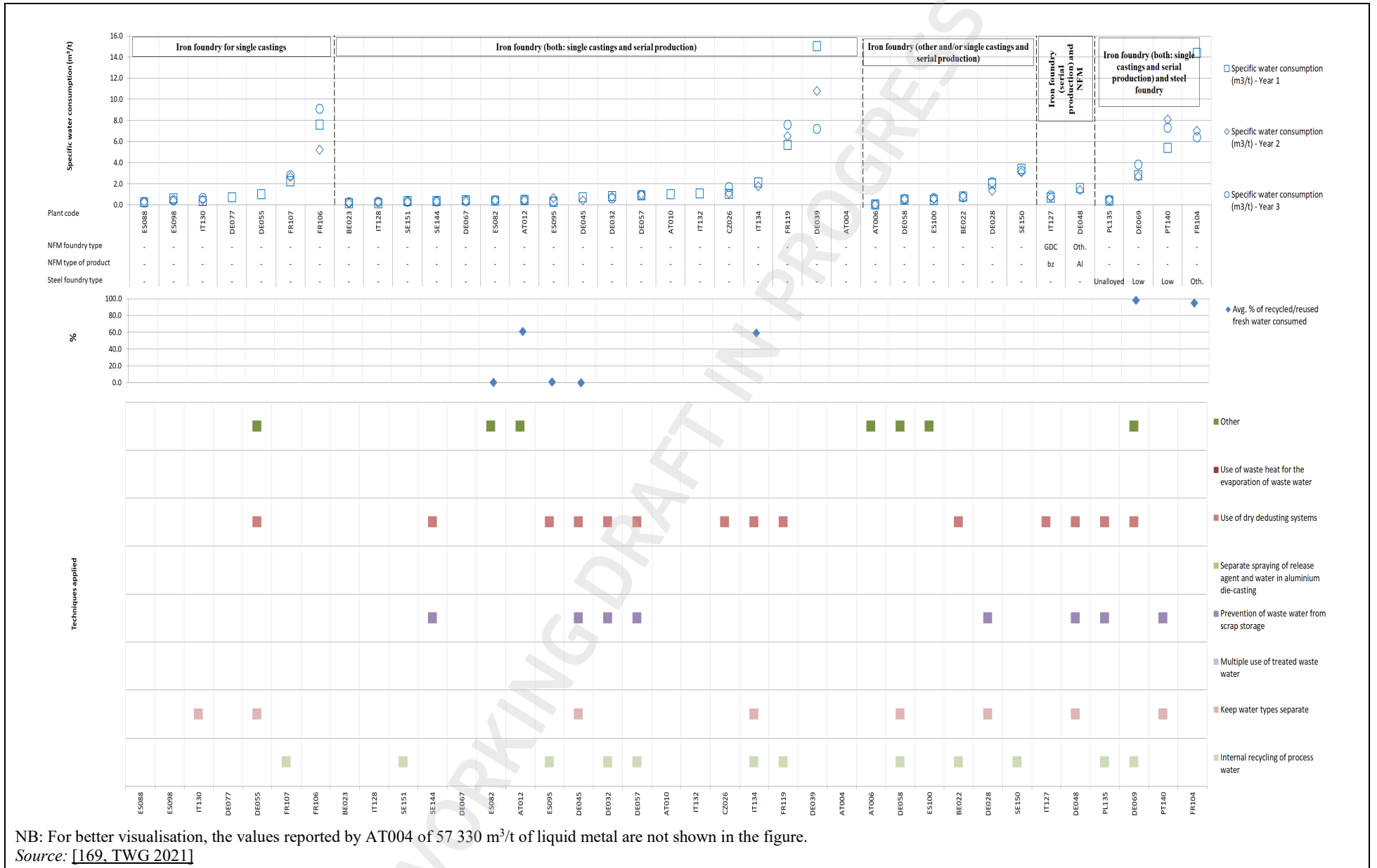


Figure 2.134: Specific water consumption (at plant level) (2/3)

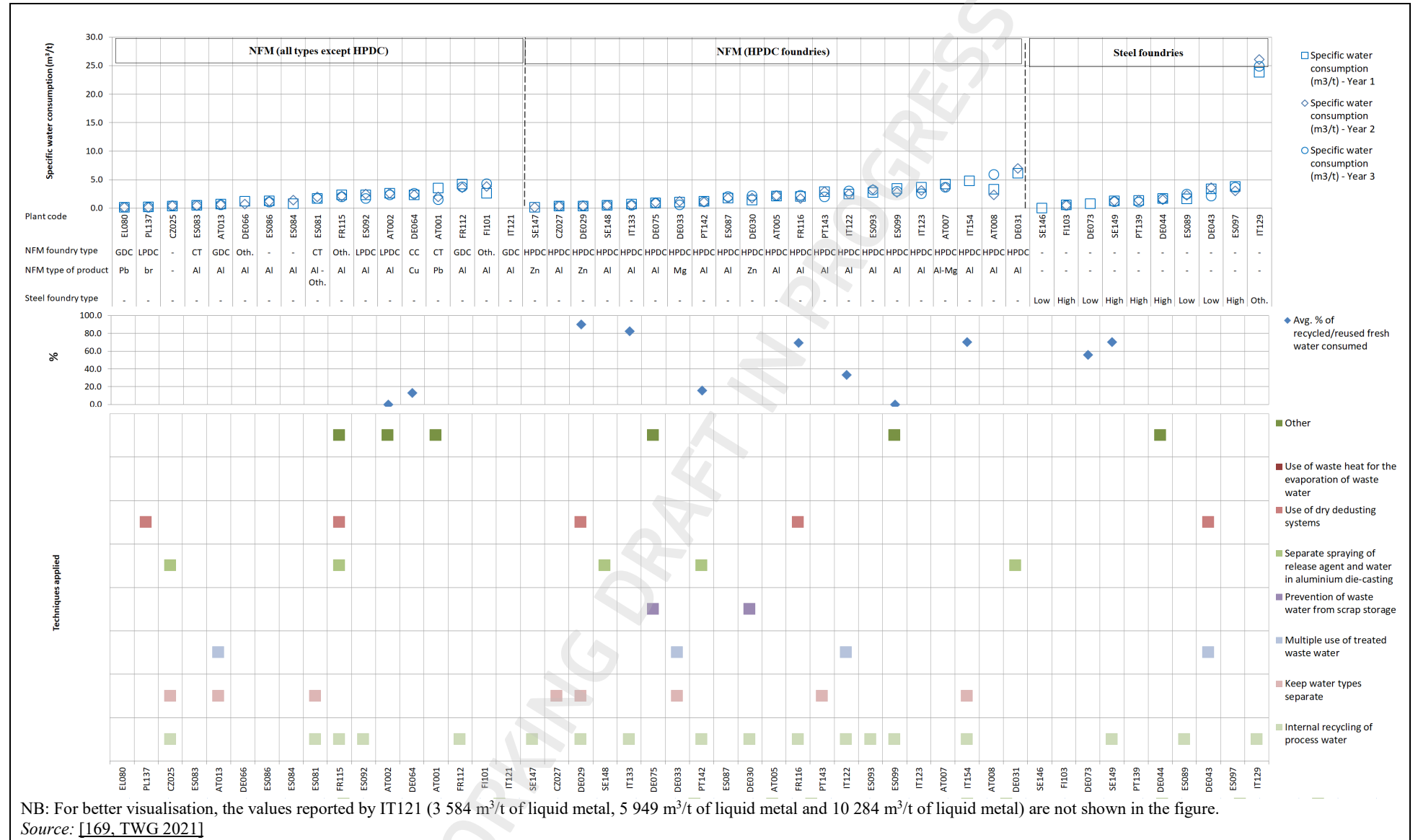


Figure 2.135: Specific water consumption (at plant level) (3/3)

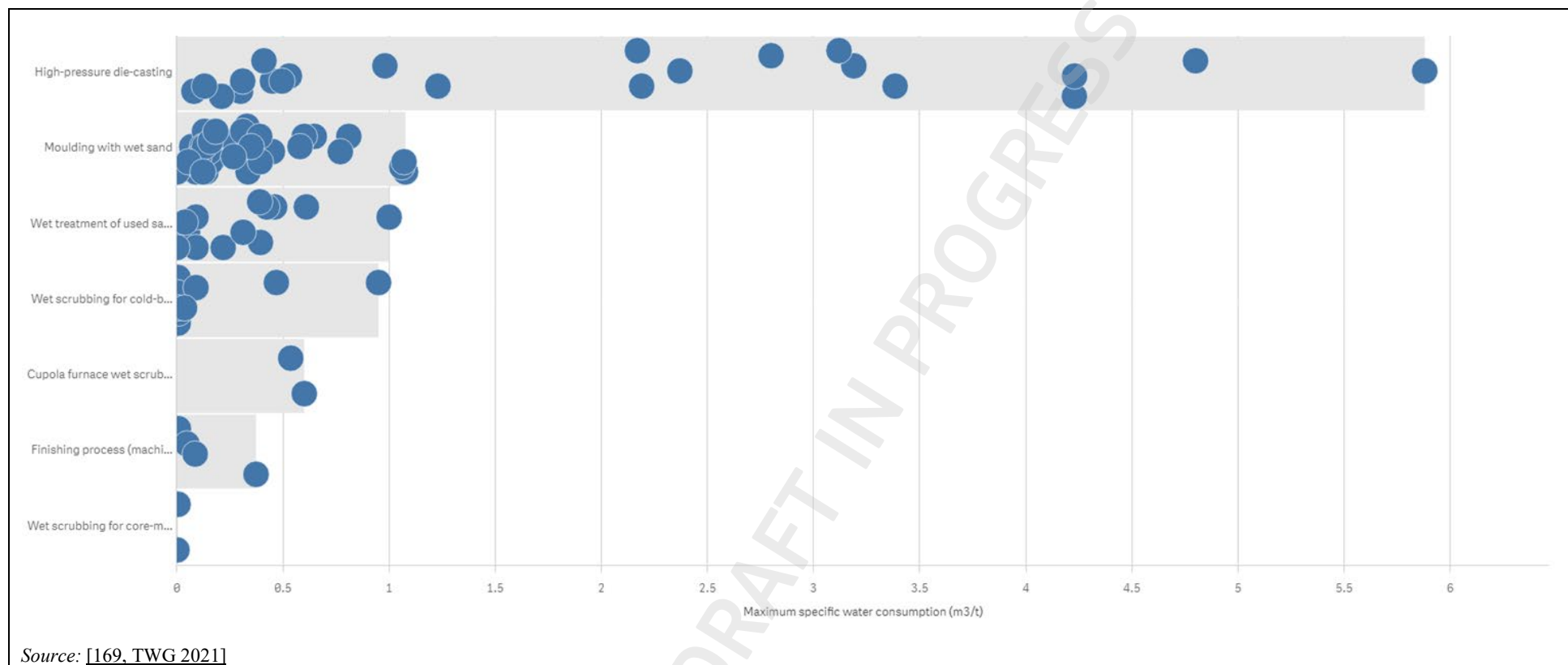


Figure 2.136: Distribution of specific water consumption at process level

2.3.5 Operational Material Efficiency (OME)

The operational material efficiency (OME), also called metal yield, is the ratio of the total yearly amount (expressed in t) of final castings without defects divided by the total yearly amount of liquid metal output. Five main factors affect the OME, i.e.:

- quality requirement;
- choice of mould-box size;
- the extent of runner and feeder systems;
- metal shrinkage;
- scrap casting rate.

[30, ETSU 1995]

Good castings loss (and therefore reduction in OME) occurs during all the following process steps [182, Salonitis et al. 2016]:

- melting: in the form of dross;
- holding: in the form of dross;
- casting: in the form of dross;
- fettling: the main process of generated recycling scrap;
- machining: the second major process of generated recycling scrap;
- inspection: recycling of rejected products.

Fettling is used to separate the casting from its running system. The casting itself is only about 50 % by weight of the entire casting system, although this depends on a number of aspects such as the number of castings per shot, the feeding and running system, etc. and can be up to 90 % for applications such as in the aerospace sector. Thus, reducing the weight of the running system can reduce the metal loss in fettling. Machining (including grinding, drilling and milling) contributes to metal losses as well. Therefore, the closer the casting is produced to net shape, the more the need for machining operations is reduced. The yield is finally affected by the rejections during the inspection process. Defects such as poor tolerance, poor surface finish, inclusions and porosity lead to rejection during the inspection. The last three types of losses are internal scrap. [182, Salonitis et al. 2016]

The reported levels of OME for various foundry types are presented in Figure 2.137, Figure 2.138, Figure 2.139 and Figure 2.140.

Some statistical data on the reported levels of OME for specific foundry types are presented in the following table.

Table 2.92: Statistical parameters on the reported OME levels for specific foundry types

Foundry type \ Parameter	Number of data	Min.	10th percentile	Average	Median	90th percentile	Max.
Iron foundries (serial production)	63	0.3	4.2	54.5	60	79.8	97
Iron foundries (single castings)	11	0.6	1.24	64.8	85.5	90	94
Iron foundries (serial production and single castings)	20	0.46	36.07	57.3	63.1	75.6	94.3
Iron foundries (other)	9	0.7	-	46.8	63	-	100
Iron and steel foundries	10	0.6	-	40.56	60.5	-	99.5
Iron and NFM foundries	6	32.6	-	48.5	49.8	-	60.6
NFM (all types except HPDC)	33	0.5	28	62.7	63.5	96.2	98
NFM HPDC foundries	21	0.44	0.98	59.0	60.8	98	98
Steel foundries	17	0.5	0.67	49.3	55	68.4	100

Source: [169, TWG 2021]

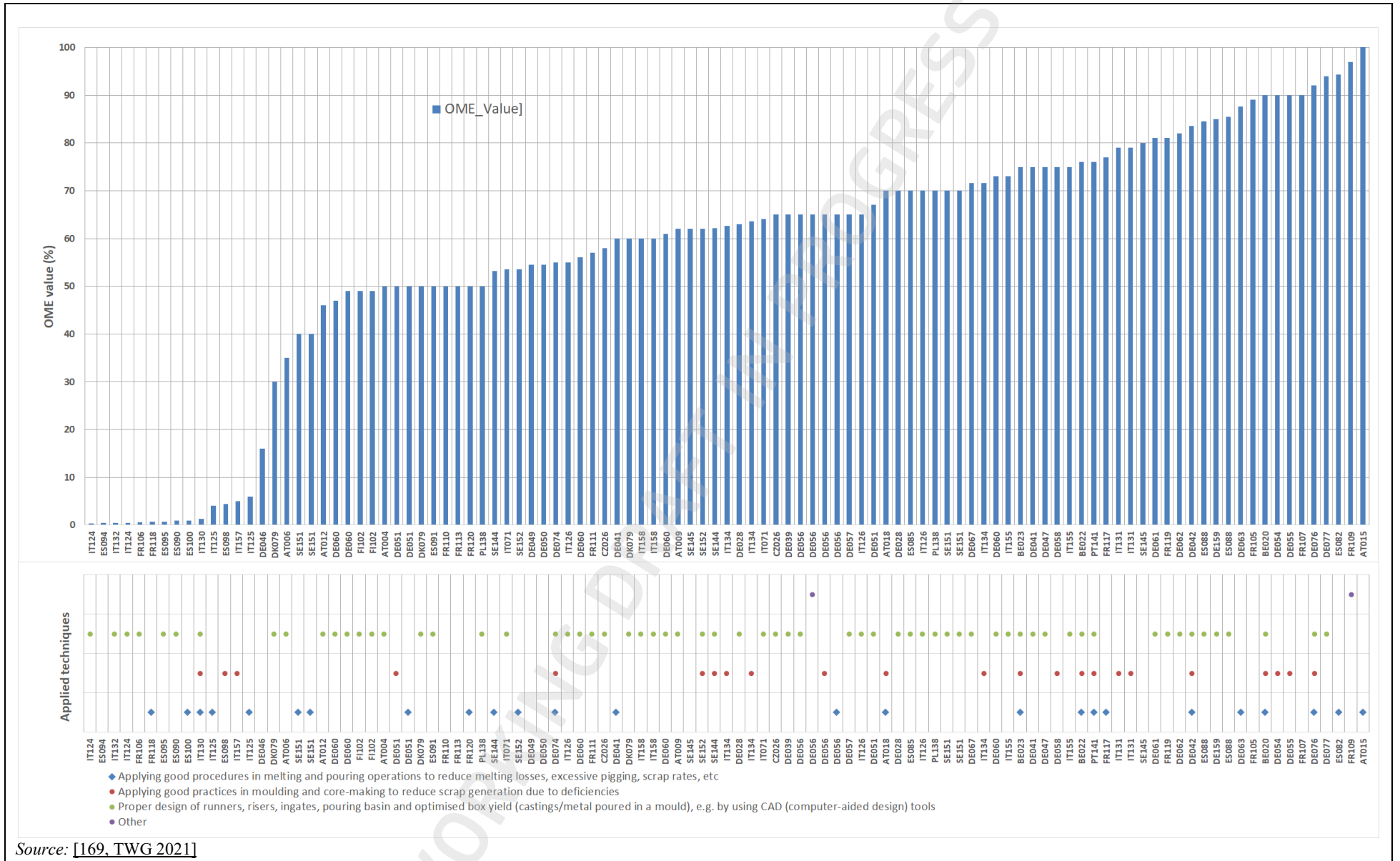


Figure 2.137: Operational material efficiency (1/5) – cast iron foundries



Figure 2.138: Operational material efficiency (2/5) – steel foundries

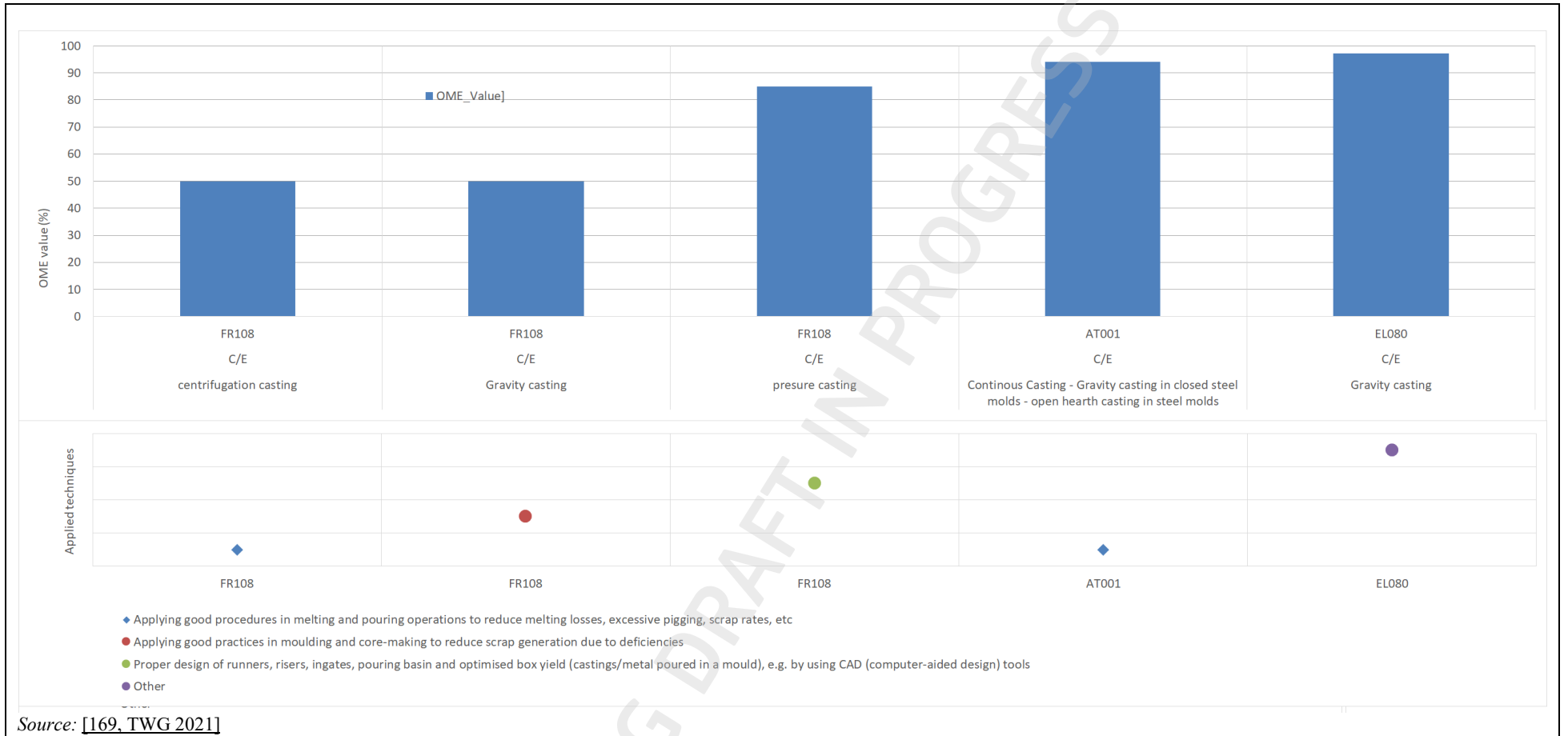


Figure 2.139: Operational material efficiency (3/5) – Lead foundries

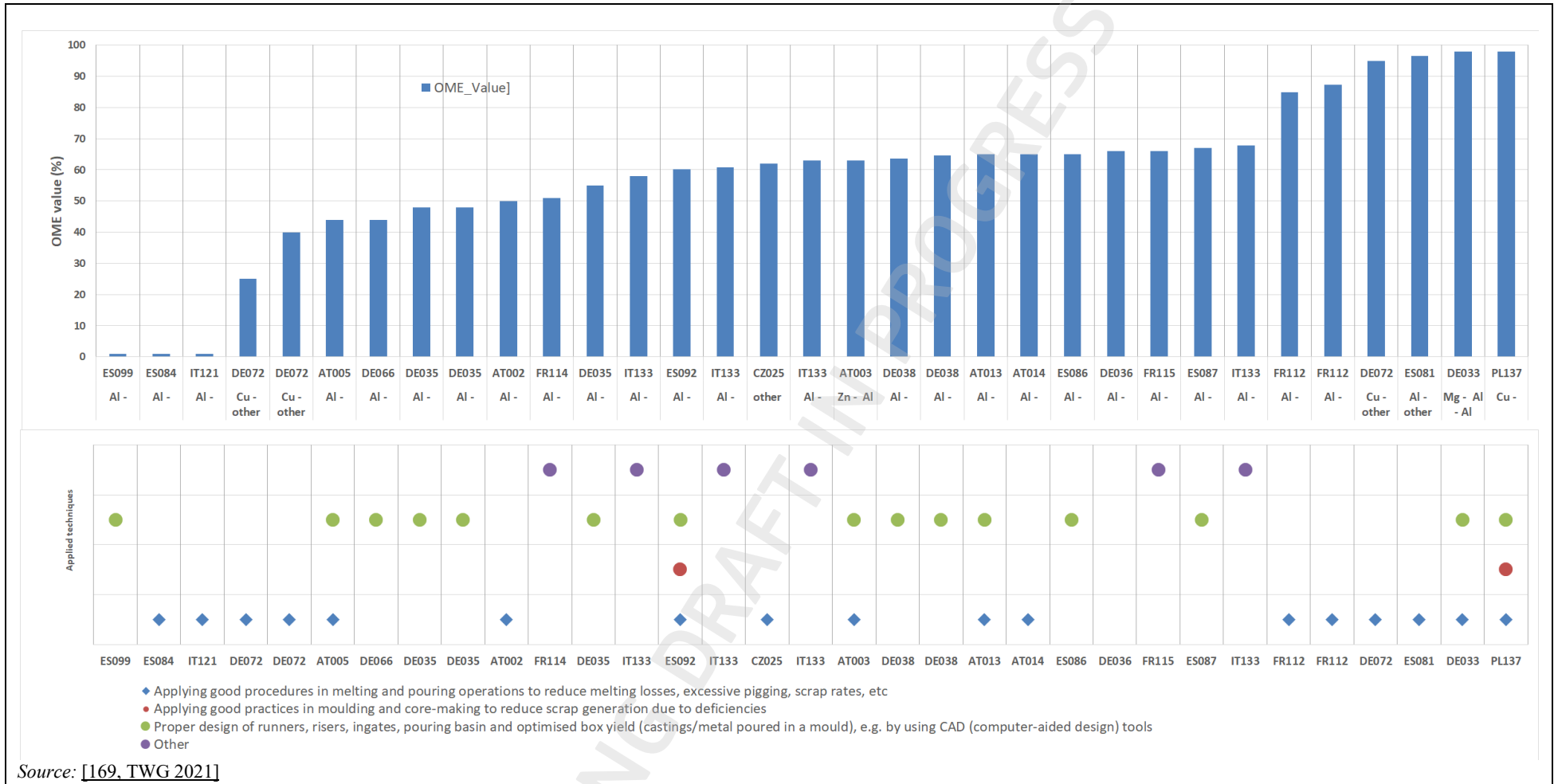


Figure 2.140: Operational material efficiency (4/5) – NFM foundries (casting other than HPDC)



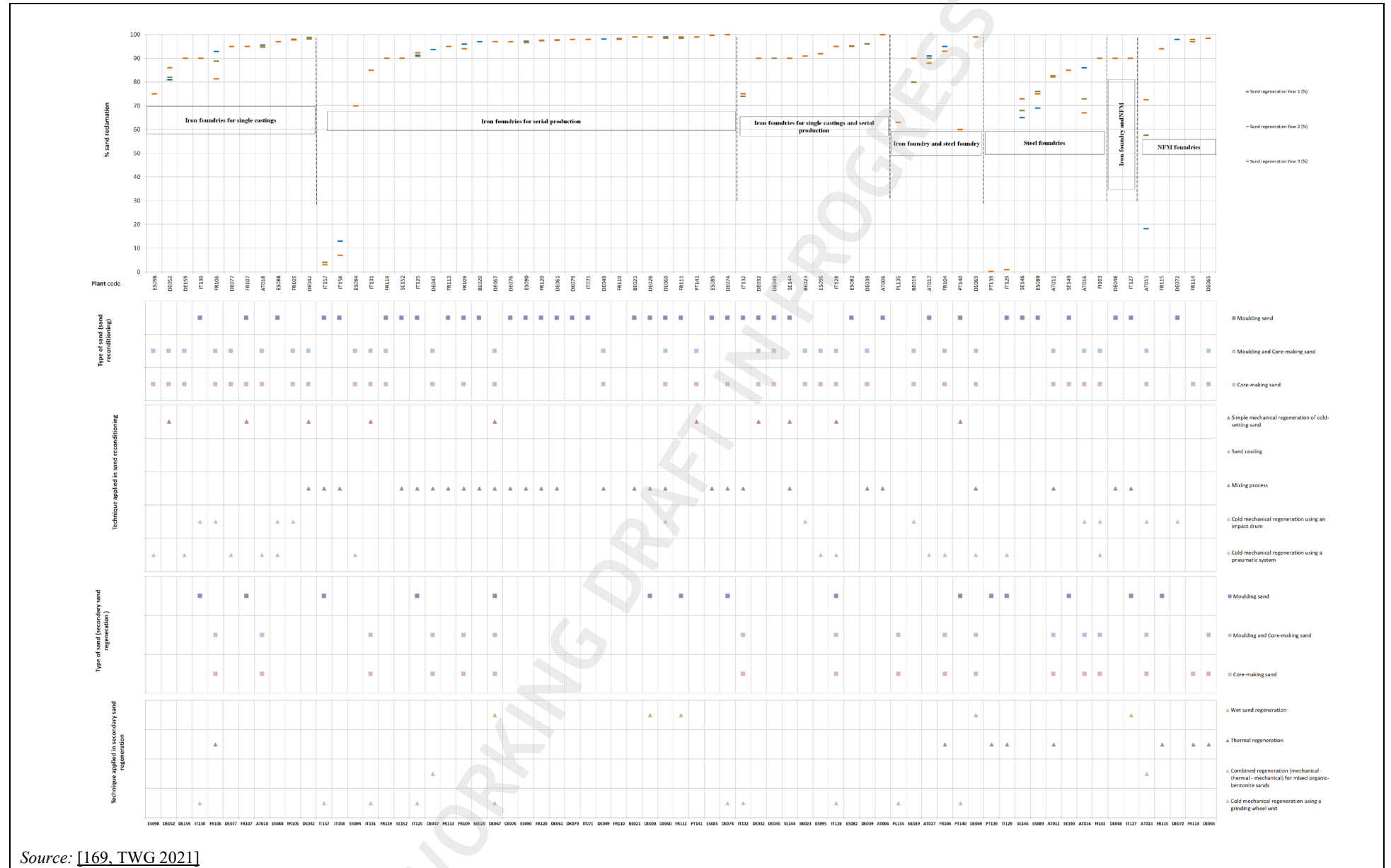
Figure 2.141: Operational material efficiency (5/5) – NFM foundries (HPDC)

2.3.6 Sand reuse (reconditioning and regeneration) ratio

Reported data on sand reuse ratio values (expressed as a percentage) are presented in this section.

It is noted that the collected data refer to the ratio of the amount of reused sand divided by the amount of total sand, where:

- reused sand is the quantity of reconditioned sand and reclaimed sand if relevant; and
- total sand is the quantity of reused sand and new sand.



Source: [169, TWG 2021]

Figure 2.142: Sand reuse regeneration ratio

2.3.7 Residues/waste generation

The main types of residues generated in foundries are the slag, dross and spent refractory linings from the melting/holding processes, spent sand from the sand reconditioning/regeneration circuit and the filter dust collected in the dedusting systems.

2.3.7.1 Slag

Slags contain oxides that float upon the melt and which arise from impurities in the feed material, wearing of the furnace refractory and from the ash of coke and from the melting loss of the metal charge [120, TWG 2003]. Slags are bonded through the addition of binders, such as vermiculite.

The typical composition of cupola slag is given in the following table. A cupola furnace typically produces 40 – 80 kg slag per tonne of liquid iron.

Table 2.93: Typical cupola slag composition

Compound	%
SiO ₂	45 – 55
CaO	25 – 40
Al ₂ O ₃	8 – 20
MgO	1 – 3
MnO	1 – 4
FeO	1 – 6
Sulphides	<1
TiO ₂	<1
ZnO	<0.1
<i>Source: [71, Neumann, F. 1994], [59, Godinot 2001]</i>	

Cupola slag consists of 30 % refractory material, 10 % sand (from internal scrap), 40 % CaO (flux), 10 % coke ashes, and 10 % burn-off material.

An important aspect of cupola slag is its high SiO₂ content. After quenching, the slag has a vitrified structure. This generates an inert non-leaching material.

The chemical composition of EAF slags are given in the following table. The reported values were based on the analyses of three samples.

Table 2.94: Chemical composition of EAF slag

Compound	Average (%)	Range (%)
SiO ₂	36.2	28.6 – 41.8
CaO	12.4	7.2 – 17.7
MgO	22.1	18.3 – 27.0
Al ₂ O ₃	8.4	7.4 – 0.1
FeO	0.7	0.5 – 1.0
MnO	14.8	4.0 – 29.6
TiO ₂	1.2	0.39 – 2.7
Na ₂ O	0.3	0.11 – 0.57
K ₂ O	0.1	0.1 – 0.23
<i>Source: [70, The Castings Development Centre 1999]</i>		

The typical properties of induction furnace slags generated in ferrous foundries are given in the following table. Induction furnaces produce 10 – 20 kg slag per tonne metal charge. The amount

of slag produced depends on the quality of the charge material. The lower limit of the given range applies if internal scrap is cleaned (blasted) before remelting.

Table 2.95: Typical composition of induction furnace slag

Compound	%
SiO ₂	40 – 70
FeO	10 – 30
Al ₂ O ₃	2 – 15
MnO	2 – 10
CaO	0 – 3
MgO	0 – 3
<i>Source: [71, Neumann, F. 1994]</i>	

In aluminium foundries, the estimated slag generation is as follows:

- for shaft furnaces, the slag (with 35 – 40 % Al) generation is of the order of 40.3 kg/t of good casting [76, Silva Ribeiro, C. A. 2002];
- for crucible furnaces, the slag generation is of the order of 61 kg/t of good casting [76, Silva Ribeiro, C. A. 2002].

In aluminium foundries, the metal loss, shown in Table 2.26, is typically within the range of 1 – 3 % (for shaft furnaces) and 1 – 2 % (for crucible furnaces). The metal loss normally would encompass both the slag and dross generation.

Slag from the AOD converter is particularly ‘clean’ of metal oxides, since, due to the peculiarity of the process, they are usually consumed. The slag composition is given in Table 2.96.

Table 2.96: AOD converter slag composition

Compound	%
CaO	50 – 70
Al ₂ O ₃	5 – 25
SiO ₂	10 – 25
MgO	5 – 15
<i>Source: [100, TWG 2002]</i>	

The reported levels for slag generation and management are presented in Section 2.3.7.6.

2.3.7.2 Dross

The reported levels for dross generation and management are presented in Section 2.3.7.6.

2.3.7.3 Waste refractory linings

The cupola furnace has the specific feature that the lining material (quartz-clay mixture) of the furnace at the melting zone only lasts for one melting campaign. The main part of the refractory is converted into slag. The amount to be removed and disposed of as waste is much smaller than the applied amount.

The reported levels for waste refractory linings’ generation and management are presented in Section 2.3.7.6.

2.3.7.4 Filter dust

The reported levels for filter dust generation and management are presented in Section 2.3.7.6.

2.3.7.5 Spent sand

Data and contextual information on the management of spent sand has been reported by:

- 88 plants for moulding sand;
- 40 plants for core-making sand;
- 19 plants for undefined use of sand.

The reported data (by management technique) are presented in the following tables.

Table 2.97: Reported data for reuse of spent sand (in kg/t of liquid metal)

Plant number	Min.	Average	Max.
ES088	2	3	3
DK079	55	75	95
DE052	286	308	345
PT140	705	786	920
FR114	997	1 028	1 060
FR115	997	1 028	1 060
FR105	1 551	1 587	1 631
FR104	1 450	2 097	2 640
SE150	2 998	3 044	3 088
AT017	3 013	3 159	3 232
FR106	4 320	5 101	5 938
IT071	6 814	6 904	6 993
DE040	6 643	6 898	7 241
ES082	7 005	7 109	7 283
FI102	7 412	7 418	7 423
FR109	10 000	10 000	10 000
DE070	9 589	10 125	10 510
SE151	307	5 683	11 058
FR111	15 486	17 283	20 086
DE066	31 620	31 760	31 960
DE077	360 000	531 000	788 000

Table 2.98: Reported data for recycling of spent sand (in kg/t of liquid metal)

Plant number	Min.	Average	Max.
IT157	0	0	0
FI103	1	1	1
DE043	1	1	1
DE069	1	1	1
DE049	1	1	2
ES082	-	2	3
FR109	0	4	5
AT006	9	11	13
FR114	2	11	21
FR105	21	22	23
ES096	1	18	26
FR119	4	20	38
IT071	14	26	39
BE023	20	33	41
DE065	8	32	51

Plant number	Min.	Average	Max.
ES091	1	29	64
FR115	62	64	67
DE039	59	63	69
DE058	70	76	81
BE020	68	76	83
AT017	70	83	100
IT130	89	103	114
DE040	118	121	122
AT011	124	130	139
AT009	124	134	143
FR110	0	92	164
IT127	166	183	211
AT012	198	206	214
FR111	187	206	238
FR112	54	122	238
BE022	37	127	255
PT141	11	122	255
FR113	232	241	257
SE149	313	330	358
IT134	266	342	419
DE070	276	346	432
SE150	449	471	494
IT125	410	471	526
ES092	578	597	617
ES089	362	546	748
PL135	950	1 007	1 100
PT140	116	1 058	2 300
AT004	2 167 000	2 403 500	2 640 000

Table 2.99: Reported data for recovery of spent sand (in kg/t of liquid metal)

Plant number	Min.	Average	Max.
FR118	3	3	4
SE150	6	13	18
AT010	24	24	24
DE039	55	58	63
FR112	34	47	67
ES085	25	60	88
DE051	32	79	125
ES094	136	136	136
DE049	131	140	149
DE050	0	82	167
DE057	174	174	174
FII02	14	111	209
IT132	193	214	235
PL138	65	157	249
DE041	26	151	349
DE056	348	357	376
BE023	126	271	438
SE151	491	491	491
ES095	368	448	527
DE046	103	403	796

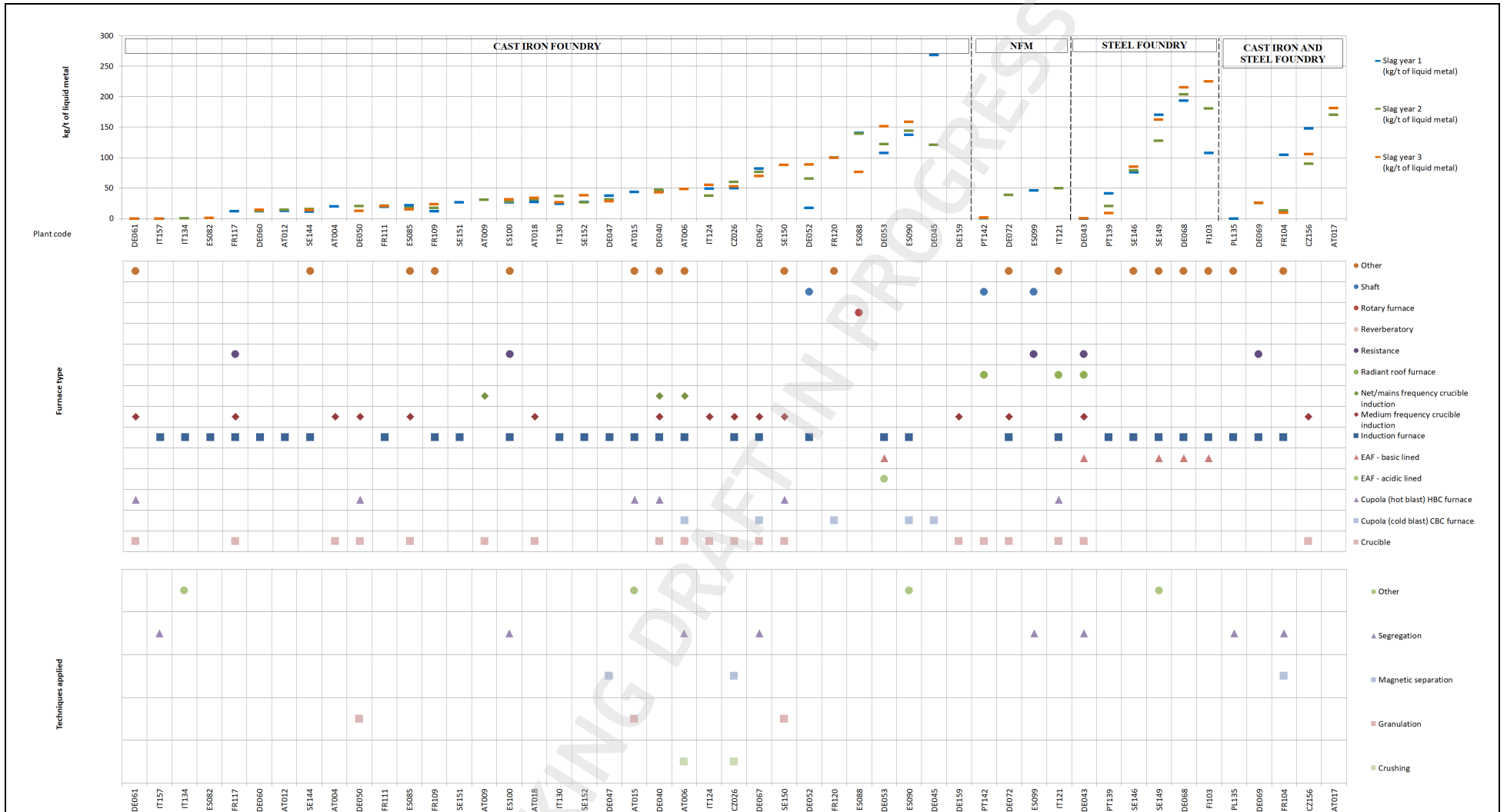
Table 2.100: Reported data for disposal of spent sand (in kg/t of liquid metal)

Plant number	Min.	Average	Max.
DE043	0	0	0
DE061	0	0	0
PT139	0	0	0
AT012	1	1	1
DK079	2	4	5
DE050	0	4	8
SE150	5	8	12
FR107	18	18	18
ES096	19	19	19
DE054	21	21	21
FR118	26	28	30
DE072	13	24	34
AT009	3	19	34
DE065	0	15	34
AT015	36	36	36
FR113	15	28	40
DE070	0	13	40
ES085	5	20	43
ES082	58	60	63
DE060	3	35	70
DE042	56	63	75
DE040	80	83	86
FR117	4	32	94
DE052	59	84	106
DE074	45	76	107
ES094	105	141	159
FR104	112	139	166
DE053	128	150	179
DE067	153	177	194
SE145	20	124	230
DE032	213	224	234
DE045	244	254	263
SE152	16	140	264
ES095	293	293	293
SE144	210	245	296
FR120	278	285	298
DE046	22	139	301
DE048	266	290	314
DE047	20	166	329
AT017	234	281	335
IT124	278	311	343
DE068	269	298	357
DE066	260	315	380
PL137	355	378	422
AT018	114	264	485
DE044	54	281	509

Plant number	Min.	Average	Max.
SE146	304	401	523
DE076	12	262	525
DE069	427	514	592
ES090	562	588	606
CZ026	687	698	716
ES089	476	608	777
FR106	540	730	980
CZ156	1 526	2 184	3 358
AT013	101	2 329	6 728

2.3.7.6 Figures showing residue quantities sent for disposal

In the following figures in this section, the specific quantities for each residue type sent for disposal with additional contextual information on the furnace type and the applied residue management techniques are presented.



NB: For better visualisation, the values over 300 kg/t of liquid metal reported by the following plants are not shown in the figure:

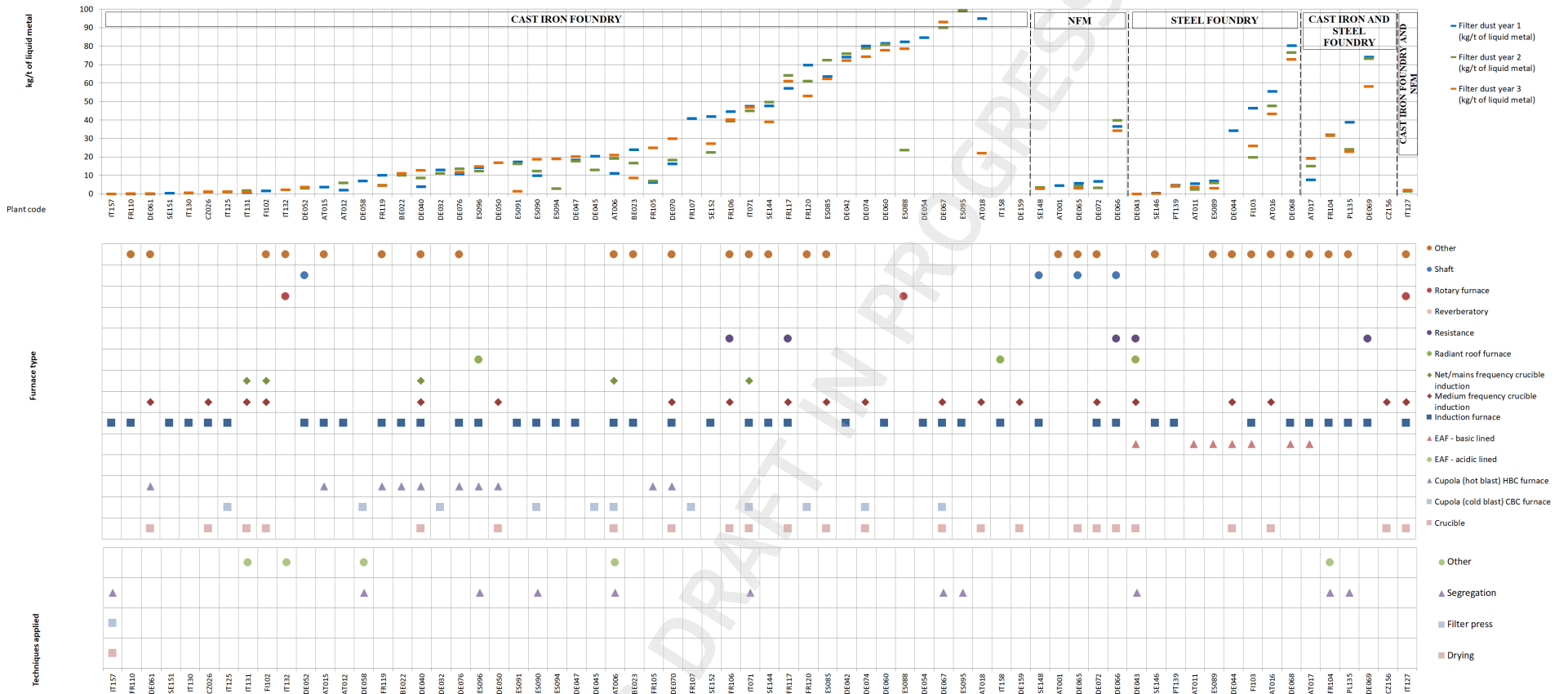
Plant number	Slag year 1	Slag year 2	Slag year 3
DE159	1089.3	914.7	861.1
IT121	28540		1000

Source: [169, TWG 2021]

Figure 2.143: Slag sent for disposal



Figure 2.144: Dross sent for disposal



NB: For better visualisation, the values over 300 kg/t of liquid metal reported by the following plants are not shown in the figure:

Plant number	Filter dust year 1	Filter dust year 2	Filter dust year 3	Plant number	Filter dust year 1	Filter dust year 2	Filter dust year 3
ES095	121.1			DE159	2315.85	1589.84	1704.27
AT018		162		CZ156	308	477	444
IT158	352.52	472.7	399.8				

Source: [169, TWG 2021]

Figure 2.145: Filter dust sent for disposal

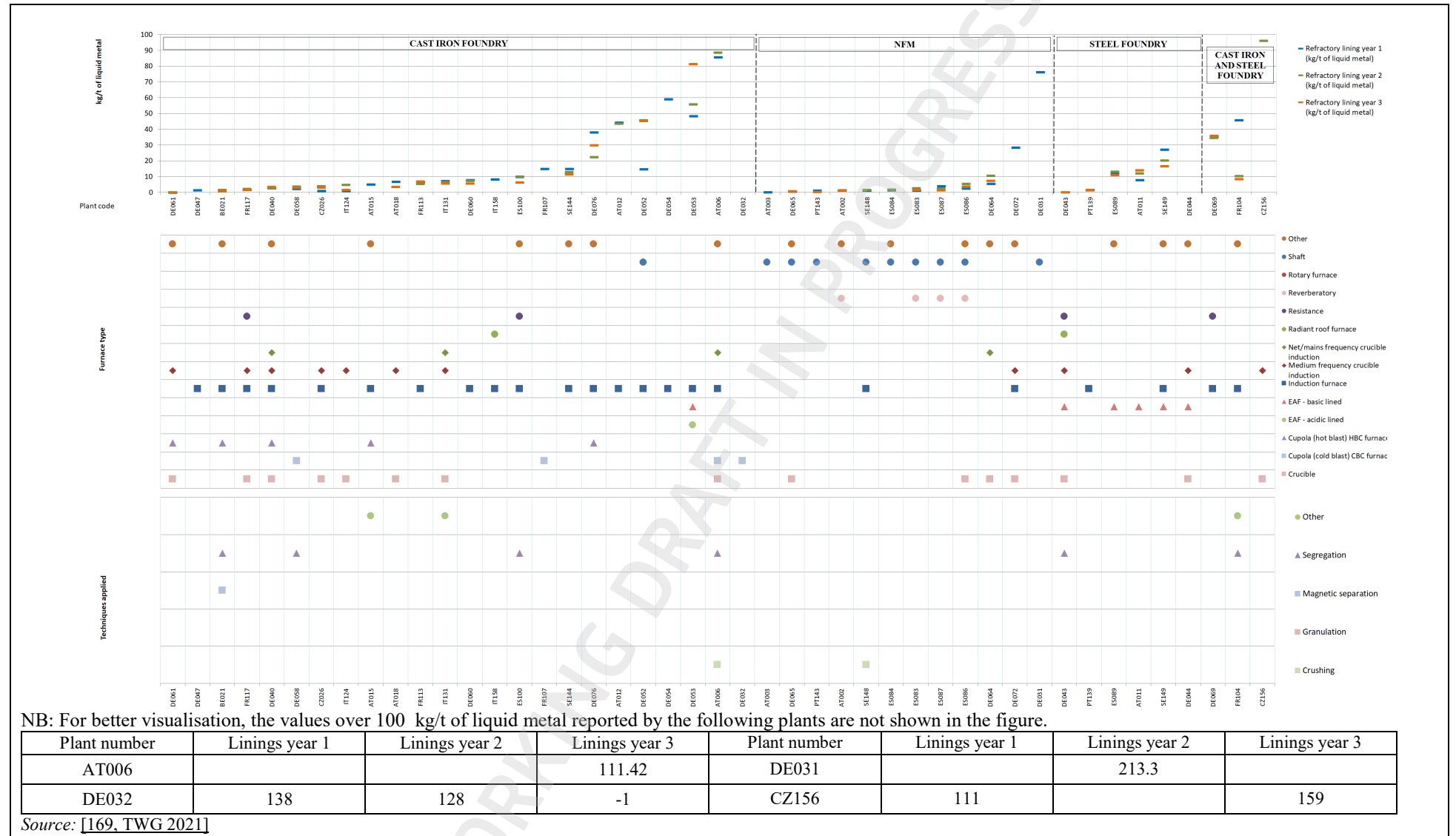


Figure 2.146: Refractory lining sent for disposal

2.3.8 Energy consumption

Data from energy audits in 17 European foundries in the frame of the Foundry bench project indicate that the energy consumption data in iron foundries data was relatively uniform but the deviation in steel and non-ferrous foundries depends to a great extent on the production technology, steel quality and castings. In particular, this depends on the heat treatments needed for the steel castings (see Table 2.101). [183, Foundrybench project 2012]

Table 2.101: Average energy use in different foundry types

Unit/Foundry type	Iron foundry	Steel foundry	NFM foundry
Energy/tonne (MWh/t liquid metal)	2.5	5 – 8	4 – 10
Energy cost of business value (%)	5 – 8	6 – 11	4 – 8

Source: [183, Foundrybench project 2012]

The energy-saving potential range differs from foundry to foundry. There are significant differences among foundries related, for example, to the quality of the material produced and the climatic conditions of the location. The savings potential of the 17 audited foundries showed a value of 17 % (+ 7 %). [183, Foundrybench project 2012]

Table 2.102: Average energy use in different foundry types

Unit processes	Iron foundry energy share (%) and the range (\pm %)	Steel foundry energy share (%) and the range (\pm %)	Non-ferrous foundry energy share (%) and the range (\pm %)	Savings potential (%)
Melting	55 \pm 10	45 \pm 5	65 \pm 10	6 – 10
Annealing	1 \pm 1	25 \pm 2	-	steel (3)
Drives	12 \pm 4	9 \pm 2	11 \pm 5	1
CA-system	7 \pm 3	5 \pm 2	5 \pm 3	2
Ladle preheating	4 \pm 2	4 \pm 2	3 \pm 2	2
Ventilation	14 \pm 5	7 \pm 5	10 \pm 8	4 – 7
Heating	3 \pm 2	2 \pm 1	3 \pm 2	1
Lighting	4 \pm 1	3 \pm 1	3 \pm 1	1
Total	100	100	100	17 – 24

Source: [183, Foundrybench project 2012]

A survey of 58 steel foundries located in the USA provided statistics on energy consumption. The reported energy consumption for steel melting varies between 350 kWh/t and 700 kWh/t, with an average of 527 kWh/t. [197, Biswas et al. 2012]

2.3.8.1 Coke and energy consumption in cupola furnaces

See Section 2.3.1.1.

2.3.8.2 Energy consumption in coreless induction furnaces

A coreless induction furnace can melt a tonne of iron and raise the temperature of the liquid metal to 1 450 °C using under 600 kWh/tonne of electricity. However, in practice, only a few foundries can achieve this level of specific consumption on a week-by-week basis. The actual energy consumption varies according to the size and working regime of the furnace. Large furnaces, working 24 hours a day and using a molten heel can achieve a 600 kWh/tonne value. Surveys of foundries show that consumption levels of 520 – 800 kWh/tonne of metal charge are common, the variation being due to individual melting practice, such as the rate at which the pouring line will accept the molten metal and whether furnace lids are used effectively. Attention to energy-saving measures should allow figures of 550 – 650 kWh/tonne of metal charge to be achieved. The typical heat losses from a coreless induction furnace are shown in Figure 3.2. [23, ETSU 1992], [73, Brown, J. R. 2000], [100, TWG 2002]

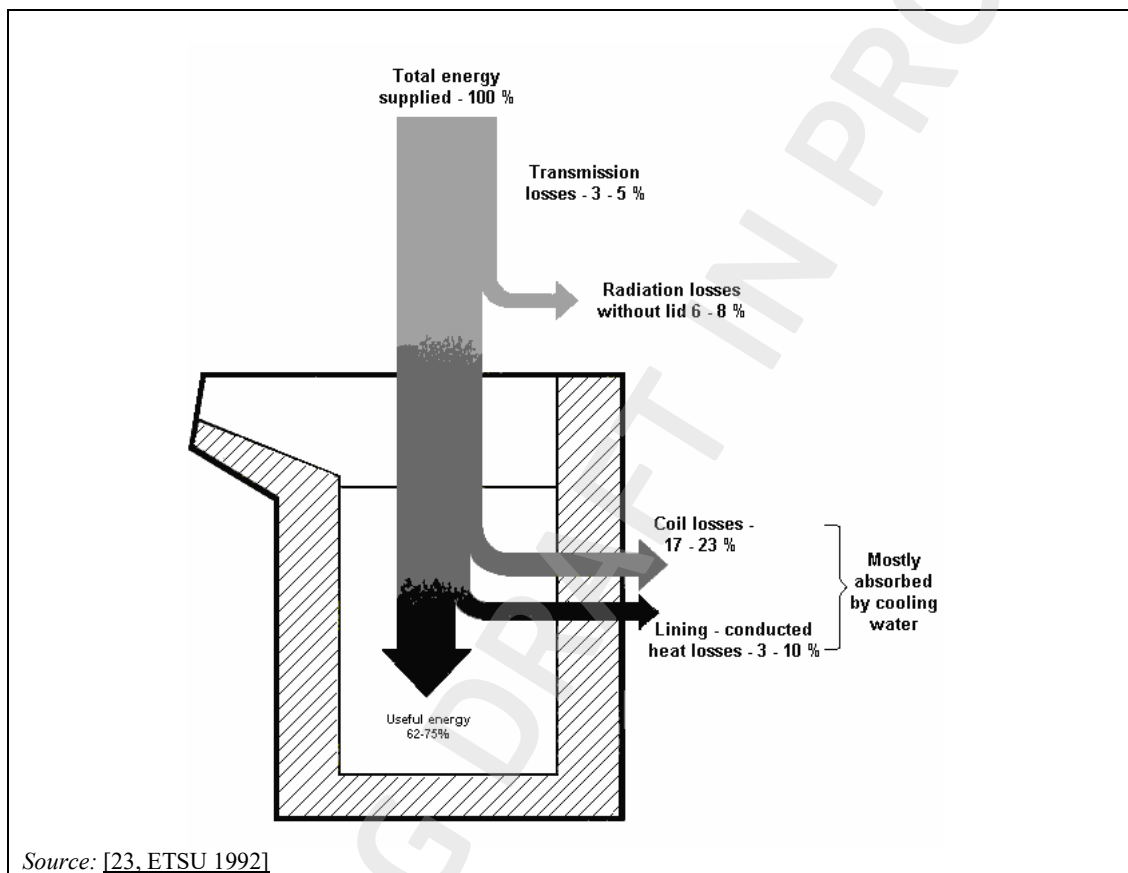


Figure 2.147: Typical energy losses from a mains frequency coreless induction furnace

2.3.8.3 Energy consumption in channel induction furnaces

In ferrous metal foundries, the channel induction furnace is mainly used as a holding and pouring furnace. It is the furnace of choice for duplex operation with the hot blast cupola. In this case, its function is either to hold or to homogenise the chemical composition of the metal, or to serve as a reservoir of the melted metal for the casting. The furnace's role is not to increase the metal temperature significantly, but rather to prevent unwanted cooling.

Figure 2.148 presents the energy consumption levels of some representative channel induction furnaces. The consumption depends on process-related parameters, such as the holding time. The graph shows that the consumption decreases with increasing annual tonnage. The extreme values are 80 kWh and 20 kWh per tonne transferred.

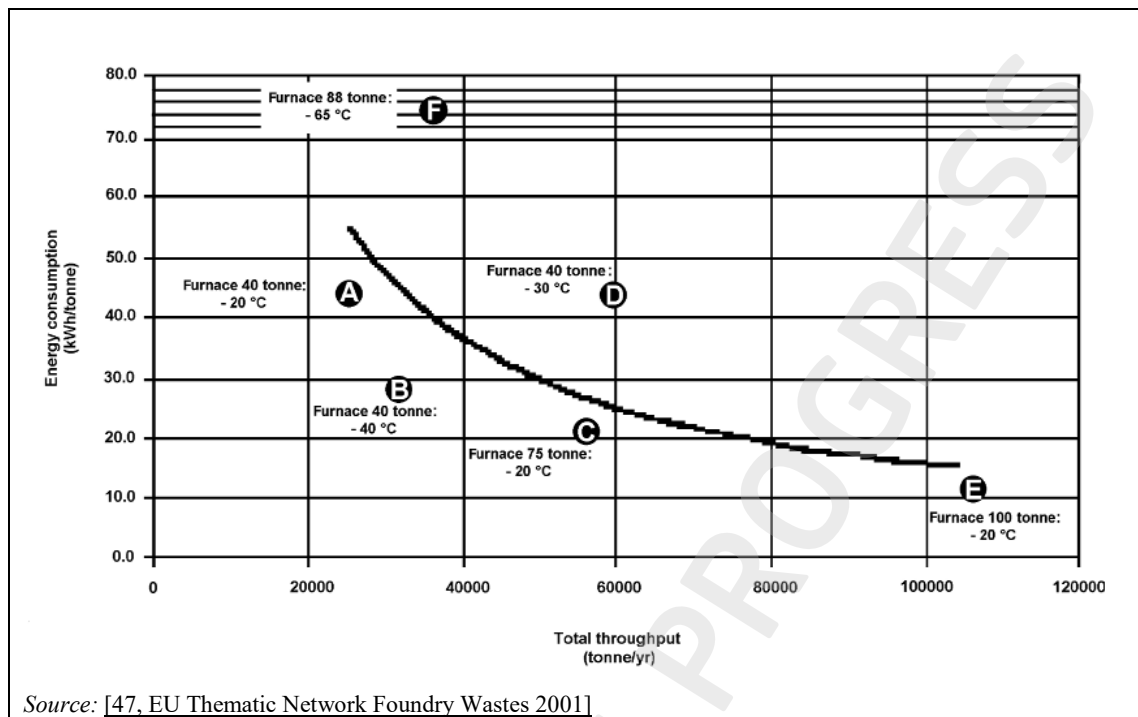


Figure 2.148: Energy consumption (kWh/tonne) as a function of transferred tonnage and loss of temperature for channel induction furnaces

2.3.8.4 Energy consumption in aluminium induction furnaces

Induction furnaces are energy-efficient melters. The energy consumption for melting is affected by the density of the charge and the melting practice used. Batch melting is less efficient than using a molten heel. A 50 % molten heel is the most efficient. The energy consumption varies from 540 kWh/tonne for a high bulk density charge (small scrap and ingot) to 600 kWh/tonne if a lower density scrap (such as pressure die-casting runners and ingot) is melted. While the energy consumption is low, the costs for melting may be higher than for gas-fired furnaces because of the generally higher cost of electricity as a source of heat. [74, Brown, J. R. 1999], [52, Eurofine 2002]

2.3.8.5 Energy consumption in aluminium shaft furnaces

The specific energy consumption of shaft melting furnaces can depend strongly on the different furnace types available commercially. However, a specific energy consumption range of 580 kWh/t to 900 kWh/t of aluminium was given in 2005 by the Bavarian State Office for Environmental Protection. The efficiency of the furnace is essentially determined by the waste gas, radiation and charging losses. In addition, other operating factors can be important such as the furnace operation or the bath/tapping temperatures, the charge materials (alloy, piece size, etc.) and the furnace utilisation. In a shaft furnace with a counter-flow principle, waste gas losses in the melting and holding process are greatly reduced by the internal material preheating. The shaft principle is optimally utilised by direct monitoring, an automatic charging system, or also by shaft enlargement. The surface temperature is often used as a measure for furnace radiation losses. However, door and charging losses must also be taken into account. The latter are negligible in shaft furnaces, because the melt is charged at the cold end. With consistent use of the shaft principle and minimisation of radiation losses, an energy consumption in continuous operation of less than 540 kWh/t at a 720 °C melt temperature can be achieved; this corresponds to an efficiency of 65 %. This applies to the use of both ingots and lumpy recycled materials. [216, Beneke et al., 2015], [210, TWG 2022]

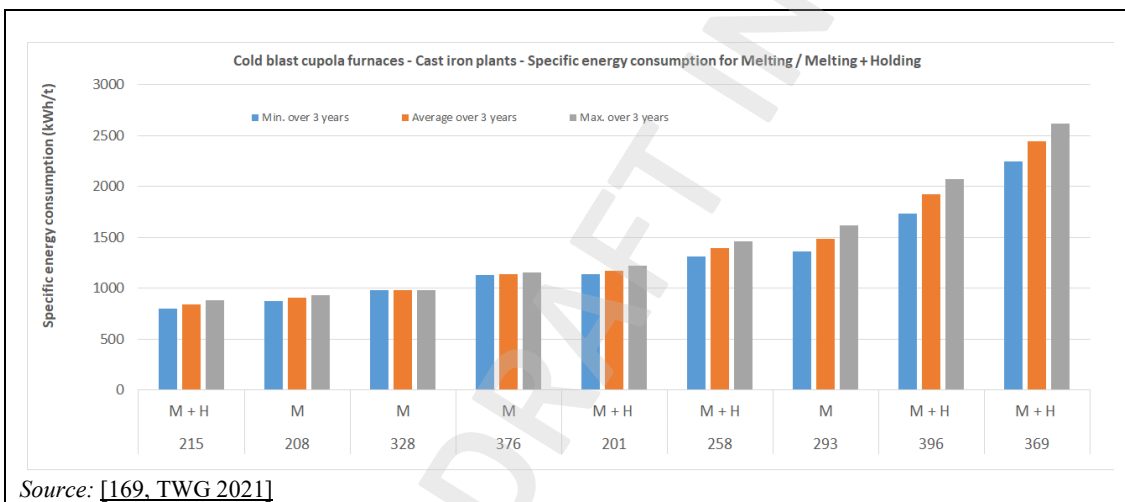
2.3.8.6 Figures for specific energy consumption

In the following figures, the reported levels for specific energy consumption expressed in kWh/t of liquid metal are presented.

The specific energy consumption data were considered confidential business information (CBI) by the TWG. In order to maintain the confidentiality of this information, the plant name is not given in the figures and tables presented in this document. Plant names are systematically replaced by randomly attributed CBI codes for each individual plant. In addition, no contextual information (e.g. process parameters or techniques applied) is included as this could reveal the identity of the plants. All the energy consumption figures are presented in ascending order of the maximum specific energy consumption values.

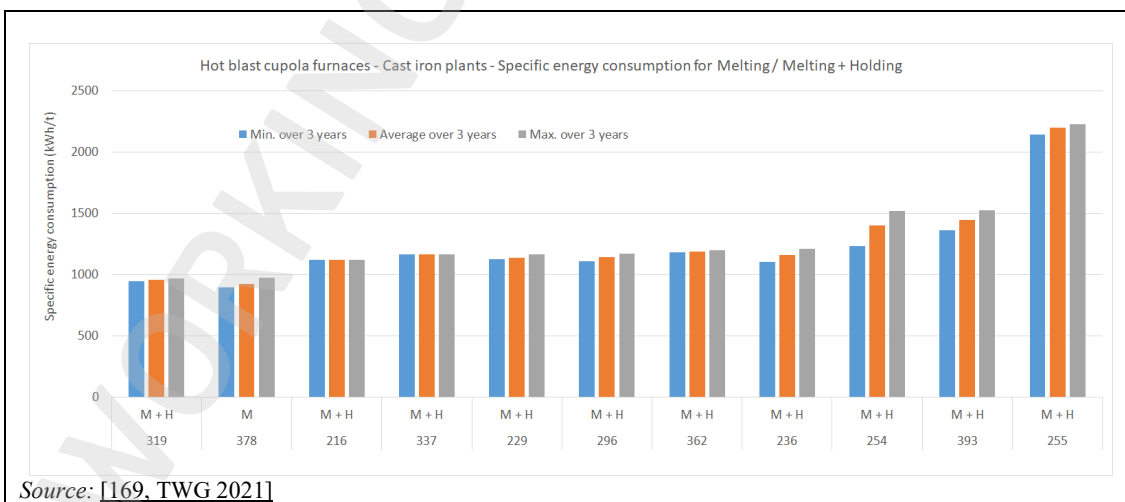
The relevant processes (according to the submitted data) are:

- metal melting;
- heat treatment;
- holding-pouring;
- ladle preheating;
- drying.



Source: [169, TWG 2021]

Figure 2.149: Specific energy consumption for melting / melting and holding in cast iron foundries using CBC



Source: [169, TWG 2021]

Figure 2.150: Specific energy consumption for melting / melting and holding in cast iron foundries using HBC

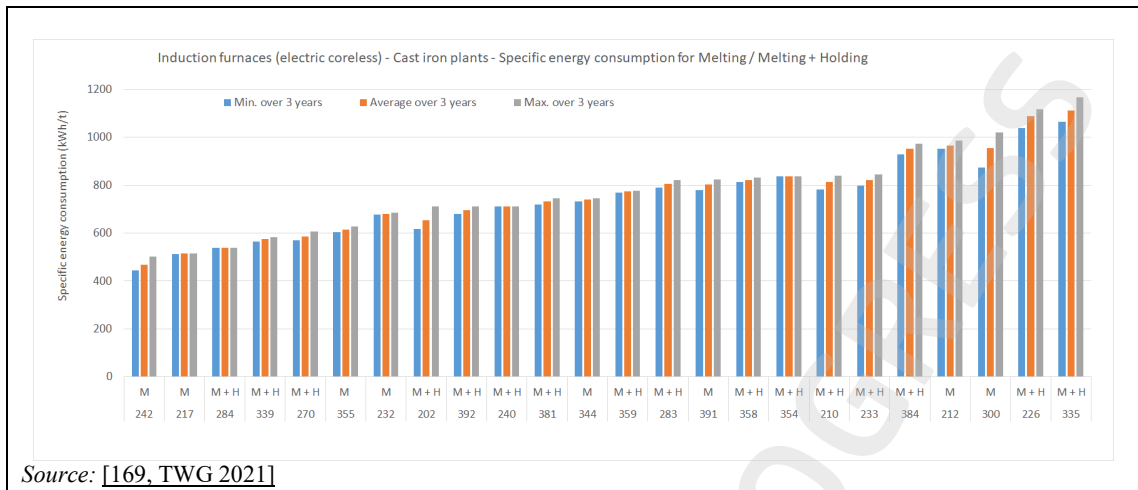


Figure 2.151: Specific energy consumption for melting / melting and holding in cast iron foundries using induction furnaces (electric coreless)

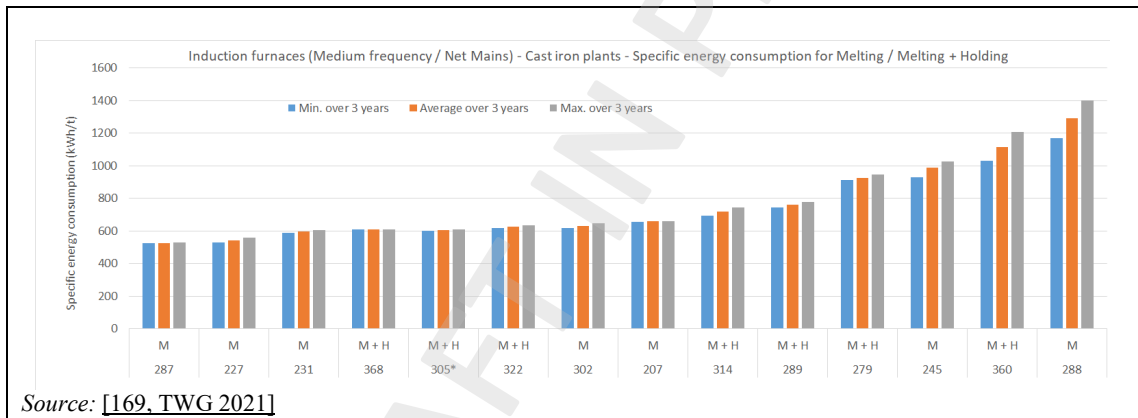


Figure 2.152: Specific energy consumption for melting / melting and holding in cast iron foundries using induction furnaces (medium - net/mains frequency)

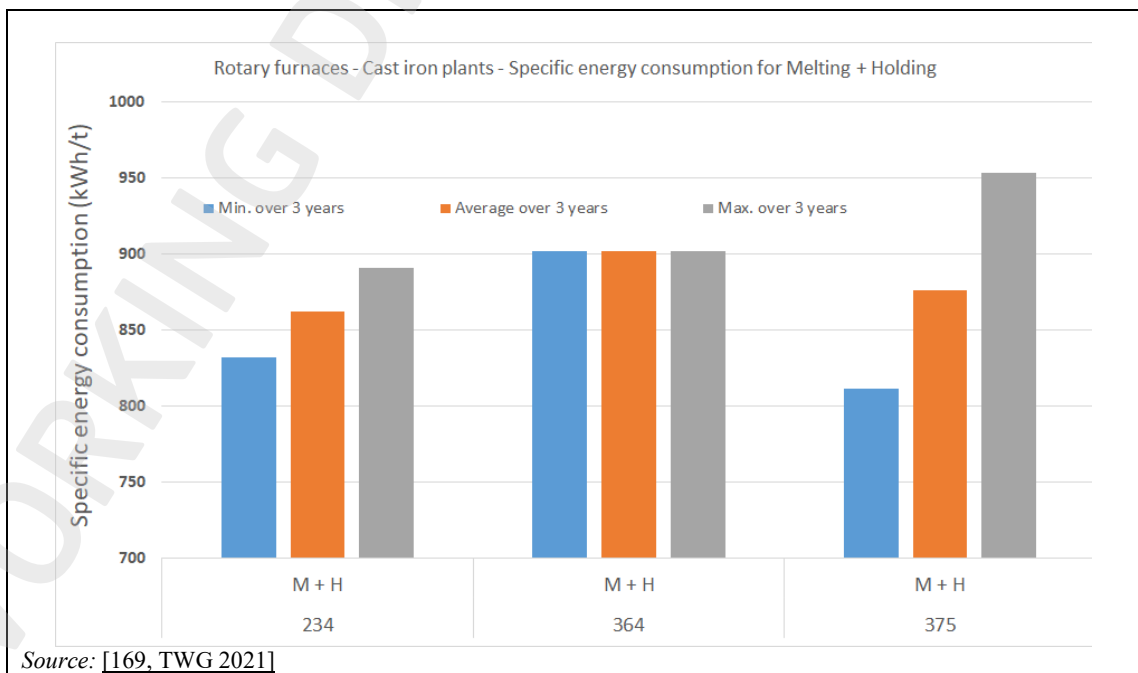


Figure 2.153: Specific energy consumption for melting / melting and holding in cast iron foundries using rotary furnaces

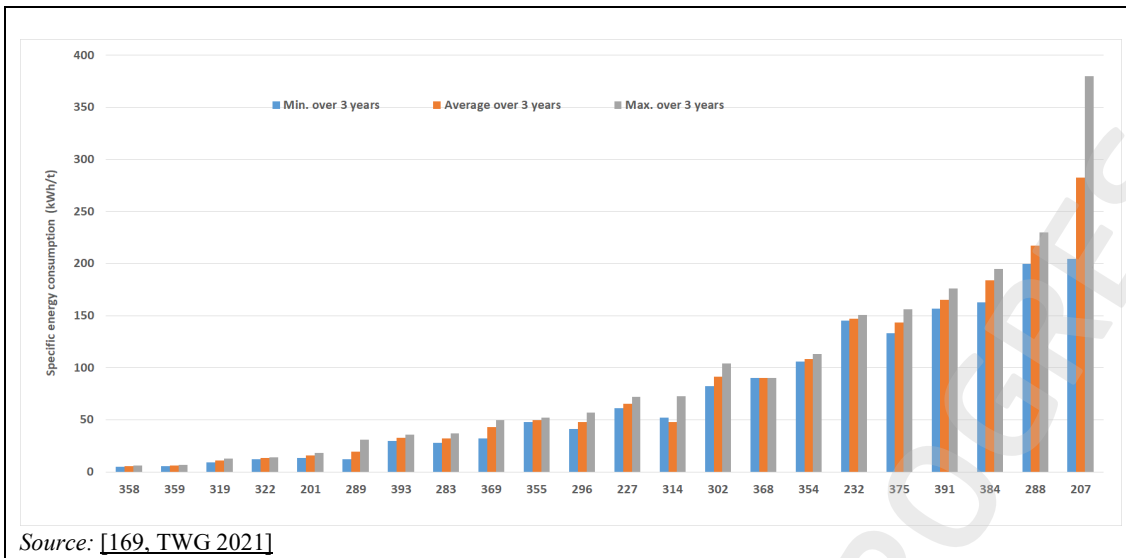


Figure 2.154: Specific energy consumption for ladle preheating in cast iron foundries

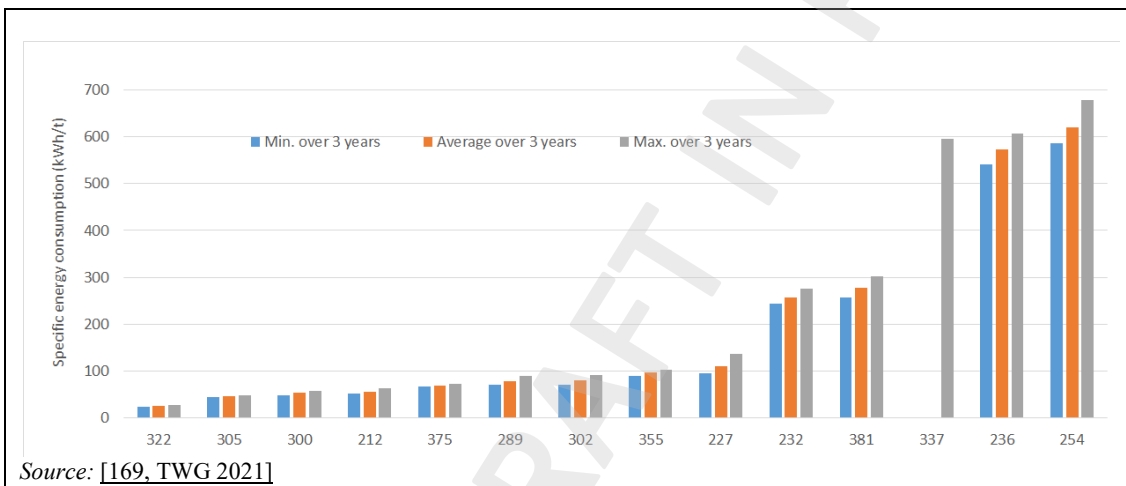


Figure 2.155: Specific energy consumption for heat treatment in cast iron foundries

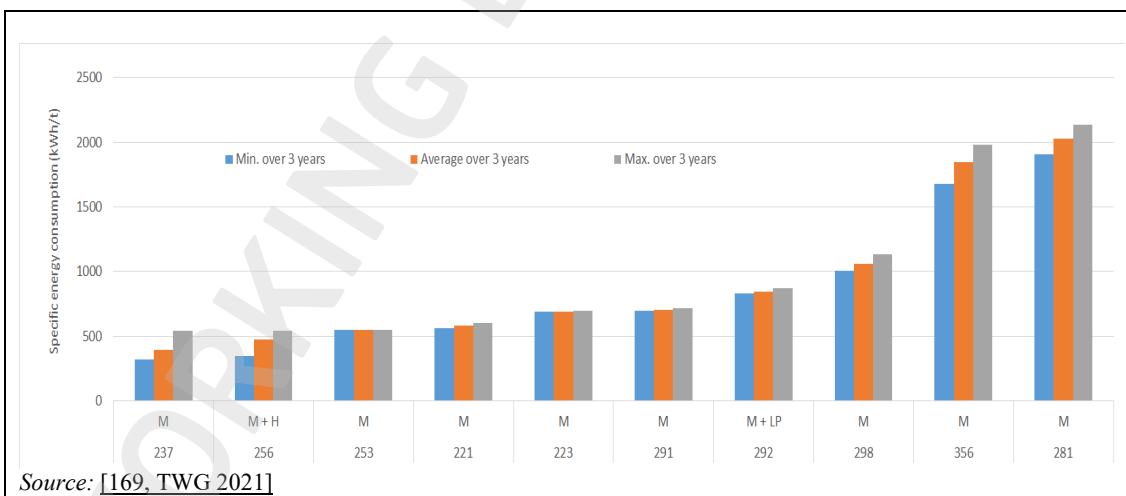


Figure 2.156: Specific energy consumption for metal melting in steel foundries

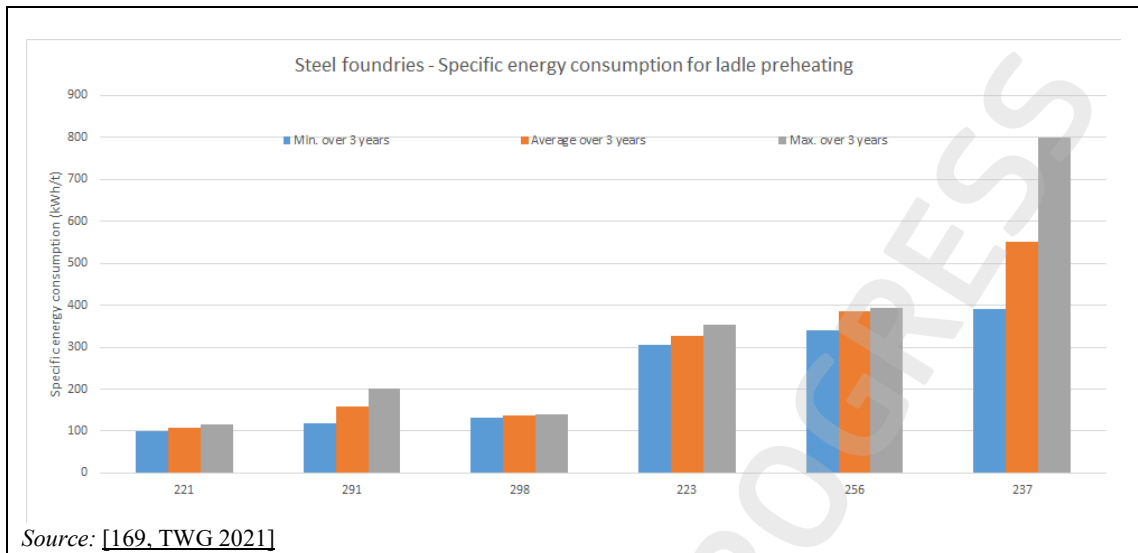


Figure 2.157: Specific energy consumption for ladle preheating in steel foundries

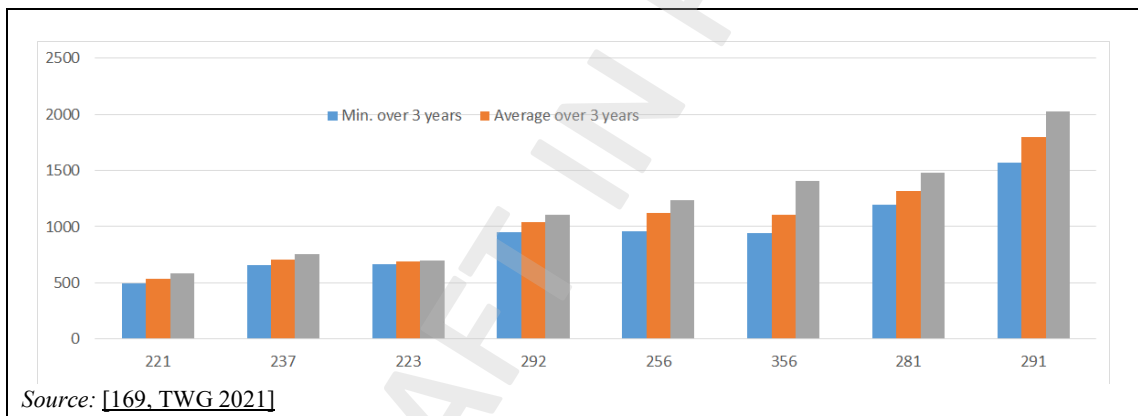


Figure 2.158: Specific energy consumption for heat treatment in steel foundries

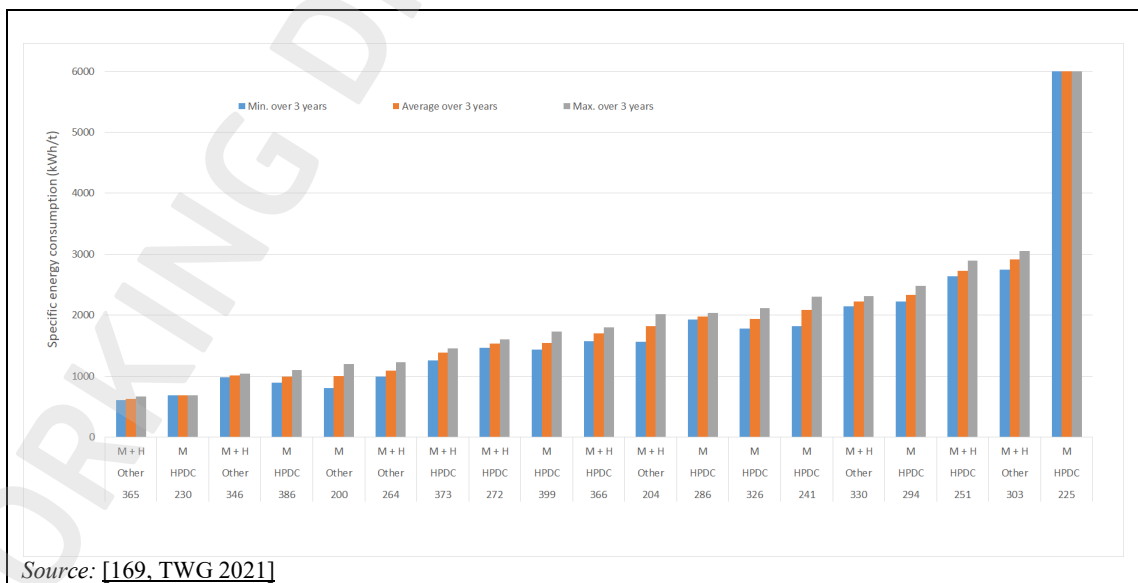


Figure 2.159: Specific energy consumption for metal melting in aluminium foundries

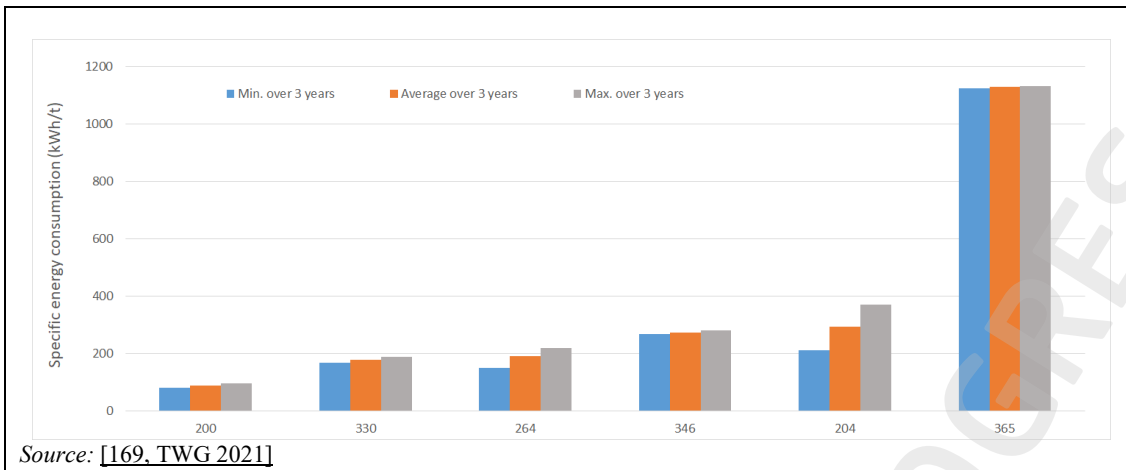


Figure 2.160: Specific energy consumption for heat treatment in aluminium foundries

3 TECHNIQUES TO CONSIDER IN THE DETERMINATION OF BAT

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

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

Annex III to the Directive lists a number of criteria for determining BAT, and the information within this chapter will address these considerations. As far as possible, the standard structure in **Table 3.1** 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 sector. Other techniques may exist, or may be developed, which could be considered in the determination of BAT for an individual installation.

Table 3.1: Information for each technique

Heading within the sections	Type of information included
Description	A brief description of the technique with a view to being used in the BAT conclusions.
Technical description	A more detailed and yet concise technical description using, as appropriate, chemical or other equations, pictures, diagrams and flow charts.
Achieved environmental benefits	The 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.).
Environmental performance and operational data	<p>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.</p> <p>Any other useful information on the following items:</p> <ul style="list-style-type: none"> • 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. <p>Links between inputs (e.g. nature and quantity of raw material and fuel, energy, water) and outputs (emissions, residues/wastes, products) are highlighted, in particular where relevant to enhancing an understanding of different environmental impacts and their interaction, for example where trade-offs have been made between different outputs such that certain environmental performance levels cannot be achieved at the same time.</p> <p>Emission and consumption data are qualified as far as possible with details of relevant operating conditions (e.g. percentage of full capacity, fuel composition, bypassing of the (abatement) technique, inclusion or exclusion of other than normal operating conditions,</p>

Heading within the sections	Type of information included
	<p>reference conditions), sampling and analytical methods, and statistical presentation (e.g. short- and long-term averages, maxima, ranges and distributions).</p> <p>Information is included on conditions/circumstances hampering the use of the (abatement) technique at full capacity and/or necessitating full or partial bypassing of the (abatement) technique and measures taken to restore full (abatement) capacity.</p>
Cross-media effects	<p>Relevant negative effects on the environment due to implementing the technique, allowing a comparison between techniques in order to assess the impact on the environment as a whole. This may include issues such as:</p> <ul style="list-style-type: none"> • 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. <p>The Reference Document on Economics and Cross-media Effects (ECM) should be taken into account.</p>
Technical considerations relevant to applicability	<p>It is indicated whether the technique can be applied throughout the sector. Otherwise, the main general technical restrictions on the use of the technique within the sector are indicated. These may be:</p> <ul style="list-style-type: none"> • 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.: <ul style="list-style-type: none"> – 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. <p>These restrictions are indicated together with the reasons for them.</p> <p>These restrictions are not meant to be a list of the possible local conditions that could affect the applicability of the technique for an individual plant.</p>
Economics	<p>Information on the costs (capital/investment, operating and maintenance costs including details on how they have been calculated/estimated) and any possible savings (e.g. reduced raw material or energy consumption, waste charges, reduced payback time compared to other techniques), or revenues or other benefits including details on how these have been calculated/estimated.</p> <p>Cost data are preferably given in euros (EUR). If a conversion is made from another currency, the data in the original currency and the year when the data were collected are indicated. The price/cost of the equipment or service is accompanied by the year it was purchased.</p>

Heading within the sections	Type of information included
	<p>Information on the market for the sector is given in order to put costs of techniques into context.</p> <p>Information relevant to both newly built, retrofitted and existing plants is included. This should allow assessment, where possible, of the economic viability of the technique for the sector concerned and possible economic limitations to its application.</p> <p>Information on the cost-effectiveness of the technique (e.g. in EUR per mass of pollutant abated) and related assumptions for its calculation can be reported.</p> <p>The Reference Document on Economics and Cross-media Effects (ECM) and the Reference Report on Monitoring of Emissions to Air and Water from IED Installations (ROM) are taken into account with regard to economic aspects and monitoring costs, respectively.</p>
Driving force for implementation	<p>Where applicable, specific local conditions, requirements (e.g. legislation, safety measures) or non-environmental triggers (e.g. increased yield, improved product quality, economic incentives – e.g. subsidies, tax breaks) which have driven or stimulated the implementation of the technique to date are provided.</p> <p>This subsection should be very short and use a list of bullet points.</p>
Example plants	<p>Reference to a plant(s) where the technique has been implemented and from which information has been collected and used in writing the section. An indication of the degree to which the technique is in use in the EU or worldwide.</p>
Reference literature	<p>Literature or other reference material (e.g. books, reports, studies) that was used in writing the section and that contains more detailed information on the technique. When the reference material consists of many pages, reference will be made to the relevant page(s) or section(s).</p>

3.1 Common techniques to consider in the determination of BAT for smitheries and foundries

3.1.1 Overall environmental performance

This section covers the areas, processes and activities of the installation that are not covered elsewhere, as they refer to issues that are common for both the smitheries and foundries sectors.

3.1.1.1 Environmental management system (EMS)

Description

A formal system to demonstrate compliance with environmental objectives.

Technical description

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

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

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

All effective EMSs incorporate the concept of continuous improvement, meaning that environmental management is an ongoing process, not a project which eventually comes to an end. There are various process designs, but most EMSs are based on the plan-do-check-act cycle (which is widely used in other company management contexts). The cycle is an iterative dynamic model, where the completion of one cycle flows into the beginning of the next (see Figure 3.1).

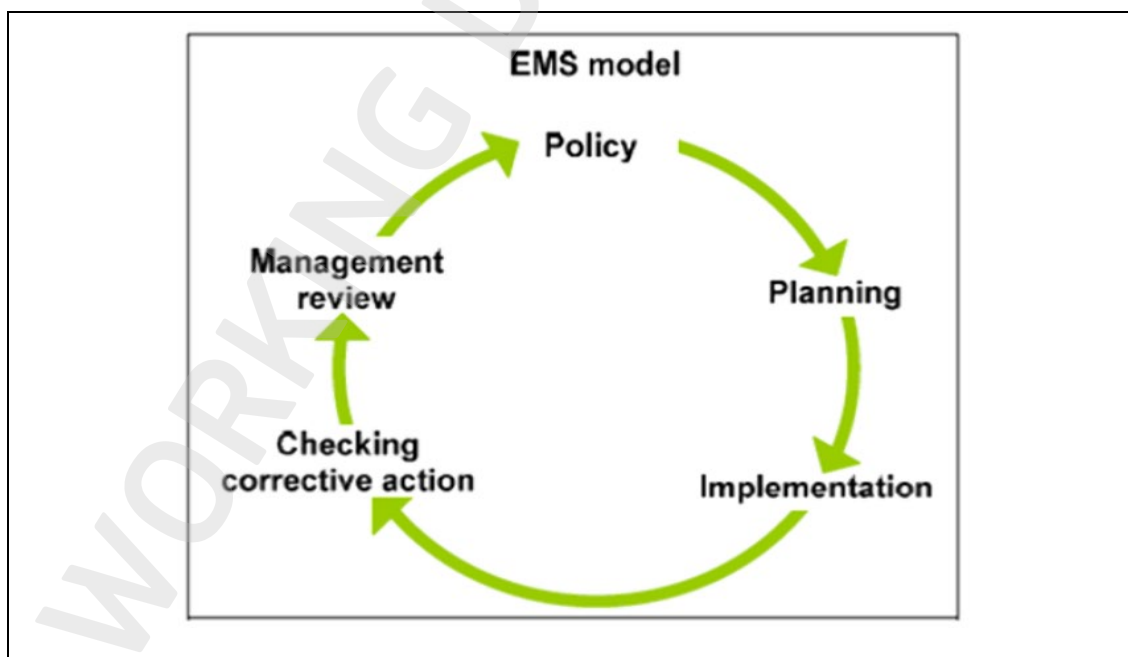


Figure 3.1: Continuous improvement in an EMS model

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 as well as of the applicable legal requirements relating to the environment and human health;
- 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 smitheries and foundries sector, the following features are included in the EMS:

- xxi. an inventory of inputs and outputs (see Section 3.1.1.2);
- xxii. a chemicals management system (see Section 3.1.1.3);
- xxiii. a plan for the prevention and control of leaks and spillages (see Section 3.1.1.4.1);
- xxiv. an OTNOC management plan (see Section 3.1.1.5);
- xxv. an energy efficiency plan and audits (see Section 3.1.3.1);
- xxvi. a water management plan and audits (see Section 3.2.1.16.1);
- xxvii. a noise and/or vibration management plan (see Section 3.1.5.1);
- xxviii. a residues management plan (see Section 3.1.6.1);
- xxix. an odour management plan for foundries (see Section 3.2.1.15.1).

Achieved environmental benefits

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

Cross-media effects

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

Technical considerations relevant to applicability

The components described above can typically be applied to all installations within the scope of this document. The level of detail and the degree of formalisation of the EMS will generally be related to the nature, scale and complexity of the plant, and the range of environmental impacts it may have.

Driving force for implementation

The driving forces for the implementation of an EMS include:

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

Example plants

EMSs are applied in a number of installations throughout the EU.

Reference literature

[140, IAF 2010], [141, EU 2009], [142, COM 2010], [144, CEN 2015]

3.1.1.2 Inventory of inputs and outputs

Description

The compilation of relevant basic data on input and output streams of resources (e.g. inputs like materials, energy, water, and outputs like waste gases, waste waters, residues, energy losses, etc.). Basic data for streams include the information on environmentally important characteristics, like presence of hazardous substances, their toxicity, composition and quantities. These data are used in mass balances, efficiency plans and for monitoring of emissions.

Technical description

All environmental problems are directly linked to input/output streams. In the interests of identifying options and priorities for improving environmental and economic performance, it is therefore vital to know as much as possible about their quality and quantity.

Input/output stream inventories can be drawn up on different levels. The most general level is an annual site-specific overview.

As part of the EMS (see Section 3.1.1.1), an inventory of inputs and outputs has to be established, maintained and regularly reviewed (including when a significant change occurs), that incorporates all of the following features:

- i. information about the production processes, including:
 - (a) simplified process flow sheets that show the origin of the emissions to air, water and soil;
 - (b) descriptions of process-integrated techniques and waste water/waste gas treatment techniques to prevent or reduce emissions, including their performance (e.g. abatement efficiency);
- ii. information about the quantity and characteristics of raw materials (e.g. scrap, feedstock, sand) and fuels (e.g. coke) used;
- iii. information about water consumption and usage (e.g. flow diagrams and water mass balances);
- iv. information about energy consumption and usage;
- v. information about the characteristics of the waste water streams, such as:
 - (a) average values and variability of flow, pH, temperature and conductivity;
 - (b) average concentration and mass flow values of relevant substances/parameters (e.g. total suspended solids, TOC or COD, hydrocarbon oil index, metals) and their variability;
- vi. information about the quantity and characteristics of the process chemicals used:
 - (a) the identity and the characteristics of process chemicals, 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 (e.g. dust, NO_x, SO₂, CO, metals) and their variability;
 - (c) presence of other substances that may affect the waste gas treatment system (e.g. oxygen, nitrogen, water vapour) or installation safety;
 - (d) presence of substances classified as CMR 1A, CMR 1B or CMR 2; the presence of such substances may for example be assessed according to the criteria of Regulation (EC) No 1272/2008 on classification, labelling and packaging (CLP);
- viii. information about the quantity and characteristics of residues/waste generated.

Achieved environmental benefits

The described evaluation and inventory of input/output mass streams is an essential management tool for the identification of optimisation potential, both environmental and economic. It is the prerequisite for a continuous improvement process.

Environmental performance and operational data

The application of such a management tool requires 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 plant, 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

[169, TWG 2021]

3.1.1.3 Chemicals management system (CMS)

Description

The chemicals management system (CMS) is part of the EMS (see Section 3.1.1.1) 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, the elaboration and implementation of a chemicals management system (CMS), as part of the EMS, is implemented.

The chemicals management system (CMS) contains the following features:

- I. A policy to reduce the consumption and risks associated with process chemicals, including a procurement policy to select less harmful process chemicals and their suppliers with the aim of minimising the use 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, ecotoxicity 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;
 - 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;

- 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 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 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

The need to implement a chemicals management system in relevant IED installations depending on the amount, quantity and diversity of chemicals used is described in more detail in the conclusions of the HAZBREF project (Work package 3 – Activity 3.2). [176, HAZBREF 2021]

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 plant.

Economics

No information provided.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

No information provided.

Reference literature

[176, HAZBREF 2021]

3.1.1.4 Prevention or reduction of emissions to soil and groundwater

3.1.1.4.1 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 3.1.1.1) and includes, but is not limited to:

- site incident plans for small and large spillages;
- identification of the roles and responsibilities of persons involved;

- ensuring staff are environmentally aware and trained to prevent and deal with spillage incidents;
- identification of areas at risk of spillage and/or leaks of hazardous materials 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 (at least on an annual basis) inspections 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 of the plan will generally be related to the nature, scale and complexity of the plant, 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 in foundries.

Smithery plant ES008 in the data collection.

Reference literature

[169, TWG 2021]

3.1.1.4.2 Structuring and management of process areas and raw material storage areas

Description

Process areas and raw material storage areas need to be structured and managed.

This includes techniques such as:

- impermeable (e.g. cemented) floor for process areas and for scrap/feedstock yards;
- separate storage for various types of raw materials, close to the production lines; this can be achieved using for example compartments or boxes in the storage areas and bunkers.

Technical description

Structuring and management of process areas and raw material storage areas ensure that raw materials are efficiently stored and handled.

For example, in foundries, the scrap/feedstock storage area can be structured and managed in such a way that the following factors are taken into account:

- The composition of the furnace charge necessitates knowledge of the feed material. Applying separate storage for various metal types or grades allows control of the charge composition. This can be achieved using compartments or boxes in the storage area or bunker.
- The introduction of mineral and oxide materials such as rust, soil or dirt causes increased refractory wear. The use of a cemented scrap yard prevents the entrainment of soil, dirt or water.
- A water collection and treatment system can be used to prevent contamination of soil or water.

Furthermore, the materials are well sorted, kept in a dry area under roofing (see Section 3.1.1.4.3) or in closed storage containers and can quickly be 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 in foundries.

Smithery plant ES008 in the data collection.

Reference literature

[100, TWG 2002], [169, TWG 2021]

3.1.1.4.3 Prevention of the contamination of surface run-off water**Description**

Production areas and/or areas where process chemicals, residues or waste are stored or handled, are protected against surface run-off water. This is achieved by using at least the following techniques:

- drainage channels and/or an outer kerb bund around the plant;
- roofing with roof guttering of 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 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 in foundries.

Smithery plant ES008 in the data collection.

Reference literature

[169, TWG 2021]

3.1.1.4.4 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, treatment, reuse.

Technical description

The potentially contaminated surface run-off water is collected separately and only discharged when appropriate measures are taken to prevent cross-contamination of uncontaminated water streams or the contamination of the final receptor.

In the event of fire, extinguishing water retention measures are required, which can be either centralised or decentralised. The type of measures also depend on the quantity of fire-extinguishing water and its potential contamination with polluting substances.

Achieved environmental benefits

- Avoidance of cross-contamination of uncontaminated water streams.
- Reduction of waste water generation.

Environmental performance and operational data

Detailed information was provided for an Italian cast iron foundry which implemented specific measures in 2011. In particular, the area used for the storage of the loading materials of the furnaces (scrap, metallurgical coke, pig iron, return outlets) was equipped with a dedicated drainage network, through the creation of collection traps, which convey the water to a 20 m³ storage tank from which the water flow is then sent to a physico-chemical treatment plant. The area concerned is approximately 2 300 m² (2 120 m² + 155 m²). Both the water coming from the 2 120 m² area and that coming from the 155 m² area, before being introduced into the accumulation tank, pass through a spillway well equipped with a bypass, capable of separating first rainwater from that of second rain. The second rainwater is sent via the aforementioned bypass to the spillway located upstream of the first rainwater treatment plant. The outgoing water from the physico-chemical treatment facility is sent to the network which conveys the remaining rainwater from the rest of the plant to the rainwater treatment plant (drainage area 50 000 m² - total tank volume 250 m³).

Cross-media effects

When treatment applies, this entails the use of chemicals and the generation of sewage sludge.

Technical considerations relevant to applicability

Generally applicable.

Economics

Operational costs associated with the collection and potential treatment processes.

For the case of the Italian foundry mentioned above (see Environmental performance and operational data), the construction/installation costs were as follows (2011 data):

- 200 m canalisation system (supply, installation and testing) – total cost EUR 45 000;
- 20 m³ tank before run-off rainwater from the raw materials storage area (supply, installation and testing) – total cost EUR 11 000;
- 20 m³ tank after run-off rainwater from the raw materials storage area (supply, installation and testing) – total cost EUR 11 000;
- physico-chemical treatment facility (supply, installation and testing) – total cost EUR 28 700.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

Widely used.

Reference literature

[169, TWG 2021], [208, COM 2020], [210, TWG 2022].

3.1.1.4.5 Safe handling and storage of process chemicals

Description

This includes the following:

- storage in roofed and ventilated areas with floors that are 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;
- loading/unloading areas for process chemicals, lubricants, coatings, etc. are designed and constructed in such a way that potential leaks and spillages are contained and sent to on-site treatment or off-site treatment;

- highly flammable liquids (e.g. methyl formate, TEA, DMEA, mould coatings containing alcohol) are stored separately from incompatible substances (e.g. oxidisers) in enclosed and well-ventilated storage areas.

Technical description

Use of oil-tight trays or cellars:

Hydraulic stations and oil- or grease-lubricated equipment are situated in oil-tight trays or cellars to avoid penetration of oil into the ground in the event of leakage. Accidental releases are prevented by periodic checks and preventive maintenance of seals, gaskets, pumps and piping.

In foundries, binder chemicals carry specific manufacturer’s recommendations for storage. Failure to comply with these recommendations will result in unusable or substandard products that either require disposal as special waste or lead to poor casting quality due to substandard moulds/cores. The following table summarises the quality problems arising from the incorrect storage of liquid binder chemicals. Correct storage takes account of these problems.

Table 3.2: Problems arising from an incorrect storage of liquid binder chemicals

Problem	Effect on product	Implications	Effect on castings
Exposure to excessive cold	Aqueous-based products may freeze	Product segregation may occur, causing mould failure. Affected products require disposal	Casting production may not be possible
Exposure to excessive heat and sunlight	Premature ageing, cross-linking of resin and increased viscosity	Poor mixing properties, low mould strengths and poor resistance to high temperatures	Fining defects
Prolonged storage or cold storage	Increased viscosity	Dispersion onto sand grains difficult. Sand mixture flows less well and is difficult to compact. Low-strength moulds	Erosion, exogenous (sandy) inclusions fining and dimensional faults
Contamination by moisture	Products containing isocyanates will deteriorate due to reaction with water	Binder performance is poor and product may need disposal	Increased risk of gas defects (pinholes)
Sediment disposal in bulk silicate storage tanks	Pumped liquid may become inconsistent	Low-strength moulds	Oversize castings and shrinkage effects

Source: [28, ETSU 1998]

Some basic measures include:

- roofed and ventilated area;
- impermeable floors;
- collection of spilled liquid;
- locked storage area.

Depending on the climate, exposure to excessive cold or heat and to sunlight can be accounted for. Additional precautions are necessary for the storage of highly flammable liquids such as methyl formate, triethylamine (TEA), dimethylethylamine (DMEA) and mould coatings containing alcohols.

Achieved environmental benefits

- Prevention of contamination of surface and groundwater.
- Avoidance/reduction of generation of waste chemicals.

- Reduction of the amount of waste chemicals arising, which are unsuitable for use.

Most binder chemicals are hazardous and are characterised by one or more of the following properties: toxic, corrosive, flammable. These properties mean that even small spills can pose a danger to workers' health and safety, while larger releases can result in a serious incident. A major spill that is allowed to enter a surface water drain can cause serious pollution of watercourses.

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 foundry operations.
- Legal requirements.
- Local conditions.

Example plants

Widely used.

Smithery plant ES008 in the data collection.

Reference literature

[31, ETSU 1996], [169, TWG 2021], [168, COM 2022], [210, TWG 2022].

3.1.1.4.6 Good housekeeping

Description

A set of measures aiming at preventing, or reducing, the generation of emissions (e.g. regular maintenance and cleaning of equipment, working surfaces, floors and transport routes, and containment as well as rapid take-up of any spillages).

Achieved environmental benefits

- Prevention or reduction of diffuse 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

[169, TWG 2021]

3.1.1.5 Other than normal operating conditions (OTNOC) management plan

Description

A risk-based OTNOC management plan includes all of the following elements:

- a. 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;
- b. appropriate design of critical equipment (e.g. off-gas treatment, waste water treatment);
- c. set-up and implementation of an inspection plan and preventive maintenance programme for critical equipment (see Section 3.1.1.1 – point xii. of the EMS);
- d. monitoring (i.e. estimating or, where possible, measuring) and recording of emissions during OTNOC and of associated circumstances;
- e. periodic assessment of the emissions occurring during OTNOC (e.g. frequency of events, duration, amount of pollutants emitted) and implementation of corrective actions if necessary;
- f. regular review and update of the list of identified OTNOC under point i. following the periodic assessment of point v.;
- g. regular testing of backup systems.

Technical description

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 the process control or used for emission monitoring (such as instrumentation drift);
- testing of new apparatus;
- calibration of the monitoring system.

In order to reduce the frequency of the occurrence of OTNOC and to reduce emissions during OTNOC, a risk-based OTNOC management plan as part of the environmental management system (see Section 3.1.1.1) is put into place and may include the elements described in the description section above.

Achieved environmental benefits

Emissions associated with shutdown and start-up operations are in part avoided. Planning for and achieving a reduced number of shutdowns is likely to reduce the annual mass emission levels of any plant.

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 maintenance requiring switching off emissions control equipment/systems (e.g. containment, extraction systems, off-gas treatment) is planned to take place when there are no emissions (e.g. shutdown times) or when emission levels are low;
- replace parts 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 plant, 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.

Smithery plant ES008 in the data collection.

Reference literature

[169, TWG 2021], [210, TWG 2022].

3.1.2 Monitoring

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 process chemicals, expressed as a yearly average;
- the generation of waste water, 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

No information provided.

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

The majority of plants (foundries) reported monitoring of the parameters mentioned above. Smithery plant ES008 in the data collection.

Reference literature

[169, TWG 2021], [210, TWG 2022].

3.1.3 Energy efficiency

In the following sections, general techniques related to energy efficiency are discussed. In addition to these, specific energy efficiency techniques are also discussed in the following sections:

- Section 3.2.1.3 for all foundry types;
- Section 3.2.2.1 for cast iron foundries;
- Section 3.2.4.1 for NFM foundries;
- Section 3.3.1 for smitheries.

3.1.3.1 Energy efficiency plan and audits**Description**

An energy efficiency plan is part of the EMS (see Section 3.1.1.1) and entails defining and monitoring the specific energy consumption of the activity/processes (e.g. kWh/t liquid metal), setting objectives in terms of energy efficiency and implementing actions to achieve these objectives.

Audits (also part of the EMS, see Section 3.1.1.1) are carried out at least once every year to ensure that the objectives of the energy efficiency plan are met and the audits' recommendations are followed up and implemented.

The energy efficiency plan may be integrated in the overall energy efficiency plan of a larger installation (e.g. surface treatment activities).

Technical description

Extensive information about energy efficiency can be found in the Energy Efficiency BREF (ENE BREF) [177, COM 2009]. Some techniques applicable to increase the energy efficiency of SF plants 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. kWh/tonne of 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.
- f. Applying operating, maintenance and housekeeping measures to the most relevant energy consumption processes, such as:
 - furnaces, die casting machines, heat treatment;
 - air conditioning, process refrigeration and cooling systems (leaks, seals, temperature control, evaporator/condenser maintenance);
 - operation of motors and drives (e.g. high-efficiency motors);
 - compressed gas systems (leaks, procedures for use);
 - steam distribution systems (leaks, traps, insulation);
 - room heating and hot water systems;
 - lubrication to avoid high friction losses (e.g. mist lubrication);
 - boiler maintenance, e.g. optimising excess air;
 - other maintenance relevant to the activities within the plant;
 - reviewing equipment requirements on a regular basis.

- g. Using techniques that reduce energy consumption and thereby reduce both direct (heat and emissions from on-site generation) and indirect (emissions from a remote power station) emissions. For example:
- building insulation;
 - use of energy-efficient site lighting;
 - vehicle maintenance;
 - efficient plant layout to reduce pumping distances;
 - phase optimisation of 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.
- h. Applying basic, low-cost, physical techniques to avoid gross inefficiencies; including insulation, containment methods (for example seals and self-closing doors) and avoiding unnecessary discharges of heated water or air (for example by fitting simple control systems).
- i. Applying energy efficiency techniques to building services.
- j. Using heat from the furnaces and engines for vaporisation, drying and for preheating activities.

Energy audits are carried out at least once a year 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 and emissions relevant for that energy use.

Through the implementation of energy audits and the establishment of energy management systems, a continuous improvement process is initiated, leading to reduced energy demand, lower CO₂ emissions and reduced environmental impact. Most energy efficiency measures lead to material cycles being closed and input materials being used more efficiently.

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.

Technical considerations relevant to applicability

The level of detail of the energy efficiency plan and of the audits will generally be related to the nature, scale and complexity of the plant and the types of energy sources used.

Economics

No information provided.

Driving force for implementation

Energy savings.

Example plants

Widely used.

Reference literature

[169, TWG 2021], [177, COM 2009], [210, TWG 2022].

3.1.3.2 Energy balance record**Description**

The technique involves the drawing up on an annual basis of an energy balance record 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.

This includes:

- (i) definition of the energy boundaries of the processes;
- (ii) information on energy consumption in terms of delivered energy;
- (iii) information on energy exported from the plant;
- (iv) energy flow information (e.g. Sankey diagrams or energy balances) showing how the energy is used throughout the 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.

Technical considerations relevant to applicability

The level of detail of the energy balance record will generally be related to the nature, scale and complexity of the plant and the types 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

[177, COM 2009], [210, TWG 2022].

3.1.3.3 Use of general energy-saving techniques

Description

This includes techniques such as:

- burner maintenance and control;
- energy-efficient motors;
- energy-efficient lighting;
- optimising steam and compressed air distribution systems;
- regular inspection and maintenance of the steam distribution systems to prevent or reduce steam leaks;
- process control systems;
- variable speed drives;
- optimising air conditioning and building heating.

Technical description

Optimisation of furnaces and furnace operation will yield major efficiency improvements because preheating/heating/reheating, heat treatment, melting and holding account for the majority of the total energy consumption. Energy consumption 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 high-intensity discharge with high-intensity fluorescent lights, using daylighting and using LED lighting (see also the ENE BREF). [177, COM 2009]

Achieved environmental benefits

Reduction of energy consumption.

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

Reduction of energy costs.

Example plants

Widely used in foundries.

Smithery plants DE002, DE003, DE005, DE006, DE007 and ES008.

Reference literature

[169, TWG 2021], [177, COM 2009], [210, TWG 2022].

3.1.4 Emissions to air**3.1.4.1 Use of electricity from fossil-free energy sources in thermal processes (in foundries and smitheries)****Description**

This technique consists of the:

- use of electric furnaces (e.g. coreless and channel induction, resistance, electric arc) in foundries for the processes of metal melting and heat treatment of castings;
- use of electric furnaces in smitheries for the processes of heating/reheating and heat treatment of workpieces.

In both cases, the electricity used is generated from fossil-free energy sources (e.g. hydroelectric, solar, wind, nuclear).

Technical descriptionFoundries

Metal melting and heat treatment constitute the two main thermal processes where electric furnaces are employed for the production of either ferrous or non-ferrous molten metal. This also includes remelting of molten metal and heat conservation of molten metal in holding furnaces.

The various types of furnaces employed for metal melting or heat treatment in foundries at the time of writing this document (2023) are summarised below:

- *Cast iron foundries:* A significant proportion of cast iron is produced using fossil-fuel-fired furnaces such as cupola (hot blast or cold blast) and rotary furnaces. Alternatively, cast iron is usually melted in electric furnaces, in particular medium-frequency or coreless induction furnaces. Channel induction furnaces are also used but principally for holding purposes. Heat treatment of ductile iron (e.g. annealing, tempering, austempering) may be carried out either in electric or gas-fired furnaces.
- *Steel foundries:* A large majority of foundries use electric furnaces for metal melting, in particular electric arc or induction furnaces. Large steel foundries are usually equipped with electric arc furnaces, but the majority of smaller steel foundries use induction furnaces. For heat treatment, carbon steel and low-alloy steel are generally submitted to normalising or to austenitising, quenching and tempering heat treatments. This may be carried out either in electric or gas-fired furnaces.
- *NFM foundries:* A variety of different melting furnaces are used depending on the type of alloy and melting capacity. Often, small foundries use either gas-fired or crucible induction furnaces. Large NFM foundries generally use either gas-fired furnaces (e.g. shaft or reverberatory) or electric furnaces (e.g. induction furnaces). For heat treatment

(e.g. stress relieving, annealing, quenching, artificial ageing), either electric or gas-fired furnaces may be used.

As an example, in Germany, cast iron foundries produced about 4 million tonnes of castings in 2019. About half of the total production was produced using electric furnaces; the rest was produced using fossil fuel-fired furnaces. For steel foundries, approximately 75 % of castings were produced using induction furnaces and 25 % using EAFs. In non-ferrous metal foundries, approximately 70 % of the furnaces are heated using fossil fuels and 30 % are heated electrically. [231, UmweltBundesamt 2023]

The foundry type, furnace type and number of furnaces in foundries operating in Germany (2019) are summarised in Table 3.3.

Table 3.3: Number of furnaces per furnace type and foundry type in foundries operating in Germany (2019)

Foundry type	Furnace type	Energy carrier	Number of furnaces
Cast iron	Cold blast cupola	Coke	Approx. 30
	Hot blast cupola	Coke, natural gas	Approx. 25
	Induction furnaces	Electricity	> 140
	Rotary furnaces	Natural gas, oil	Approx. 10
Steel	Induction furnaces	Electricity	> 40
	Arc furnaces	Electricity	Approx. 15
Non-ferrous metal	Gas-fired furnaces (e.g. shaft)	Natural gas	1 500 to 2 000
	Oil-fired furnaces	Oil	600 to 800
	Electric furnaces	Electricity	900 to 1 200

Source: [231, UmweltBundesamt 2023]

Smitheries

In smitheries, the main thermal processes are heating and reheating to raise the temperature of the feedstock prior to the hammering process and heat treatment (e.g. annealing, tempering, austempering) carried out after the hammering process in order to give the workpiece its required metallurgical properties. Heating/reheating of the feedstock is usually carried out either by direct or indirect heating as follows:

- *Direct heating:* Electric energy is used, either inductive or conductive.
- *Indirect heating:* Generally, this is carried out in natural-gas-fired furnaces or continuous furnaces. In some cases, electric furnaces are also used.

In heat treatment, both electric and gas-fired furnaces may be used.

Summary

Overall, this technique consists of operating the thermal processes mentioned above using electricity. In order to ensure that emission reductions are not counterbalanced by emissions and other potential negative environmental impacts from power generation, electricity generated from fossil-free energy sources is used. 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 can provide information to the operator on the source of the electricity supply.

In cases where electric furnaces are already in use (e.g. coreless induction in cast iron or aluminium foundries, EAFs or induction furnaces in steel foundries), the primary objective of a

smithery or foundry operator would be to obtain electricity from a fossil-free energy source depending on local conditions and availability of a fossil-free energy supply.

In cases where fossil-fuel-fired furnaces are in use (e.g. hot and cold blast cupola furnaces in cast iron, shaft or reverberatory furnaces in NFM foundries), the replacement of existing fossil-fuel-fired furnaces with new electric furnaces may be considered. Such replacement may consider the metallic charge materials that are available, in line with the requirements of circular economy.

Achieved environmental benefits

- Elimination of emissions of CO, CO₂, SO₂ and NO_x and reduction of dust emissions from SF thermal processes on site.
- Reduction and/or avoidance of CO, CO₂, SO₂, NO_x and dust emissions from power generation.
- Improved energy efficiency of the metal melting and preheating/heating/reheating processes.
- Prevention or limitation of negative impacts to the environment as a whole, e.g. emissions to air, water and soil as well as use of resources and waste generation.

Environmental performance and operational data

The use of electricity generated from fossil-free energy sources in the smitheries and foundries thermal processes can lead to substantial reductions in terms of CO₂, CO, dust, SO₂ and NO_x emissions.

Emissions data for CO, SO₂, dust and NO_x for metal melting in foundries in relation to the furnace type are summarised for fuel-fired furnaces (e.g. hot blast or cold blast cupola furnaces) in comparison to electric furnaces (e.g. coreless or medium frequency) in Table 2.37 (CO), Table 2.38 (SO₂), Table 2.30 (dust) and Table 2.36 (NO_x).

Data for the specific energy consumption associated with metal melting in fuel-fired furnaces (cast iron: hot blast or cold blast cupola furnaces) compared to electric furnaces (e.g. coreless or medium frequency) are provided in Figure 2.149, Figure 2.150, Figure 2.151 and Figure 2.152 respectively.

Cross-media effects

Energy generation from fossil-free energy sources may have other environmental impacts (e.g. dust generation from electricity production from biomass combustion, generation of nuclear waste materials in nuclear power plants, noise emissions from wind turbines).

Technical considerations relevant to applicability

The following factors may need to be considered in relation to the selection of the furnace type (electric or fuel-fired):

- *Availability of electrical power output:* The use of electricity in heating 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 furnaces. In this case, strong power lines as well as transformers are required. Peak load management is important to coordinate the melting operations with the power of the grid.
- *Availability of electricity from fossil-free energy sources:* The current energy policy of the European Union promotes decarbonisation of electricity generation. Accordingly, the share of fossil-free electricity in the European electricity mix is expected to rise drastically in the short to medium term. However, there are still significant differences between Member States in terms of the sources of electricity production. In 2022, for instance, in France the share of electricity production from fossil-free energy sources (wind, solar, nuclear, biomass, hydroelectricity – about 87 %) largely outweighs the share of electricity production from natural gas or coal (about 13 %). In Poland,

however, the share of electricity production from coal and natural gas is very significant (about 71 %).

- *Infrastructure and operational modifications:* In cast iron foundries, continuously operated cupola furnaces with production capacity up to 100 t/h have a significantly higher melting capacity than induction furnaces (typically 40 t/h). Accordingly, the replacement of cupola furnaces requires several induction furnaces that need to be operated and synchronised to ensure the same production capacity and continuous operation. Besides, the entire material flow in the foundry will also need to be redesigned. Overall, the conversion of fuel-fired furnaces with continuous operations (e.g. cupola furnaces) is much more complex than the conversion of fuel-fired furnaces with discontinuous operations. These aspects also need to be considered in NFM foundries where, for example, reverberatory hearth furnaces with a melting rate up to 30 t/h are substituted by multiple induction furnaces with a lower melting rate (e.g. 10 t/h). [231, UmweltBundesamt 2023]
- *Space availability:* In the evaluation of the viability of conversion to electric heating, the power or heat load requirements of the existing furnace and suitable electrical supply infrastructure are important considerations. In general, conventional fuel-fired burners deliver a higher power density (kW/m³) in the furnace compared to electric heating. Therefore, electric heating elements may require more space compared to conventional burners. The replacement of a cupola furnace by several induction furnaces may lead to an increase in the footprint of the plant.

Economics

- The choice between the use of existing gas-fired furnaces or their replacement with new electric furnaces will be based on the availability of technical options and their respective costs.
- The costs of fossil-free electricity in comparison to fossil fuels is a key economic factor, with sizeable differences across the EU.
- The infrastructure costs (e.g. grid lines, transformation station) for fossil-free electricity supply needs to be considered.
- Currently, the investment costs for induction furnaces are higher than those of fuel-fired furnaces. However, the operational costs are advantageous, mainly due to the about 35 % savings in terms of energy consumption and > 50 % decrease in metal losses (burn-off). [234, EEB 2023]
- Induction furnaces for cast iron need higher quality (unalloyed) steel scraps. To avoid trace elements adversely affecting the material properties, steel scraps need to be sorted according to their alloying elements, using manual mobile analytic devices. Limit levels for certain alloying elements, (e.g. Manganese), must not be exceeded. Thus, sorted steel scraps are generally more costly than cupola scrap.
- During the substitution of a medium-capacity cupola furnace with several induction furnaces, the commissioning phase may last between 6 months and 1 year and the costs associated with the production losses may vary between EUR 50 000 and EUR 200 000 per day. [231, UmweltBundesamt 2023]

A feasibility study was carried out in 2020 by a German foundry (Busch) in order to replace a cupola furnace (with a melting capacity of 28 t/h) combined with two induction furnaces (with melting capacities of 15 t/h), with a combination of three induction furnaces (with melting capacities of 2 x 13.6 t/h and 1 x 15 t/h, combined melting capacity of 42.2 t/h). The overall investment cost was EUR 39 millions [233, Nissen A. 2021]. At this plant, savings in production costs were identified linked to the elimination of holding furnaces, lower transportation costs and the reduced amounts of residues generated (e.g. filter dust). Additional costs were also identified linked to the need to use higher qualities of carbon and silicon for alloying purposes in induction furnaces and the necessity to use scrap of higher quality compared to cupola furnaces.

Further plants where information is available are summarised below [234, EEB 2023]:

- At the plant Eisenguss Hasloch Smart Foundries GmbH & Co. KG Hasloch (Germany), a small-series hand-molding foundry in 1-shift operation, melting individual materials in

batches, three furnaces (3 t capacity) for the production of nodular iron (6 t/h) were installed to replace a cupola furnace with the same capacity. The operational costs were reduced by 7 %.

- Decatur Foundry, Decatur Ill. USA. For production of 60 t of nodular iron per day, the replacement (2008) of a cupola furnace with two induction furnaces with the same capacity led to savings of 76 % in energy, 76 % in alloy materials, 51 % in slag disposal and 42 % in labour costs.
- Rowe Iron Foundry, Martinsville Ill. USA. The investment in two medium-frequency induction furnaces (8 t capacity) costing USD 7.5 million to replace a cupola furnace resulted in 7 – 8 % reduction on the overall costs for melting, with 4 years amortisation.

Driving force for implementation

- Increased energy efficiency.
- Elimination of emissions from thermal processes on site (at the SF plant) and from the generation of electricity.
- Improved process/temperature control.
- Improved workplace conditions in the vicinity of the furnace.
- Decarbonisation and integrated pollution prevention in the SF sector.

Example plants

Foundries

Electric furnaces are widely used in foundries for metal melting (cast iron, steel and NFM). In steel foundries, the majority of plants use electric furnaces (i.e. induction and electric arc).

In 2020/2021, the Kovis company in Brežice (Slovenia), which produces grey and nodular cast iron castings, converted its melting operations from using two cupola furnaces with a capacity of 5 t/h each (90 t per day) with two medium-frequency induction furnaces (twin power system) with a maximum power of 6.1 MW (259 Hz) and a capacity of 11.7 t each. With this added melting capacity, fitted to the existing molding line, the production capacity was increased by about 50 %. [232, Kovis 2021]

Further examples where one or several cupola furnaces were replaced by induction furnaces are given in the table below.

Table 3.4: Example plants using electric furnaces

Year	Company	Country	N. of furnaces	Capacity (t)	Power (W) / Frequency (Hz)
2021	ZML	ITA	2	23.2	12 000 / NI
2021	ZML	ITA	2	9.9	6 100 / NI
2021	Saint Gobain PAM	FR	1	32.0	18 000 / 250
2023	Saint Gobain PAM (on-going)	FR	2	32.0	18 000 / 250
2008	Römhheld & Moelle	DE	2	13.4	9 000 / 250
2002	Rexroth Guss GmbH	DE	2	13.4	10 000 / 200
2003	Scania	SE	2	9.9	5 800 / 190
Source: [234, EEB 2023]					

Each of the plants mentioned in the table above consists of two furnaces. This is referred to as tandem operation (twin power), where one furnace operates as a melting furnace with full power,

while the other is used as a holding and pouring furnace with holding power. This ensures a continuous supply of liquid iron to the moulding lines. The 18 MW plant at Saint-Gobain PAM is currently the most powerful induction plant in the iron foundry industry worldwide. [234, EEB 2023]

Smitheries

At the time of writing this document (2023), the use of electric furnaces is not widespread for heating/reheating. However, electric furnaces have been used for heat treatment of workpieces.

The results from the data collection showed that for heating/reheating the majority of plants in the data collection use gas-fired furnaces (e.g. pusher-type, bogie hearth). However, one plant reported the use of six induction furnaces for preheating (ES008) and another plant reported the installation of two new induction furnaces in 2019 (DE005). Furthermore, DE002 reported the use of one heating furnace (continuous furnace) using electric energy.

Reference literature

[169, TWG 2021], [210, TWG 2022], [231, UmweltBundesamt 2023], [232, Kovis 2021], [233, Nissen A. 2021], [234, EEB 2023]

3.1.5 Noise and vibrations

Noise emissions and vibrations may occur throughout all the production processes of the smitheries and foundries installations, such as preparing and processing raw materials, heating, reheating, melting, forging/hammering, heat treatment, surface treatment, material transport and storage of products as well as from the dispatch and shipping of the final products. [139, Probst 2006], [169, TWG 2021]

The overall reduction of noise levels involves developing a noise reduction plan. All sources of noise emissions need to be checked and evaluated.

The foundry process contains various point sources of noise. These include:

- scrap handling;
- furnace charging;
- burners;
- HPDC machines;
- shake-out;
- grit-blasting;
- core (and mould) shooting;
- finishing;
- all motors and hydraulic systems;
- transport (tipping, loading, etc.).

Furthermore, point sources of noise for both smitheries and foundries might be fans, ventilation, compressors and pumps.

Techniques with lower noise levels may be applied and/or point sources may be enclosed.

Full enclosure of the foundry building may be considered as well. This will also require the setting up of a climate control system, to limit the temperature inside the building.

Where residential areas are located close to a plant, the planning of new buildings at the smitheries or foundries site is connected with a necessity to reduce noise emissions and vibrations.

More information on techniques to minimise vibrations in smitheries is given in Section 3.3.3.

3.1.5.1 Noise and vibration management plan

Description

To set up, implement and regularly review a noise and/or vibration management plan, as part of the EMS (see Section 3.1.1.1), that includes all of the following elements:

- a protocol containing appropriate actions and timelines;
- a protocol for monitoring emissions of noise and/or vibrations;
- a protocol for responding to identified noise and vibration events, e.g. managing complaints and/or taking corrective actions;
- a noise and/or vibration reduction programme designed to identify the source(s), to measure/estimate noise and/or vibration exposure, to characterise the contributions of the sources and to implement prevention and/or reduction measures.

Technical description

As part of the EMS, a noise and vibration management plan is implemented and regularly reviewed.

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 (reported by the majority of plants with periodicity from once every year up to once every 5 years);
- development of noise maps and associated noise calculations (reported by Plant SE150);
- periodic meetings and discussions with neighbours to identify noise nuisance issues (reported by Plant AT006).

Achieved environmental benefits

Reduction of noise emissions and vibrations.

Environmental performance and operational data

See Technical description above.

Cross-media effects

None.

Technical considerations relevant to applicability

The applicability is restricted to cases where a noise and/or vibration nuisance at sensitive receptors is expected and/or has been substantiated.

Economics

No information provided.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

AT006, SE150.

Reference literature

[169, TWG 2021]

3.1.5.2 Appropriate location of equipment and buildings

Description

Increasing the distance between the emitter and the receiver, by using buildings as noise screens and by relocating equipment and/or building openings.

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 exits or entrances of the buildings. 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 emissions and vibrations.

Environmental performance and operational data

No information provided.

Cross-media effects

None.

Technical considerations relevant to applicability

For existing plants, the relocation of equipment and openings of buildings 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.

See also Section 3.3.4 for smitheries.

Reference literature

[169, TWG 2021], [210, TWG 2022].

3.1.5.3 Operational measures

Description

These include at least the following:

- 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, during production and maintenance activities, transport and handling of feedstock and materials, e.g. reducing the number of material transfer operations, reducing the height from which pieces fall on to hard surfaces.

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) have to be avoided at night.

Achieved environmental benefits

Reduction of noise emissions and vibrations.

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

Legal requirements.

Local conditions.

Example plants

Widely used.

Reference literature

[169, TWG 2021], [210, TWG 2022].

3.1.5.4 Low-noise equipment

Description

This includes techniques such as direct drive motors; low-noise compressors, pumps and fans; and low-noise transportation equipment.

Technical description

When new equipment is purchased, the associated noise levels are taken into consideration.

Low-noise equipment includes special blowing heads (reported by Plant ES099).

Achieved environmental benefits

Reduction of noise emissions.

Environmental performance and operational data

No information provided.

Cross-media effects

None.

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

Widely used.

See also Section 3.3.4 for smitheries.

Reference literature

[169, TWG 2021], [210, TWG 2022].

3.1.5.5 Noise control equipment**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, hammering, compressors, fans, shake-out, finishing);
- use of building materials with high sound insulation properties (e.g. for walls, roofs, windows, doors).

Technical description

Noise reduction can be achieved by applying air exhaust silencers and by decreasing the airspeed, as reported by Plant DE004.

Achieved environmental benefits

Reduction of noise emissions.

Environmental performance and operational data

No information provided.

One smithery plant (DE004) reported measured noise emission data for three emission points regarding discharging the exhaust gas via two kilns for, respectively, a 630 kJ and a 450 kJ counterblow hammer before and after installation of noise silencers.

	Noise emission measurement		
	Noise emission point 1	Noise emission point 2	Noise emission point 3
Before installation of silencers	65 dB(A)	76 dB(A)	68 dB(A)
After installation of silencers	<62 dB(A)	66 dB(A)	<62 dB(A)

Source: [169, TWG 2021], [219, DE 2019]

Cross-media effects

None.

Technical considerations relevant to applicability

Applicability to existing plants may be restricted by a lack of space.

Economics

Investment cost of the noise control equipment.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

Widely used.

Reported by Plant DE004.

Reference literature

[169, TWG 2021], [210, TWG 2022], [219, DE 2019].

3.1.5.6 Noise abatement**Description**

Inserting obstacles between emitters and receivers (e.g. protection walls, embankments).

Technical description

Examples of obstacles between noise emitters and receivers are:

- installation of noise walls (e.g. installation of 8-metre-high noise walls around noisy equipment was reported by Plant ES095, or installation of acoustic screens before sensitive receptors was reported by Plant ES008);
- installation of soundproof panels for noisy equipment enclosure (reported by Plant PT139).

See also specific information on noise emissions in smitheries in Section 3.3.4.

Achieved environmental benefits

Reduction of noise emissions.

Environmental performance and operational data

No information provided.

Cross-media effects

None.

Technical considerations relevant to applicability

Only applicable to existing plants, as the design of new plants should make this technique unnecessary. For existing plants, the insertion of obstacles may not be applicable due to a lack of space.

Economics

No information provided.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

Widely used in foundries.

Reported by Plants DE001, DE002 and ES008 (smitheries).

Reference literature

[169, TWG 2021], [210, TWG 2022].

3.1.6 Residues

3.1.6.1 Residues management plan

Description

A residues management plan is part of the EMS (see Section 3.1.1.1) and comprises a set of measures aiming to:

- minimise the generation of residues;
- optimise the reuse, recycling and/or recovery of residues; and
- ensure the proper disposal of waste.

The residues management plan may be integrated in the overall residues management plan of a larger installation (e.g. surface treatment activities).

Technical description

A variety of techniques can be used for residue optimisation and they range:

- from basic housekeeping techniques;
- through statistical measurement techniques;
- to the application of clean technologies;
- the use of process chemicals before their expiry date;
- to the use of residues as fuel; and
- the reuse or recycling of packaging.

In particular, a residue/waste management plan could be based on the five-stage hierarchy of the EU Directive 2018/851/EU and the Commission notice on technical guidance on the classification of waste 2018/C 124/01, and includes the following:

- Identifying, characterising and quantifying each of the 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 waste 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

No information provided.

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 plant.

Economics

No information provided.

Driving force for implementation

- Reduced costs due to increased material efficiency.
- 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

WFD, Directive EU/2018/851

3.1.7 Decommissioning

Description

Elaboration of plans and measures, applied throughout the installation's lifetime, related to minimising environmental impact and related costs of decommissioning.

Technical description

Some techniques to consider are:

- considering later de-commissioning at the design stage, thereby minimising risks and excessive costs during later de-commissioning
- for existing installations, where potential problems have been identified, putting in place a programme of improvements. These improvements designs need to ensure that:
 - underground tanks and pipework are avoided where possible (unless protected by secondary containment with leakage monitoring and overflow protection or a suitable monitoring programme);
 - there is provision for the draining and cleaning-out of vessels and pipework prior to dismantling;
 - lagoons and landfills are designed with a view to their eventual clean-up or surrender
 - insulation is used which can be readily dismantled without dust or hazards arising;
 - any materials used are recyclable (although bearing in mind they still meet operational or other environmental objectives);
 - developing and maintaining a site closure plan, to demonstrate that, in its current state, the installation can be decommissioned to avoid any pollution risk and to return the site of operation to a satisfactory state. The plan should be kept updated as material changes occur.

However, even at an early stage, the closure plan can include:

- either the removal or the flushing out of pipelines and vessels where appropriate and their complete emptying for any potentially harmful contents;

- plans of all underground pipes and vessels;
- the method and resource necessary for the clearing of lagoons;
- the method of ensuring that any on-site landfills can meet the equivalent of surrender conditions;
- the removal of asbestos or other potentially harmful materials unless agreed that it is reasonable to leave such liabilities to future owners;
- methods of dismantling buildings and other structures, for the protection of surface and groundwater at construction and demolition-sites;
- development of a construction and pollutant register;
- testing of the soil to ascertain the degree of any pollution caused by the activities and the need for any remediation to return the site to a satisfactory state as defined by the initial site report.

It is also noted that IED Article 22 (Site closure) contains the basic elements applicable to IED plants in relation to definitive cessation of activities (including the baseline report referred to in paragraph 2 of Article 22) (DE-28 in [\[210, TWG 2022\]](#)).

Achieved environmental benefits

Prevents environmental issues during de-commissioning.

Technical considerations relevant to applicability

Techniques mentioned here are applicable throughout the installation's operational lifetime, during the design and building stage of the site and activities and immediately after the site closure.

Reference literature

[\[131, UK Environment Agency 2001\]](#), [\[210, TWG 2022\]](#)

3.2 Techniques to consider in the determination of BAT for foundries

3.2.1 Techniques to consider for all foundry types

3.2.1.1 Use of alternative substances which are non- or less hazardous in moulding and core-making

Description

Hazardous substances and substances of very high concern used in moulding and core-making are substituted by non-hazardous substances or – when this is not feasible – by less hazardous substances, by using for example:

- aliphatic organic (instead of aromatic) binders in moulding and core-making;
- non-aromatic solvents for cold-box core making;
- inorganic binders in moulding and core making;
- water-based coatings in moulding and core-making.

Technical description

A technical description for each of these techniques is provided in Sections 3.2.1.9.10 (aliphatic organic binders), 3.2.1.9.8 (non-aromatic solvents), 3.2.1.9.11 (inorganic binders) and 3.2.1.5.5 (water-based coatings).

In foundries, hazardous substances and substances of very high concern which are used in moulding and core-making and which are listed in Regulation (EC) No 1272/2008 include, for example:

- *Furan*: Classified as carcinogen (Category 1B – H350: ‘May cause cancer’).
- *Phenol*: Classified as mutagen (Category 2 – H341: ‘Suspected of causing genetic defects’).
- *Methylene diphenyl diisocyanate (MDI)*: Classified as carcinogen (Category 2 – H351: ‘Suspected to be carcinogenic’).
- *Formaldehyde*: Classified as carcinogen (Category 1B – H350: ‘May cause cancer’) and mutagen (Category 2 – H341: ‘Suspected of causing genetic defects’).
- *Furfuryl alcohol*: Classified as carcinogen (Category 2 – H351: ‘Suspected to be carcinogenic’).
- *Benzene*: Classified as carcinogen (Category 1B – H350: ‘May cause cancer’) and mutagen (Category 1B – H340: ‘Germ cell mutagenicity’).

3.2.1.2 Monitoring of emissions to air and to water

3.2.1.2.1 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 of a foundry plant helps to maintain the proper operation of the plant and to detect accidental releases and thus helps to prevent any possible adverse environmental effects when the waste gas is emitted.

Environmental performance and operational data

Data for the common parameters monitored in foundry plants may be found in Section 2.3 (current consumption and emission levels for foundries). Some of the key parameters to be monitored are dust, metal compounds (such as Pb), NO_x, CO, amines, benzene, SO₂, formaldehyde, HCl, HF, PCDD/Fs, phenol, TVOC.

Cross-media effects

Some equipment, ancillary materials and energy are required for carrying out monitoring.

Technical considerations relevant to applicability

Generally applicable to all foundries where there are channelled emissions to air.

Economics

The costs associated with monitoring the waste gas of a foundry plant relate to personnel and equipment used for sampling and measurement.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

See Section 2.3.

Reference literature

[169, TWG 2021], [174, COM 2018]

3.2.1.2.2 Monitoring of emissions to water

Description

Regular monitoring of emissions to water.

Technical description

Monitoring of the relevant parameters can be accomplished by online measurements (that facilitate rapid intervention and control of the waste water treatment plant – WWTP) or analytical results derived from waste water samples. Parameters to be monitored and the frequency of monitoring depend on the activities which are connected to the WWTP and to the destination of the treated effluent (direct discharge or indirect discharge after further treatment in another industrial WWTP or a municipal WWTP). Discharges may come from a WWTP that treats streams originating from one foundry installation only or from a common WWTP that treats waste water streams from several foundries and may also include streams from non-foundry activities.

The monitoring of emissions is carried out in accordance with EN standards or, if EN standards are not available, in accordance with ISO, national or other international standards which ensure the provision of data of an equivalent scientific quality.

Achieved environmental benefits

Monitoring the waste water of a foundry plant helps to maintain the proper operation of the plant and to detect accidental releases and thus helps to prevent any possible adverse environmental effects upon discharge of waste waters.

Environmental performance and operational data

Data on monitored parameters are found in the Section 2.3 (current consumption and emission levels for foundries) and these parameters include AOX, BOD, COD, HOI, metals/metalloids (As, Cd, Cu, Cr, Fe, Ni, Pb, Zn, Hg), phenol index, TN, TOC and TSS.

Cross-media effects

Some equipment, ancillary materials and energy are required for carrying out monitoring. The COD measurement relies on the use of very toxic compounds (i.e. mercury and chromate).

Technical considerations relevant to applicability

Generally applicable to all plants from where there are emissions to water.

Economics

The costs associated with monitoring the effluent waste water of a waste water treatment plant relate to personnel and equipment used for sampling and measurement.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

See Section 2.3

Reference literature

[169, TWG 2021], [174, COM 2018]

3.2.1.3 Energy efficiency

Metal melting and the holding of molten metal in the molten state generally take up a significant part of a foundry's energy consumption. In many foundries more energy is used in holding the metal in the molten state than in the actual melting process. Furthermore, considerable energy is expended in areas other than that of metal supply. For example, foundries are generally large users of compressed air. Other large users of energy are likely to be items such as high-pressure die-casting machines, whose mainly hydraulic power units are also driven by electricity. Sand and gravity die foundries may employ hot core-making processes, such as shell or hot-box, using gas or electricity to heat the boxes. The heating of dies and ladle and furnace linings can amount to an appreciable fraction of the total energy used. The typical relative distribution of energy use in two foundry types is given in Table 3.5.

[26, ETSU 1997]

Table 3.5: Typical energy use in a non-ferrous foundry and an EAF steel foundry

Activity	Non-ferrous foundry (%)	EAF steel foundry (10000 t/yr good casting) (%)
Melting	30	44
Holding	30	-
Plant actuation	15	-
Air compression	14	10
Tool heating	3	-
Heat treatment (gas)	-	7
Others *	8	39

(* Includes all activities for which no values are given in the same column and activities which are not mentioned
Source: [26, ETSU 1997], [100, TWG 2002]

These data show that foundry processes (i.e. all but melting and holding) are responsible for up to half of foundry energy consumption. This includes activities using items such as motors and drives, compressed air, lighting, space heating and boiler plant. Energy efficiency measures should have regards to both the melting and the services field. [22, ETSU 1995]

Energy-efficient operation is brought about by applying good practice measures to reduce energy use in all of the mentioned steps. Improved energy efficiency is one of the main environmental benefits mentioned throughout the techniques discussions this chapter. The following sections focus on specific energy efficiency techniques.

3.2.1.3.1 Selection of an energy-efficient type of furnace

Description

Furnace energy efficiency is taken into consideration in the furnace selection, e.g. furnaces that allow the preheating and drying of incoming charge prior to the melting zone.

Technical description

In foundries, one of the most important pieces of equipment is the melting furnace. A number of factors have to be considered when selecting a melting furnace including, e.g. the capital and operating costs, the type of metal, the production process used. Some of the key parameters to consider are described in Section 3.2.1.7.1. In addition, it is essential to consider the energy efficiency and potential melt losses of the different types of melting furnaces used in ferrous and non-ferrous metal melting.

Non-ferrous metal melting

Different types of melting furnaces may be used. Some of the advantages/disadvantages of the various furnaces are presented below.

- *Crucible furnaces*: Most crucible furnaces are small-capacity furnaces used for melting or as holding furnaces. They present several advantages such as simple operation and maintenance and relatively low capital investment. In aluminium melting, crucible furnaces generally have a capacity of 1 000 kg (static type) or up to 1 500 kg (tiltable furnaces). The melting rate of electric crucible furnaces is typically about 250 kg Al/h whereas gas-fired furnaces can reach rates up to 400 kg Al/h. However, aluminum melting gas-fired crucible furnaces exhibit very low energy efficiency, ranging from 7 % to 19 % and a relatively high melt loss of 4–6 %. In this type of furnace, more than 60 % of the heat loss is due to radiation; the remaining heat losses are via hot exhaust gases leaving the furnace.
- *Reverberatory furnaces*: There are three main types of fuel-fired reverberatory furnaces: i) dry hearth reverberatory furnaces where the metal is preheated prior to melting, ii) wet-bath reverberatory furnaces where the metal is directly charged to the molten bath without preheating, and iii) side-well reverberatory furnaces equipped with a number of burners inside the hearth with a charging well and pump that is usually placed outside the furnace. The energy efficiency of reverberatory furnaces is usually very low, ranging from 20 % to 25 %.
- *Shaft furnaces*: Shaft furnaces present the highest thermal efficiency of all the gas-fired furnaces, typically within a range of 35 % to 65%. This is mainly due to the special design of the furnace which allows the incoming metal to be charged through the exhaust stack. As a result, the heat from the flue-gases is used to preheat the metal prior to melting. Shaft furnaces have lower melt losses than reverberatory furnaces, typically within a range of 1 % to 3 %.

Cast iron melting

In cast iron melting, two types of induction furnaces may be used, the coreless induction furnaces and the channel induction furnaces. Coreless induction furnaces are marginally less efficient than channel induction furnaces but they are generally more flexible. Coreless induction furnaces can operate at low, medium or high frequencies and can be started cold and usually poured until fully empty, which simplifies alloy changes. Typically, electric induction furnaces can have a very high energy efficiency of 75 %.

Steel melting

Steel can be melted either in electric arc or induction furnaces. Typically, the coreless induction furnaces are found in newer installations compared to EAFs. Generally, the specific energy consumption of coreless induction furnaces is slightly lower than EAFs.

Achieved environmental benefits

Reduced energy consumption.

Environmental performance and operational dataNon-ferrous metal melting

- *Crucible furnaces*: As an alternative to gas-fired furnaces, electric resistance crucibles are less energy-intensive. Their energy consumption may range from 460 kWh/t to 570 kWh/t compared to 1 600 kWh/t to 2 600 kWh/t for gas-fired furnaces.
- *Reverberatory furnaces*: Dry hearth furnaces have a typical energy consumption of about 1 200 kWh/t. Wet-reverberatory furnaces exhibit lower melt losses (2 – 5 % for gas-fired and < 1 % for electric furnaces) and have a typical energy consumption of about 1 000 kWh/t. If metal circulation, metal preheating and regenerative burners are used, it is possible to reduce the energy consumption to about 650 kWh/t.
- *Shaft furnaces*: The replacement of reverberatory furnaces with shaft furnaces can lead to substantial savings in terms of energy consumption. Measurements carried out at two die-casting foundries in the US showed that the melting efficiency was 25 % for a reverberatory furnace and 44 % for a shaft furnace, both operated under the same conditions. In the second foundry equipped with both a reverberatory and a shaft furnace of equal capacity (1 360 kg/h) processing the same charge, the melt losses were 5.5 % using the reverberatory furnace but only 0.9 % for the shaft furnace. The energy consumption in the shaft furnace was 616 kWh/t but was significantly higher in the reverberatory furnace (1 275 kWh/t).

Cast iron melting

The energy consumption of a coreless induction furnace in cast iron melting for raising the metal temperature up to 1 450°C can be less than 600 kWh/t, but usually ranges from 600 kWh/t to 1 000 kWh/t. The latter value constitutes a worst-case scenario which may for example be due to specific process conditions or the power supply frequency .

Steel melting

In theory, the electrical energy consumption required to melt steel to a temperature of 1 600 °C is 342 kWh/tonne. However, the majority of steel foundries consume from 454 kWh/tonne to 726 kWh/tonne in melting due to heat losses. This is based on data from steel foundries in the US where steel is mostly melted using EAFs (about 82 %).

Cross-media effects

Reverberatory furnaces can be built with large capacities while shaft furnaces have to be relatively high to achieve the preheating effect (typically about 6 m). The refractory lining at the bottom of the shaft furnaces can suffer from mechanical stress which results in a need for more frequent maintenance.

In shaft furnaces, the charge needs to be stacked properly, meaning that this type of furnace does not accept all shapes of aluminum scrap.

Technical considerations relevant to applicability

Only applicable to new plants and/or major plant upgrades.

Economics

No information provided.

Driving force for implementation

Reduction of energy consumption and related cost savings.

Example plants

Widely used.

Reference literature

[145, US EPA 2016], [194, Groteke et al. 1999], [195, Malpohl et al. 2010], [196, Butler 2006], [197, Biswas et al. 2012]

3.2.1.3.2 Techniques for maximising the thermal efficiency of furnaces

Description

Measures taken to maximise the efficiency of energy conversion in melting and heat treatment furnaces while minimising emissions (in particular of dust and CO). This is achieved by applying a series of process optimisation measures according to the furnace type including optimisation of the temperature (e.g. efficient mixing of the fuel and combustion air) and residence time in the combustion zone, and use of furnace automation and control (see Section 3.2.1.3.3).

Technical description

Measures for some specific furnaces include the following:

Cupola furnaces

In cupola furnaces, the amount of dust and exhaust gases resulting are directly related to the amount of coke charged per tonne of iron. Therefore, all measures that improve the thermal efficiency of the cupola will also reduce the emissions from the furnace.

Measures for maximising the thermal efficiency of cupola furnaces include the following:

- *Optimisation of operational regime:* The furnace is operated in its optimum regime as much as possible. For any given cupola, the influence of the blast rate and the coke charge on the tapping temperature of the metal and the melting rate can be expressed in the form of a net diagram or Jungblüth diagram. A net diagram is only valid quantitatively for the cupola for which it was obtained. It displays how the metal temperature and melting rate behave upon changes in the blast rate and coke charge, and allows determination of the point (or line) of optimal thermal efficiency.
- *Avoidance of excess temperature:* Measures are taken to avoid excess temperatures of the melt and reduce the superheating temperatures during the handling of tapped metal.
- *Uniform charging:* Care is taken during charging to get a uniform distribution of metal and coke.
- *Improving the control of the charge weight, the blast airflow and the metal temperature.*
- *Minimisation of air losses:* The correct supply of air is essential for efficient cupola operation. This is often hampered by air losses. Therefore, it is important to pay close attention to the prevention of all leaks to ensure efficient operation. Slag holes on intermittently tapped cupolas are often left open and are frequently oversized, resulting in considerable air losses. Air losses are particularly common for hot blast cupolas. They take place in the heat exchanger. The consequence is that oxygen must be injected in the tuyères instead of the air which is lost.
- *Avoiding 'bridging' in the cupola:* Bridging and scaffolding are the hanging or non-descent of cupola charges in the cupola shaft. This causes a loss of melting efficiency, and in severe instances melting can be completely stopped.
- *Good lining practice:* As melting proceeds, the diameter and the area of the melting zone increase due to lining erosion and wear. This affects the operation, moving it away from the optimum. Minimising the lining attack is therefore an energy saving measure. For satisfactory and economic cupola operation the melting zone needs to be efficiently repaired after each melt.

Coreless induction furnaces

Measures for maximising the thermal efficiency of a coreless induction furnace include techniques such as:

- *Optimisation of feedstock condition:* This involves avoiding rusty and dirty inputs, utilising optimum size and density input/scrap, and using cleaner carburisers. These measures shorten the melting time, reduce the specific energy needed for melting and/or reduce the amount of slag formed.
- *Closure of furnace lid:* Oxidation is reduced by avoiding badly fitting lids and unnecessary/prolonged openings, by quick charging or by using a protective atmosphere over the melt (N_2), the latter being impossible if exhaust gases are captured. Opening times need to be minimised to prevent energy losses. The necessary opening times for charging, removing slag, temperature measuring, sampling and pouring vary between 50 % and 25 % of the shift time. The latter figure applies for new furnaces, working in optimised conditions. A well-fitted closed lid limits the surface heat loss to about 1 % of the input power. When open, the heat loss can amount to up to 130 kWh/tonne for a 10-tonne-capacity unit. When melting under a closed lid, care should be taken not to overheat the furnace.
- *Restricting the holding time to a minimum:* Since melting is the first step in the foundry process chain, a shortening of the holding time can only be obtained by an integrated process optimisation for the whole foundry process and by minimising delays, problems and irregularities in any of the foundry departments. During holding, composition adjustment is performed based on the results of an analysis made on a chill cast sample. Optimisation of the sampling, testing and adjusting procedures is another measure for reducing the holding time.
- *Keeping a liquid heel in the furnace:* Maintaining a certain volume of liquid metal (a liquid heel) in induction furnaces can reduce the amount of metal produced in one tap but results in less fluctuation in melting operations. [145, US EPA 2016]
- *Addition of carburisers at the beginning of the melting cycle:* The addition of carburisers in the furnace has an influence on the energy consumption. Their addition at the beginning of the melting cycle along with the metallic load, instead of after melting, results in reduced energy consumption. [145, US EPA 2016]
- *Operation at maximum power input level:* Furnaces are more efficient in their use of energy when they are being operated at maximum power input levels, and best results are obtained when the available power can be fully utilised for the largest proportion of the melting cycle. This also includes reducing cold start melts (optimise production programme), and allowing follow-up using monitoring and computer control.
- *Avoiding excessive temperature and unnecessary superheating:* It is important that the metal reaches the required temperature just at the time that the moulding department is in a position to receive it. Good co-operation between the melting and moulding shop is essential in order to minimise the electricity usage.
- *Optimising high temperature melts for slag removal (good balance):* Low melting point slag build-up can be reduced by heating the furnace up to elevated temperatures (1 580 °C vs. 1 450 °C normal). This results in a higher energy consumption, and can affect the metallurgical aspects of the melt. If the slag is allowed to build up on the furnace lining, this can affect the electrical efficiency of the furnace. Slag removal requires the opening of the furnace lid, and thus causes a thermal loss. A good balance needs to be found between increasing the melt temperature and the slag removal practice.
- *Preventing slag build up:* More common and more troublesome are instances where high melting point build-up is involved. This mainly results from charging sand and, in the case of iron melting, metallic aluminium into the melt. Some furnace operators have attempted flux additions and cleaning routines but prevention is better than cure in this respect. This involves minimising the presence of sand and Al in the raw materials.
- *Trickling the oxygen injection:* Instead of using conventional decarburisation.
- *Minimisation and control the refractory wall wearing:* The refractory life depends on the choice of materials as a function of the slag chemistry (acidic or basic), the operational

temperature (steel, cast iron, non-ferrous), and the care taken upon relining (sintering). The lifetime may vary from 50 (steel, cast iron) to 200–300 (cast iron) melts. Operational control measures are taken to follow the refractory wear. These include visual inspection, physical measurement and instrumental monitoring programmes. Good charging practice measures prevent the cumulative effects of physical chokes and mechanical stresses. These include the use of automatic charging systems, hot charging, avoiding high drops and the use of compact and dry scrap.

See also Section 3.2.1.3.2.1 for information on the optimisation of energy use (peak load management) in induction furnaces.

Rotary furnaces

Measures for maximising the thermal efficiency of rotary furnaces include techniques such as:

- use of anthracite and silicon for melt protection;
- adjustment of the continuous or discontinuous speed rotation of the furnace to achieve maximum heat transfer;
- adjustment of the power and angle of the burner to achieve maximum heat transfer.

Electric arc furnaces

Measures for maximising the thermal efficiency of electric arc furnaces include techniques such as keeping a liquid heel in the furnace, shorter metal melting and/or treatment times using advanced control methods for example for the composition and the weight of the charged materials, the temperature of the melt, as well as by efficient sampling and deslagging methods.

This consists more particularly of:

- closer control of the composition (e.g. C, S, P content) and the weight of the charged materials and slag-forming materials;
- reliable temperature control of the melt, which can improve the yield of the refining reactions and avoid overheating;
- more efficient methods for sampling and deslagging, which can reduce furnace downtime.

Secondary metallurgy, using AOD/VODC treatment, shortens the melting/treatment time in the EAF and has a positive impact on energy conservation. The technique is discussed further in Section 3.2.3.2.1.

Shaft furnaces

Measures for maximising the thermal efficiency of shaft furnaces include techniques such as: [\[210, TWG 2022\]](#), [\[212, Reeves M. 2022\]](#)

- choice of the furnace size according to continuous melt demand, to obtain a continuous melting process;
- keeping the shaft filled with charging material to have optimum heat recovery;
- obtaining an optimum charging material distribution in the shaft by adapting the shaft design to the designated charging material;
- regular cleaning of the furnace: an internal geometry reachable with manageable tools, no hidden or difficult-to-reach corners, and materials that resist adhesion as long as possible are key factors for efficient furnace cleaning;
- independent control of the fuel/air ratio for each gas-fired burner;
- continuous CO or hydrogen monitoring for each row of burners;
- addition of oxygen above the melting zone to provide afterburning in the upper level of the shaft;
- preheating of the charge using waste heat recovered from the flue-gases.

Reverberatory furnaces

Measures for maximising the thermal efficiency of reverberatory furnaces include techniques such as:

- preheating of the charge in the case of dry hearth or side-well reverberatory furnaces;
- use of burners with automatic temperature control.

Crucible furnaces

Measures for maximising the thermal efficiency of crucible furnaces include techniques such as:

- preheating of the crucible prior charging;
- use of crucibles with high thermal conductivity and thermal shock resistance (e.g. graphite);
- cleaning of crucible walls immediately after emptying to remove slag or dross.

Achieved environmental benefits

- Increased furnace efficiency through shorter melting times and reduced downtime.
- Reduction of coke consumption and reduction of residues in cupola furnaces.

Environmental performance and operational data

Coreless induction furnaces

As already mentioned in Section 2.3.8.2, a typical coreless furnace can melt a tonne of iron and raise the temperature of the liquid metal to 1 450 °C using under 600 kWh of electricity. However, in practice, only a few foundries can achieve this level of specific consumption on a week-by-week basis. Some foundries consume in the region of 1 000 kWh for every tonne of iron produced by their coreless furnaces. Prevailing circumstances in many foundries can restrict the scope for good energy management, but in fact almost all coreless melting operations could be improved in some way, in order to achieve a worthwhile saving in the quantity of electricity used per tonne of iron processed.

Rotary furnaces

An optimisation programme on a 3-tonne/h cast iron melting furnace suggested the following as good operational practice:

- Use of clean scrap and loading in the following order: (1) ingots and materials with low Si content; (2) internal return material and foundry scrap; (3) alloying elements and melt protection; (4) steel scrap.
- Melt protection: use of anthracite for melt protection (2 % of metal charge) and silicon (2 %).
- Rotation: in discontinuous phase, 1/3 of a rotation every minute with a total of 7.5 turns until the phase change. During continuous rotation: 1.7 rotations/minute.
- Power and angle of burner: use a parallel burner-head position for the lower injectors. Start at maximum power for 20 minutes, reducing 10 % every 20 minutes until change of phase (60 minutes after start).

Using these measures, a metal efficiency (molten metal/charged metal) of > 95 % could be maintained. The principles of the optimisation are generally valid for iron melting in rotary furnaces using oxygen burners. The operational data have been established for a 3-tonne/h furnace. For furnaces of other sizes, a site-specific optimisation is necessary.

Reverberatory furnaces

Preheating the hearth by using the heat from the flue-gases to heat scrap prior to charging into the furnace can reduce the energy use. For a furnace using 50 % new metal and 50 % scrap, preheating the metal for half an hour in the hearth prior charging can decrease the energy use by 10 – 12 %.

[145, US EPA 2016]

Cross-media effects

None.

Technical considerations relevant to applicability

This technique applies to all new and existing furnaces.

Driving force for implementation

- Optimisation of furnace operation.
- Legal requirements.

Example plants

Widely used.

Reference literature

[14, CAEF 1997], [20, ETSU 1993], [100, TWG 2002] [23, ETSU 1992], [38, Vito 2001], [51, Inductotherm 2002], [120, TWG 2003], [145, US EPA 2016], [210, TWG 2022], [212, Reeves M. 2022]

3.2.1.3.2.1 Optimisation of energy use (peak load management) in induction furnaces

Description

When several induction furnaces are operated, the energy use is optimised through peak load management.

Technical description

When several furnaces are operated at the same time, peak load limitation is one way to reduce energy costs. In addition, modern energy management systems also reduce the specific energy requirement.

Energy-intensive companies pay, in addition to the energy rate, a demand charge that is based on the peak load. This is the highest measured power consumption in a given period.

Peak demands usually result from the simultaneous use of electrical energy by multiple consumers. The energy supplier must ensure availability of this maximum amount of electrical energy (peak) permanently due to its random occurrence.

With regard to the network load, peak loads are a crucial point. They cause additional supply costs to the energy supplier, which are invoiced to the purchaser of electrical energy. By reducing the peak demand, the energy costs can be reduced.

When peak loads are reached, modern load management systems do not cut the furnace off from the main supply but decrease the performance of individual furnaces for a certain time. This is achieved by an intelligent process technique.

Using multiple simultaneously operating melting aggregates results in characteristic data curves of the melting process. They represent the energy demand of the melting units in a given period. The processor attempts to coordinate the demands of the individual melting aggregates and thus to continuously improve the overall characteristic curve resulting from the energy demands of the sum of furnaces. The energy amount, resulting from the overall harmonisation and optimisation process, is then assigned to the individual furnaces. Priority can be given to individual furnaces manually.

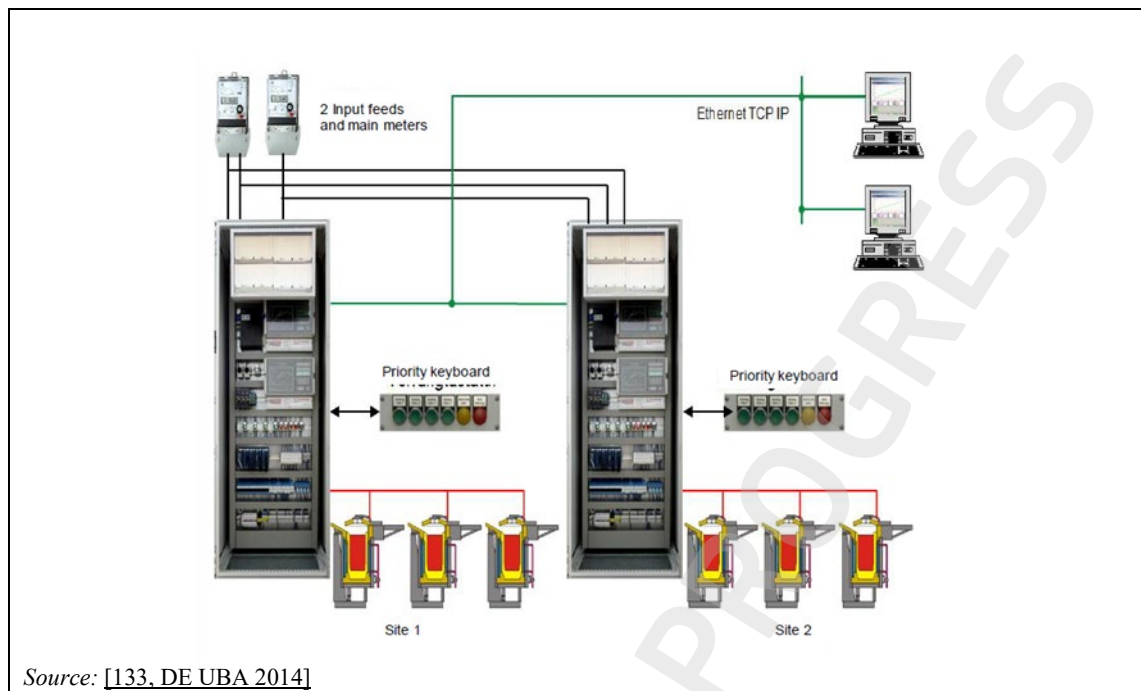


Figure 3.2: Principle of control of electric furnaces

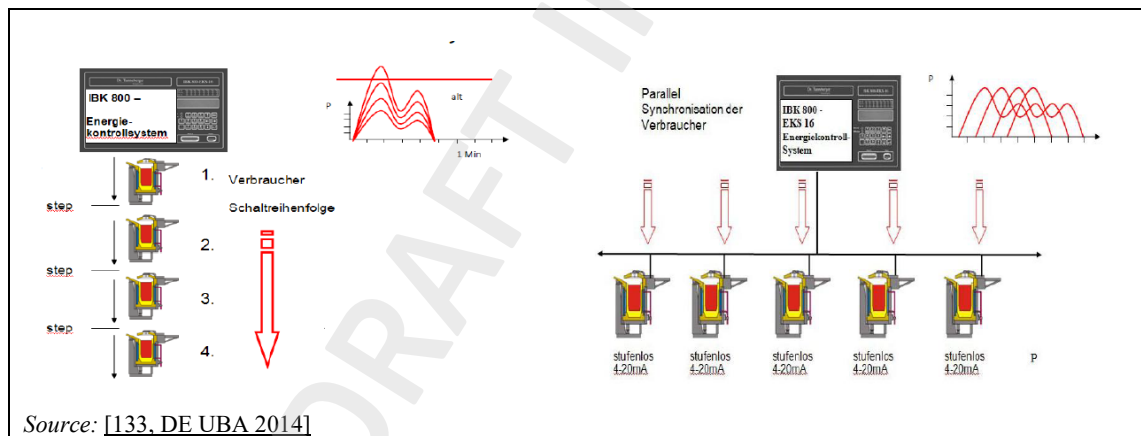


Figure 3.3: Serial load shedding following the trend calculation method (L) and parallel dedicated control for each furnace with its own load management (R)

Achieved environmental benefits

- By avoiding peak demands, provision of energy from the supplier can be balanced and use of a peak-load electricity generation plant – and with this environmental burden of starting such plants – can be avoided,
- Reduction of CO₂ emissions. Quantitative information about potential reduction of energy consumption is not available.

Environmental performance and operational data

In one foundry (Reinhard Tweer GmbH), the annual production volume of the foundry is 27 000 t of cast steel and cast iron with spheroid graphite. For melting, six medium-frequency furnaces are used, which have a significant influence on the energy costs of the foundry. The following illustration shows harmonisation of energy demands by reduction of peak demands. Without peak energy management, a peak demand as high as 10 250 kW was observed. After load optimisation, the maximum peak demand was reduced to 8 000 kW.

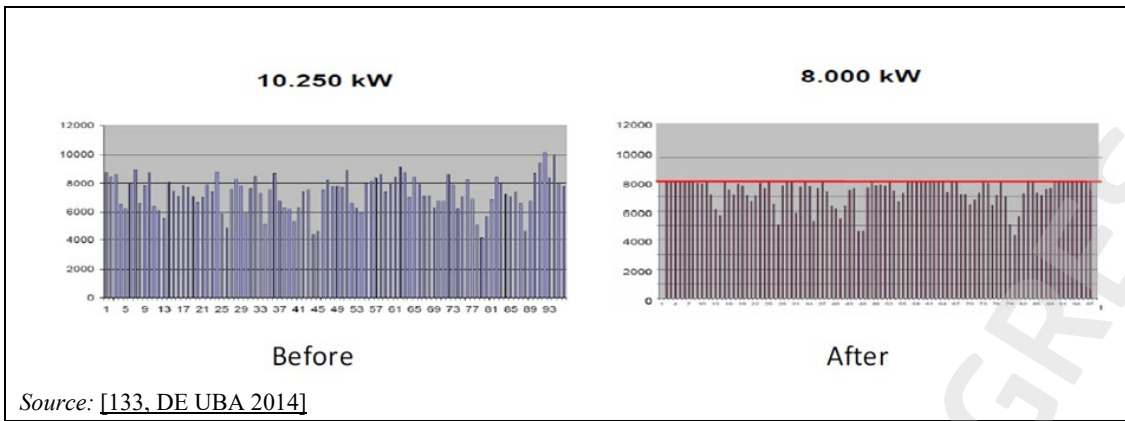


Figure 3.4: Effects of load optimisation on the peak demand of a German foundry (L: before load management optimisation; R: after load management optimisation)

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable in foundries with a significant number of electrically powered furnaces.

Economics

Table 3.6 provides a list of savings achieved by selected European foundries applying peak load management for induction furnaces.

Table 3.6: Savings achieved from peak load management in several foundries

Installation	Savings (EUR/year)
Walzengießerei Coswig	160 000
Klaus Kuhn Edelstahl - Radevormwald	120 000
Jürgens Gießerei Emsdetten	60 000
Flender Siemens – Chemnitz	80 000
Affilips V.N. – Tienen / Belgium	100 000
Gießerei und Glasformenbau - Radeberg	80 000
KM Europa Metal AG - Osnabrück	90 000
Intermet / Sakthi - Neunkirchen	180 000
Eisenwerk Hasenclever & Sohn GmbH - Battenberg	130 000
Meuselwitzer Guss Eisengießerei GmbH	80 000
Technoguss Tangerhütte GmbH	50 000

Source: [133, DE UBA 2014]

Information about payback periods is not available.

Driving force for implementation

- Legal requirements and local conditions.
- Operational requirements:
 - Reduction of energy costs for electricity by between 5 % and 23 %.
 - Shorter holding times by just-in-time melting.

Example plants

See example plants in the Economics section above.

Reference literature

[133, DE UBA 2014]

3.2.1.3.3 Furnace automation and control

Description

The heating process is optimised by using a computer system controlling key parameters such as furnace and feedstock temperature, the air to fuel ratio and the furnace pressure.

Technical description

Furnace automation takes care of the combustion, the energy consumption, material handling, temperature control of the feedstock and process safety continuously. In addition, it enables adjustment of the air to fuel ratio for optimum combustion, which in turn minimises NO_x emissions.

The furnace control system collects all the necessary data related to the operation of the furnace such as the equipment utilisation, the furnace temperature and pressure, the metal inputs and outputs and the energy consumption (fuel/electricity). The data can be visualised in real time by the plant operator and can be transferred for further analysis. Furnace logs including data on operating modes, operating times, temperature curves and fuel consumption figures can be stored for quality assurance purposes.

Achieved environmental benefits

Optimised furnace operation.

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

Increased efficiency of furnace operation and productivity.

Example plants

Widely used.

Reference literature

[195, Malpohl et al. 2010]

3.2.1.3.4 Use of clean scrap

Description

Melting clean scrap prevents the risk of non-metal compounds being taken up by the slag and/or degrading the furnace or ladle refractory linings.

Technical description

Melting clean scrap prevents the risk of non-metal compounds being taken up by the slag and/or attacking the furnace lining. These compounds are typically lime, iron oxides, manganese oxides, and basic oxides (e.g. MgO from nodular iron returns) in combination with silicon refractory (acid). If the amount of contamination is limited, this will reduce the amount of slag formed and will allow a longer lifetime of the furnace and ladle lining. For nodular iron production using a

furnace with acid refractory, the adhering silica sand may have a beneficial effect, since it neutralises the MgO coming from foundry returns.

The presence of contaminants and oxides in the furnace load, will consume part of the melting energy. Furthermore, the removal of slags necessitates a higher bath temperature to keep the slags in a liquid state.

Internally recycled scrap consists of feeders systems and rejected casting. Feeder systems are knocked off after shake-out. In general they do not retain adhering sand, due to their geometry. Rejected castings are excluded upon quality control, which is carried out after the castings are cleaned using sand blasting or shot blasting to remove all adhering sand. The use of sand-free return material therefore, in general, necessitates no extra treatment.

In general, the level of cleanliness of the scrap needs to be adapted to the type of furnace used to melt it.

Scrap recyclers are guided by the qualitative requirements of their customers (e.g. foundries) as well as the scrap specifications, which are defined for example in the the EU-27 steel scrap specifications [228, EFR 2007]. In practice, all of the following requirements for scrap in foundries' purchasing conditions are commonly in use:

- free of non-metallic impurities;
- free of galvanised, primed or painted scrap parts;
- free of oil and grease;
- free of explosive can material;
- free of tool steels, stainless steels or chrome-alloyed steels, except for steel foundries;
- for iron and steel foundries, free of non-ferrous metal scrap parts.

Free means that residual impurities are present at such a low level that they do not adversely affect the environmental performance (e.g. increased TVOC, PCDD/F and/or heavy metal emissions) or the operation/safety of the plant.

To ensure the required quality of castings, foundries are highly interested in a defined material input – while at the same time ensuring that environmental requirements are met [229, CAEF 2023].

The BAT conclusions for the Iron and Steel production specify a number of techniques for the selection of appropriate scrap qualities in order to achieve low emission levels for relevant pollutants (see Section 1.1.3 Material management, BAT 7 [109, COM 2013]). These criteria can also apply to foundries. In fact, both foundries and steel producers purchase their scrap from the same sources; therefore, similar requirements should apply to both sectors [229, CAEF 2023].

Achieved environmental benefits

This technique reduces the amount of slags and dust that need disposal and limits VOC emissions. The energy consumption is reduced (by 10 % to 15 %) due to the reduced amount of slag. Additionally, the extracted airflow may be reduced.

Shot blasting of the scrap can be recommended for scrap where its contamination would lead to the production of excessive amounts of slag. The use of only shot blasted scrap would actually require slag-forming additives to create the slag.

Environmental performance and operational data

An energy consumption to clean 30 – 40 kg of sand from 1 tonne of casting of 12 – 15 kWh has been reported for an operational foundry. The consumption level is dependent on the size and type of casting.

For a steel foundry using EAF melting, an increase in molten metal recovery (poured metal/charged metal) of 2 % to 3 % has been reported.

A typical metal charge for EAF is: 55 % foundry steel scrap; 40 % internal returns; 5 % metal correction additions.

Cross-media effects

If foundries only accept clean scrap, the overall recycling rate for dirty scrap will reduce. This will generate a need for additional cleaning operations and increase the disposal of scrap.

The use of cleaning techniques to remove sand from return material consumes energy. This is balanced however by the energy gained in the melting stage.

Technical considerations relevant to applicability

Generally applicable.

The removal of sand from internal scrap can be applied in all new and existing foundries. The use of clean scrap for melting can be applied in all foundry types, but the choice of the scrap grade should be related to the techniques installed for melting and gas cleaning. If the whole sector shifts to clean scrap, this will generate a problem for the recycling of dirty scrap.

The use of clean ferrous scrap (both steel and pig iron) will lead to increased purchase costs and will require investment in new cleaning equipment. There are no difficulties caused by scrap surface oxidation nor by using pig iron ingots during melting in cupola furnaces (reduction process). Electric furnaces will have difficulties only with contaminated scrap which does not comply with the parameters for steel scrap used in foundries.

Cupola furnaces can easily melt scrap which is not clean. There is little coke overconsumption and little environmental consequence, if the gases are correctly treated.

Limiting the slag is very important for good operation of the coreless induction furnace. The operation is more affected by the scrap cleanliness than the other furnace types.

The use of dirty scrap has no adverse effects on rotary furnace operation but is the main determining factor for dust emissions. There is little environmental consequence if the gases are correctly treated.

Economics

The price for clean scrap (i.e. class 1) is 20 % to 30 % higher than that for contaminated (i.e. class 2) scrap. Furthermore, disposal costs for slags and dust are reduced by applying this technique.

Driving force for implementation

- High disposal fees for residues and high prices for the refractory.
- Legal requirements.

Example plants

Widely used.

Reference literature

[36, Vereniging van Nederlandse Gemeenten 1998], [38, Vito 2001], [100, TWG 2002], [169, TWG 2021], [210, TWG 2022], [229, CAEF 2023].

3.2.1.3.5 Improvement of casting yield and decrease of scrap generation

More information on the technique

This technique provides environmental benefits both in terms of energy efficiency and material efficiency. It is fully described in Section 3.2.1.4.2.1.

3.2.1.3.6 Reduction of energy losses/improvement of ladle preheating practices

Description

This includes all of the following elements:

- use of clean preheated ladles;
- keeping closed lids on ladles to preserve heat;
- use of energy-efficient techniques for ladle preheating (e.g. flameless microporous burners or oxy-fuel burners);
- use of large (as practically possible) ladles fitted with heat-retaining covers;
- minimising the molten metal transfer from one ladle to another;
- transferring the molten metal as quickly as possible.

Technical description

Energy is wasted if the molten metal transfer system allows an excessive loss of metal temperature between furnace tapping and mould pouring. Losses can be prevented by using good practice measures. These imply the following:

- the utilisation of clean ladles, preheated to bright red heat;
- using an energy-efficient method for ladle preheating (e.g. using electric ladle preheating, using porous burners or natural-gas/oxygen burners – see below);
- the utilisation of distribution and pouring ladles, which are as large as is practicable and are fitted with heat-retaining covers;
- keeping the covers on ladles which are standing empty or putting ladles upside down when not in use;
- minimising the need to transfer metal from one ladle to another;
- always conveying the metal as quickly as possible, while still complying with safety requirements.

Ladle preheating using porous burners

A modified gas-air burner technique is the so-called volume burner or gas porous burner. This process modification has been available for use in foundries since 2008. In a gas porous burner (volume burner), the combustion takes place in a porous high-temperature ceramic burner, the combustion reactor. The result is a flameless, volumetric combustion in the form of a glowing ceramic foam. This can be used as both a radiating surface and a homogeneous heat source. The combustion is limited to the numerous pores of the ceramic, which can be seen as small reactors. Porous burners can achieve power densities of more than 3 MW/m².

Serving as a combustion reactor, the ceramic foam body can be produced in almost any geometric shape. Adapted to the particular application, the round, square, or linear-shaped ceramic body provides the heat exactly where it is required in the process.

With a customised form and flameless combustion, more homogeneous heating can be achieved in particular for larger objects, such as transportation and casting ladles or crucibles of furnaces. In principle, this technique could also be applied in other heating areas besides ladle preheating.

The following schematic and picture illustrate the ladle preheating process using porous burners.

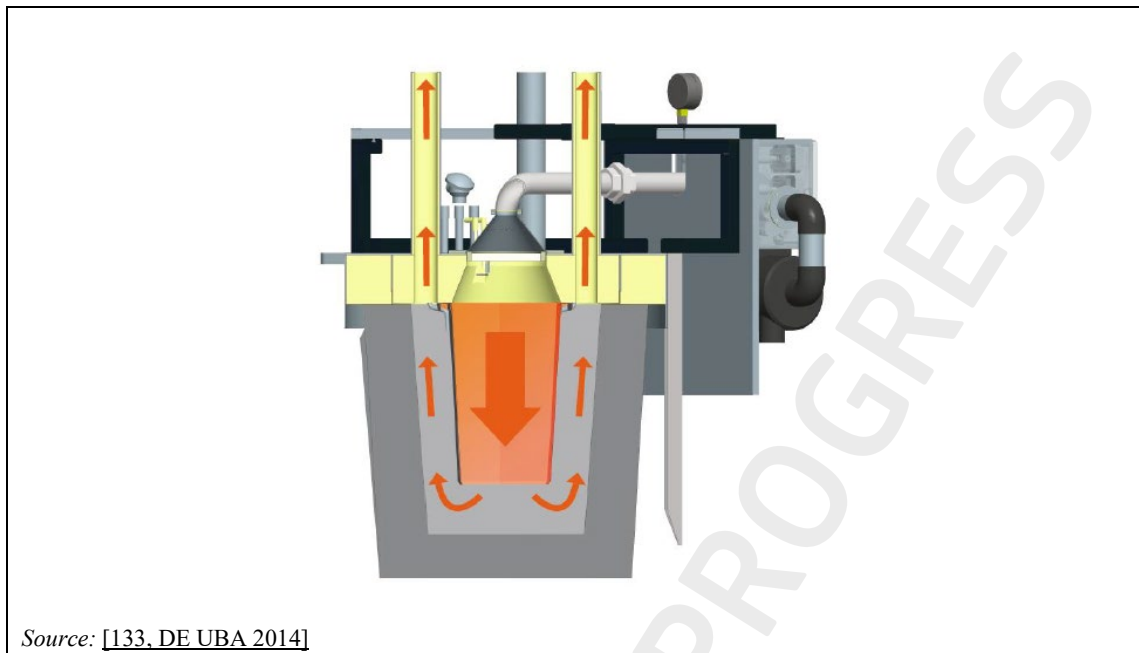


Figure 3.5: Schematic of ladle preheating using porous burners



Figure 3.6: Ladle preheating using porous burners

Ladle preheating using natural gas and oxy-fuel diffusion burners

Oxy-fuel diffusion burners using natural gas as fuel can be used to warm up transport ladles for example. The warming of the transport ladle takes place with an open flame. The flame burner fires from the top into the ladles. In addition, these burners (Figure 3.7) are also used in foundries for special applications (Figure 3.8).



Source: [133, DE UBA 2014]

Figure 3.7: Control of the oxy-fuel diffusion burner



Source: [133, DE UBA 2014]

Figure 3.8: Oxy-fuel diffusion burner with cooling water, used here to heat the feeder during the casting of a ship propeller in a bronze alloy

Achieved environmental benefits

Reduction of energy losses and increase in energy efficiency.

Environmental performance and operational data

For ladle preheating using porous burners, the following environmental benefits were reported:

- Reduction in gas consumption of up to 60 %, In one example, gas consumption could be reduced by 60 000 m³/y and related CO₂ emissions by 115 t. Excess heat could be used for heating of the production facilities.
- Increased energy efficiency.

- Substantial reduction in CO₂ and NO_x emissions.
- Reduction of noise emission by low-noise combustion.

For ladle preheating using natural-gas/oxygen diffusion burners, the following environmental benefits were reported:

- Using oxy-fuel diffusion burners, the gas to oxygen ratio is approximately 1:2. When using natural-gas-air diffusion burners, the gas to air ratio is approximately 1:10. Higher flow rates for the combustion result from the use of natural-gas-air diffusion burners compared to natural-gas/oxygen diffusion burners.
- The reduced nitrogen content from using oxy-fuel diffusion burners leads to a reduction in fuel consumption and reduction in the generation of NO_x emissions. Assuming that during the combustion of natural gas about 1.95 kg CO₂/m³ is released, the total amounts of CO₂ emissions in the example described under Economics are:
 - 58.5 kg/h for one ladle, heating 3 ladles would equate to 175.5 kg/h;
 - 78.8 kg/h for one ladle, heating 3 ladles would equate to 263.3 kg/h.

Table 3.7: Operational data for ladle preheating using porous burners

Power density	Continuously adjustable from 150 kW/m ³ to 3 000 kW/m ³ with an adjustable burner size at a reactor depth of 15 mm .
Performance	From 2 kW to over 1 000 kW.
Flame free combustion	Heat source instead of open flame, i.e.: <ul style="list-style-type: none"> • no contact of a product with the flame, • no combustion interference by external convection, or outer atmosphere, • no drafts or motion sensitivity. • direct transfer of heat by hot gas and radiation heat.
Controllability	Control range up to 1:20 at lambda 1.3. Can quickly adapt to changing process conditions. Radiation and hot gas temperature controllable. Precise controllability of 900 °C to 1 400 °C to plus/minus 3 K in a few seconds.
Homogeneity	Targeted, flat heat input at any desired location. Gentle product treatment. Homogeneous temperature distribution.
Design/Form	Any shape as a line or surface burner.
Emissions	Minimal emissions of CO and NO _x in the entire power range.
Fuels	All gases according to EN 483. Oil vapour mixtures. Low calorific gase. Insensitive to varying gas pressure.
<i>Source:</i> [133, DE UBA 2014]	

Ladle preheating using natural gas-oxygen diffusion burners

Technically, the process of combustion of gaseous fuels with pure oxygen has the effect that, due to the reduced exhaust losses, the combustion temperature and gas radiation are increased.

With oxy-fuel diffusion burners, usually temperatures of 1 200 – 1 300 °C can be reached. By modifying a conventional oxy-fuel diffusion burner, for example with water cooling, temperatures around 1 500 °C can be reached. In addition to the heating of ladles, oxy-fuel diffusion burners are used for sintering and heating of:

- e-furnaces and for e-hearths;
- casting dies and converters;
- specific feeders; and
- slag emptying into the furnaces.

For ladle preheating using natural-gas/oxygen diffusion burners, the production and transport of oxygen is related to additional environmental burdens. Infrastructure for oxygen storage is required.

Cross-media effects

None.

Technical considerations relevant to applicability

Since the general technique involves measures related to good practice, it is applicable to all new and existing foundries. Applicability may be restricted in the case of big ladles (e.g. >2 t) and bottom pouring ladles due to design constraints.

The 'ladle preheating using porous burners' technique is applicable in small and large foundries. The following factors may affect its applicability:

- When high temperatures are required, for example > 1 100 °C, the heating time can be longer than that of conventional burners. This is important to ensure the required power density of the burner (e.g. steel casting).
- If the burner can be moved manually and the geometry requires exact and careful handling, the burner can be damaged if handled carelessly.

Ladle preheating using natural-gas/oxygen diffusion burners is applicable to iron and steel foundries (mainly due to the achievable temperatures) but can also be used in non-ferrous metal foundries.

Economics

For ladle preheating using porous burners, the following economic data were reported:

Cost savings of up to 60 % can be achieved by substituting conventional burners with porous burners due to the exact controllability and uniform heat input. In conjunction with the high power modulation, the whole system improves in terms of efficiency and brings productivity gains of up to 50 %. In one example plant, ladle durability had been doubled.

The following investment costs, operating costs, maintenance costs and energy savings are based on information provided by an operator using porous burners:

- ladle size: 15 t.
- investment costs: EUR 70 000;
- operating costs: EUR 20 000/y in gas costs;
- maintenance costs: EUR 5 000/y;
- energy cost savings: EUR 8 000/y.

Information about the amortisation time is not available and depends on numerous individual factors. As an example, the following cost-benefit equation (reference values) has been made: 'With a saving of natural gas amounting to EUR 23 286 /y, a minimised ladle-lining abrasion of EUR 7 000 and an increase in productivity of approximately EUR 10 000, a static calculation states that a payback of capital results after 5.8 years'.

For ladle preheating using natural gas-oxygen diffusion burners, an exemplary case where three ladles of 8 tonnes per day are heated was reported. After about 1 hour, the ladle temperature reaches about 1 200 °C. The data are given below:

- natural gas demand is about 30 m³/h per plant + oxygen demand 60 m³/h per plant;
- cost of natural gas: EUR 0.35/m³;
- cost of oxygen: EUR 0.20/m³;
- total direct cost for natural gas: EUR 0.35/m³ x 30 m³ = EUR 10.50;

- total direct costs for oxygen: $\text{EUR } 0.20/\text{m}^3 \times 60 \text{ m}^3 = \text{EUR } 12.00$;
- total direct cost: $\text{EUR } 22.50$;
- total cost per day: $\text{EUR } 22.50 \times 3 \text{ ladles} = \text{EUR } 67.50$

To compare the economic differences between natural gas-air diffusion burners and gas-oxygen diffusion burners, an example is provided below:

Per day (single layer), the heating of three ladles with 8 tonnes takes place. Three natural gas-air burners are used, which also run constantly to keep the temperature. After about 1 hour, a ladle temperature of about $800 \text{ }^\circ\text{C}$ to $900 \text{ }^\circ\text{C}$ is reached. The data are given below:

- natural gas demand is about $45 \text{ m}^3/\text{h}$ per plant + air requirements (fan) is about $450 \text{ m}^3/\text{h}$ per plant;
- costs for heating of a ladle: natural gas demand is about $45 \text{ m}^3/\text{h} \times 1 \text{ h}$ results in 45 m^3 + air consumption (fan) is approximately 450 m^3 ;
- costs for natural gas: $\text{EUR } 0.35/\text{m}^3$;
- costs for providing air: $\text{EUR } 0.04/\text{m}^3$;
- total direct costs for natural gas: $\text{EUR } 0.35/\text{m}^3 \times 45 \text{ m}^3 = \text{EUR } 15.75$;
- total direct costs for air (fan): $\text{EUR } 0.04/\text{m}^3 \times 450 \text{ m}^3 = \text{EUR } 18$;
- total cost: $\text{EUR } 33.75$;
- the cost of continuous operation to preheat the ladles must be added, exemplary set with $\text{EUR } 80$; after all, in many foundries the ladles are under continuous heating to keep them in case of need immediately ready for use;
- total cost per day: $\text{EUR } 33.75 \times 3 \text{ ladles/d} = \text{EUR } 101.25/\text{d} + \text{EUR } 80/\text{d} = \text{EUR } 181.25/\text{d}$.
- yearly cost: $\text{EUR } 181.25/\text{d} \times 22 \text{ d/month} = \text{EUR } 3\,987.5/\text{month} \times 12 \text{ months} = \text{EUR } 47\,850/\text{y}$.

Driving force for implementation

Energy savings and reduction in energy cost.

In addition, ladle preheating using porous burners contributes to a longer life of the lining and therefore to reduction of refractory material consumption and reduction of waste refractory material generation.

Ladle preheating using natural-gas/oxygen burners increases the availability of melting units and transport ladles and improves product quality by reducing the temperature difference between the melt and the transport ladle.

Example plants

These general measures are used to a varying extent in European foundries.

Ladle preheating using porous burners was reported for the following plants:

- HegerFerrit GmbH, 67681 Sembach
- Stahlwerke Bochum GmbH, 44791 Bochum
- Edelstahlwerke Schmees GmbH, 40764 Langenfeld

Ladle preheating using natural gas-oxygen burners:

- Mecklenburger Metallguss GmbH – MMG, Waren/Müritzt, Germany

Reference literature

[20, ETSU 1993], [133, DE UBA 2014], [210, TWG 2022]

3.2.1.3.7 Oxy-fuel combustion

Description

Combustion air is replaced fully or partially with pure oxygen. Oxy-fuel combustion can be used in combination with flameless combustion.

Technical description

Flame temperatures are increased by the application of pure oxygen instead of air in the burners used for melting or preheating the pouring ladles. This enables a more efficient heat transfer to the melt and reduces the energy use.

If the air supply is blocked by a tight closure of the recipient, no NO_x can be formed through the oxidation of atmospheric nitrogen. Additionally, the total flow of flue-gases from oxy-fuel combustion is smaller due to the absence of nitrogen. This allows the application of a smaller dedusting installation.

Achieved environmental benefits

The techniques reduce energy consumption and lower the emissions of NO_x and CO₂ through higher combustion temperatures.

Environmental performance and operational data

Oxygen enrichment used in conjunction with a recuperator generally achieves a 30 % energy saving. Additionally, the higher combustion temperature assists in reducing the overall emissions of greenhouse gases and in the case of use of pure oxygen the emissions of NO_x. The exhaust gas volume is also reduced. Full oxy-fuel combustion may offer energy savings of up to 50 %, and can reduce the exhaust gas volume by up to 72 %.

Noise emissions may also be reduced. A German installation's change from oil-air firing to gas-oxygen firing caused a reduction in noise emissions of 15 – 18 dB(A) in the immediate vicinity of the furnace, dependent on the point of analysis. At the installation border, a value of 48 dB(A) was measured. With the application of energy recuperation for charge preheating, a total energy saving of 53 % was reported for the same installation.

The use of oxy-fuel combustion has been reported in a cupola furnace in Germany. In total, six oxy-fuel combustion burners were installed at the foundry Fritz Winter Eissen Giesserei GmbH producing mainly grey iron using a hot blast cupola furnace (capacity 24 t/h). The use of oxy-fuel combustion resulted in an increase of 20 % of the melt rate together with a reduction of 6 % in coke consumption, based on long-term results. [188, Niehoff, T. et al. 2004]

Oxy-fuel combustion, sometimes in combination with flameless combustion, is often used in ladle preheating. In this case, the replacement of conventional burners with oxy-fuel burners can lead to a decrease in operational costs by about 50 % due to quicker heating (1 hour instead of 2.5 hours) and lower natural gas consumption. Because ladle preheating takes a long time, ladles are frequently kept running continuously to ensure operational readiness. Oxy-fuel burners enable a quicker heating process, meaning that continuous operation might not be always required. [145, US EPA 2016]

Cross-media effects

The production, storage and use of oxygen increases the safety risks. Oxygen production is done through electrolysis of water, cryogenic distillation or Vacuum (Pressure) Swing Adsorption, which all involve electricity consumption. The consumption of the latter technique is 0.35 – 0.38 kWh/Nm³ O₂. Oxygen production is often done by an external supplier, who deliver the oxygen to a storage tank or directly through a pipeline.

Fuel or heavy oil gives rise to SO₂ or NO_x emissions, depending on their S or N content. The use of cleaner carburants such as natural gas and propane will not cause any additional pollution, except for CO₂, as is the case for all combustion processes.

Technical considerations relevant to applicability

Applicability to existing plants may be restricted by furnace design and the need for a minimum waste gas flow.

Economics

No information provided.

Driving force for implementation

- Optimisation of furnace operation and increased melting efficiency.
- Legal requirements.

Example plants

This technique finds wide application in ferrous foundries using rotary furnaces and for ladle preheating.

Reference literature

[11, Brettschneider et al. 1992], [14, CAEF 1997], [38, Vito 2001], [210, TWG 2022], [36, Vereniging van Nederlandse Gemeenten 1998], [52, Eurofine 2002], [127, Novem 2000], [64, UK Environment Agency 2002], [145, US EPA 2016], [188, Niehoff, T. et al. 2004]

3.2.1.3.8 Use of medium-frequency power in induction furnaces**Description**

Use of medium-frequency (250 Hz) induction furnaces instead of mains frequency (50 Hz) furnaces.

Technical description

Medium-frequency (250 Hz) furnaces have a higher power density (up to 1 000 kW/tonne) than mains-frequency (50 Hz) furnaces (300 kW/tonne). This allows the use of a smaller crucible (up to a factor of three smaller) which results in a smaller total heat loss. The thermal efficiency of medium-frequency furnaces is 10 % higher than for the mains-frequency types. Additionally, mains-frequency units need to be operated with a molten heel of up to two thirds of the crucible capacity to optimise specific energy consumption and also require specific starter-blocks for cold start-up. Medium-frequency furnaces can readily be started with a cold charge and can be emptied at the end of each working shift or melting batch.

When a foundry converts from mains-frequency melting to operating a medium-frequency installation, it is important that the furnace personnel undertake some retraining. Operating techniques formally used to date will have to be abandoned, and new specific procedures designed to give good specific energy consumption will have to be adapted. If retraining is overlooked, the available improvements in energy usage may not be fully realised.

Economics

A change of furnace type constitutes a considerable investment.

Achieved environmental benefits

Increased energy efficiency of the melting operation.

Environmental performance and operational data

Upgrading a mains-frequency furnace to medium-frequency leads to energy savings of 12-15 % in batch mode. Furthermore, medium-frequency furnaces present the advantage of improved electric coupling which enables a cold start. Medium-frequency furnaces provide a much higher power input density (three times higher compared to a mains-frequency furnace), which increases productivity and efficiency.

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable.

Driving force for implementation

To increase the efficiency of the foundry operation.

Example plants

The technique is commonly applied in foundries installing a new furnace.

Reference literature

[23, ETSU 1992], [145, US EPA 2016]

3.2.1.3.9 Compressed air system optimisation

Description

This includes all of the following measures:

- applying an appropriate maintenance system to reduce leaks;
- efficient monitoring of operating parameters such as flow, temperature, and pressure;
- minimising the pressure drops;
- applying efficient load management;
- reducing inlet air temperature;
- using an efficient compressor control system.

Technical description

Foundries use compressed air in numerous applications including powering tools, filling core boxes, transporting sand, blowing of moulds and core boxes and others. Best practices for energy-efficient compressed air systems include all the following measures:

- *Applying an appropriate maintenance system to reduce leaks:* A plant which is not well maintained can have a leak rate ranging from 20 % to 50 % of the total compressed air capacity. 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 program 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 building to reduce the inlet air temperature of compressors.

- *Using an efficient compressor control system:* 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

The implementation of a leak maintenance programme can reduce leak rates down to less than 10 %.

The use of compressor control systems which shut off unneeded compressors can save up to 12 % in energy costs per year.

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable.

Economics

No information provided.

Driving force for implementation

Energy savings.

Example plants

Widely used.

Reference literature

[145, US EPA 2016]

3.2.1.3.10 Microwave drying of cores for water-based coatings

Description

Use of microwave drying ovens (e.g. with a frequency of 2 450 Hz) for drying cores coated with water-based coatings, resulting in rapid and homogeneous drying of the entire core surface.

Technical description

Water-based coatings (see Section 3.2.1.5.5) require a drying treatment. The application of microwave furnaces for this purpose gives operational advantages over the use of ambient or heated air drying. Microwaves of 2 450 MHz frequency are used, and have the following properties:

- Good selectivity of energy transfer: The microwave energy is transferred preferentially to the water molecules, rather than the sand material. This implies a preferential and homogeneous drying of the surface, even for complex cores.
- Self-adaptive coupling: The drying mechanism provides a self-controlling homogenisation of the humidity of the material.
- Quick drying: The speed of drying depends on the applied power. The high drying velocity results in a limitation of the water-core contact time. This results in a good mechanical stability of the cores.

The application of microwave drying presents difficulties in the following cases:

- heterogeneous loading of the furnace (with a range of core masses and volumes);
- use of cores or inserts with iron, e.g. residues in reclaimed core sand;
- inhomogeneous drying of thicker parts of the coating;
- risk of deformation of complex cores.

Achieved environmental benefits

Increased energy efficiency of the drying process.

Environmental performance and operational data

The use of microwave drying has not been implemented on an industrial scale, although large-scale industrial tests have been performed. The results of these tests are given below. One test campaign has been run using a 50 kW microwave furnace. The stove was loaded to 50 % of its capacity with a charge of 800 kg of cores. Cores are placed on plastic trays, which are not heated by the microwaves. The thermal balance is given in the following figure. It shows that more than 30 % of the energy input is used for drying. Additionally, the cores are only slightly heated up (temperature at exit = 40 °C), which allows immediate handling. The data from two measurement campaigns are given in Table 3.8, and compared to analogous campaigns on hot air furnaces (as discussed in Section 3.2.1.9.12).

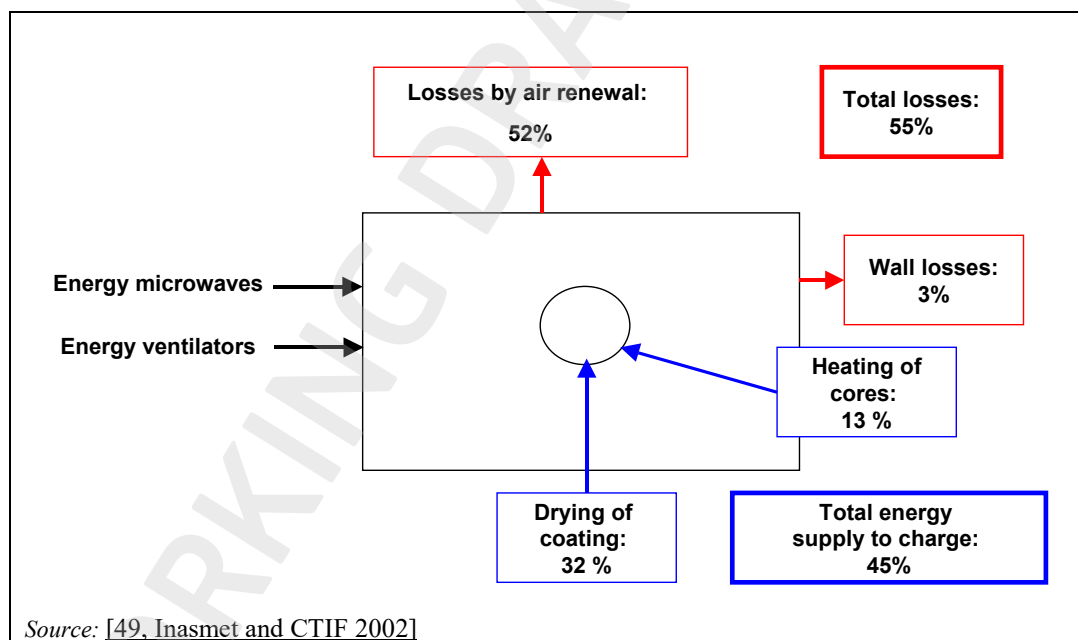


Figure 3.9: Thermal balance for the microwave drying of cores for a 50 kW furnace working at 50 % capacity

Table 3.8: Results of test campaigns on core drying, using hot air and microwave furnaces

Furnace type	Foundry A	Foundry B	Foundry B	Foundry C
	Hot air	Hot air	Microwave	Microwave
Core load	156 kg/h	270 kg/h	800 kg/h	500 – 900 kg/h
Humidity	5.5 %	2.7 %	2.7 %	2 – 3.2 %
Thermal energy supply	73 kW	70 kW	50 kW	40 kW
Duration	48 min	113 min	8 min	8 min
Specific consumption per kg evaporated water	8.5 kWh	9.3 kWh	2.3 kWh	2 kWh
Specific consumption per tonne wet cores	465 kWh	280 kWh	63 kWh	-
<i>Source: [49, Inasmet and CTIF 2002]</i>				

The data show that the drying time is considerably reduced from 1 – 2 h to less than 10 minutes. Additionally, the energy consumption is reduced by a factor of 4 – 5, and the throughput is increased.

Cross-media effects

Microwave drying also brings polymerisation reactions to a further completion. This reduces the gaseous emissions in the preceding stages of the foundry process (i.e. pouring, cooling, shake-out).

Technical considerations relevant to applicability

This technique may not be applicable in the case of continuous or large casting production processes, or when cores are made of reclaimed sand containing traces of carbon. Generally, this technique is applicable for the drying of all water-based coatings. Furthermore, it allows the greater applicability of water-based coatings to more complex core shapes and smaller series.

Economics

Microwave drying represents high investment costs. The actual investment is proportional to the power requirement, which corresponds to the amount of water to be evaporated. The high investment is partially counterbalanced by:

- higher energy efficiency, though the technique uses electricity rather than gas in the hot air furnace;
- reduced solvent cost for water-based vs. solvent-based;
- reduced maintenance costs due to a more compact installation compared to the use of (hot) air drying or a cooling line.

Driving force for implementation

- Pressure from authorities, with increasing attention being paid to the emissions of organics, combined with the need for higher energy efficiency.
- Legal requirements.

Example plants

The technique is reported to be applied in foundries in France and Spain.

Reference literature

[49, Inasmet and CTIF 2002], [120, TWG 2003], [210, TWG 2022]

3.2.1.3.11 Scrap preheating using recovered heat

Description

Scrap is preheated by recovering the heat from hot flue-gases which are redirected to come into contact with the charge.

Technical description

The high temperature from hot flue-gases can be used to preheat scrap. For example, in steel foundries, the hot flue-gases from melting in the EAF, typically from the fourth hole, can be used to preheat the scrap to temperatures ranging from 450 °C to 600 °C. An additional benefit of this technique is the complete removal of moisture from the scrap.

In non-ferrous metal foundries, shaft furnaces are a typical example of scrap preheating. In a shaft furnace used for example in an aluminium foundry, cold aluminium scrap and ingots are charged at the top of the furnace through a charging door. The hot gases from the melting burners make their way up to the stack and enters into contact with the charge, resulting in both complete drying and preheating of the charge. In this respect, shaft furnaces have significantly higher energy efficiency than reverberatory furnaces, in particular.

Achieved environmental benefits

Increased energy efficiency.

Environmental performance and operational data

Energy use can decrease by up to 50 – 75 kWh/tonne when scrap is preheated.

In non-ferrous metal foundries, the energy efficiency of shaft furnaces ranges from 40 % to 50 %, compared to only 15 % to 40 % for reverberatory furnaces, as a result of scrap preheating. It is reported that energy consumption can be reduced by 135 kWh/tonne in the case of a single shaft furnace.

Cross-media effects

In some cases, the delays caused by scrap preheating may reduce the productivity. Careless heating can cause PCDD/F emissions.

Technical considerations relevant to applicability

Only applicable to shaft furnaces in non-ferrous metal foundries and to EAFs in steel foundries.

Economics

No information provided.

Driving force for implementation

Reduced energy consumption – energy savings.

Example plants

No information provided.

Reference literature

[145, US EPA 2016], [189, BCS 2005], [210, TWG 2022]

3.2.1.3.12 Heat recovery from off-gases generated in furnaces

Description

Waste heat from hot off-gases is recovered (e.g. through heat exchangers) and reused on site or off site (e.g. in thermal oil / hot water / heating circuits, for steam generation or for preheating of combustion air (see Section 3.2.1.3.13). This may include:

- excess heat from cupola hot off-gases is used for example for steam production, thermal oil heating, water heating;
- excess heat from the furnace cooling system is used for example for drying of raw material, space heating, water heating;

- in fuel-fired furnaces in aluminium foundries, excess heat is used for example for heating the premises and/or the water for the casting cleaning facility;
- low-grade heat is converted into electricity using high-molecular-weight fluids by using the Organic Rankine Cycle (ORC).

Technical description

The need to cool off-gases before they enter the air emissions abatement system (e.g. bag filter) leads to the possibility of attaching to a secondary user and applying waste heat utilisation. The secondary user may be for example:

- a steam boiler;
- a thermal oil circuit;
- a heating circuit;
- a hot water circuit.

In the case of low-grade heat, an additional option is electricity generation using high-molecular-weight fluids through the Organic Rankine Cycle system.

Examples of in-situ waste heat utilisation are:

- power generation using steam turbines (reported by Plants AT016, CZ024, DE049 and DE050) [169, TWG 2021];
- power generation using the Organic Rankine Cycle (ORC) process;
- space heating and/or heating the water for the casting cleaning facility (see example plant below);
- heating circuit, e.g. in the case of elevated energy consumption for drying, when water-based coatings are used instead of solvent-based ones.

An option for off-site waste heat utilisation is when this can be used for steam generation in a nearby installation using a thermal oil circuit for heat transfer.

Organic Rankine Cycle

In an Organic Rankine Cycle (ORC), high-molecular-mass organic fluids are used instead of water as the working fluid. In general, the types of working fluids used are siloxanes or hydrocarbons. These fluids exhibit much lower boiling points than water. The working fluid is vaporised in a heat exchanger using the heat from waste flue-gases. The working fluid changes into a gaseous state and expands in a turbine directly connected to a generator to produce electricity. The working fluid is condensed in a water-cooled condenser and pumped back to the heat exchanger. The ORC is used to generate electrical power using low- to medium-temperature heat sources (e.g. low-grade heat), typically in the range of 80 °C to 350 °C.

Achieved environmental benefits

Recovery of waste heat, which otherwise would be lost to the outside, allowing a reduction in fuel (or other sources of energy) consumption.

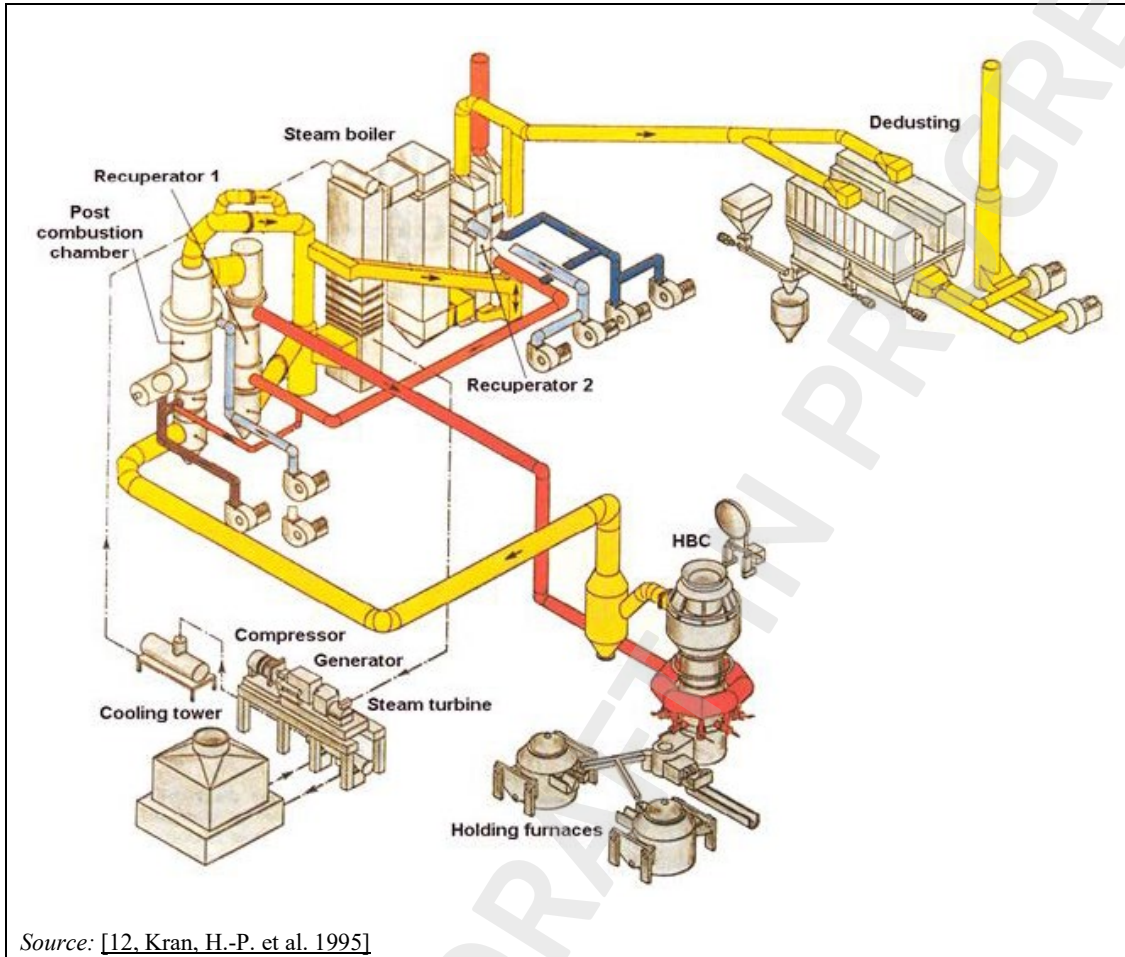
In the case of the Georg Fischer Automotive AG plant (off-site waste heat utilisation – see example plants below), the calculated reduction in primary energy consumption of the end user of the waste heat is around 50 000 MWh/yr which corresponds to a reduction of CO₂ emissions of around 11 000 tonnes.

Environmental performance and operational data

Steam boiler for electricity production

For the two example plants described in Section 3.2.2.1.7, which are equipped with a waste heat utilisation system, a short description and basic elements are presented in the following paragraphs. Plant data have been given in Table 3.54.

Plant G (example plant described in Section 3.2.2.1.7, plant data have been given in Table 3.54) uses cupola waste heat for electricity production. Part of the off-gas flow is fed to a steam boiler, which drives a turbine, coupled to a generator or compressor. A schematic representation of the installation is given in Figure 3.10. In total 29 % of the introduced coke's heat is converted into additional utilisation. Around 2.9 MW of electrical energy are generated. This means that the plant generates an electrical power of 75 kWh/tonne liquid iron.



Source: [12, Kran, H.-P. et al. 1995]

Figure 3.10: Schematic representation of a hot blast cupola with a steam boiler, turbine and generator

Thermal oil circuit

Plant H (example plant described in Section 3.2.2.1.7, plant data have been given in Table 3.54) uses cupola waste heat in a thermal oil circuit. After heat exchange for blast preheating, the off-gas passes a gasoil heat exchanger. The heated oil is used for core drying. A maximum heat recovery of 21 MW can be attained. A process flow diagram is given in Figure 3.11.

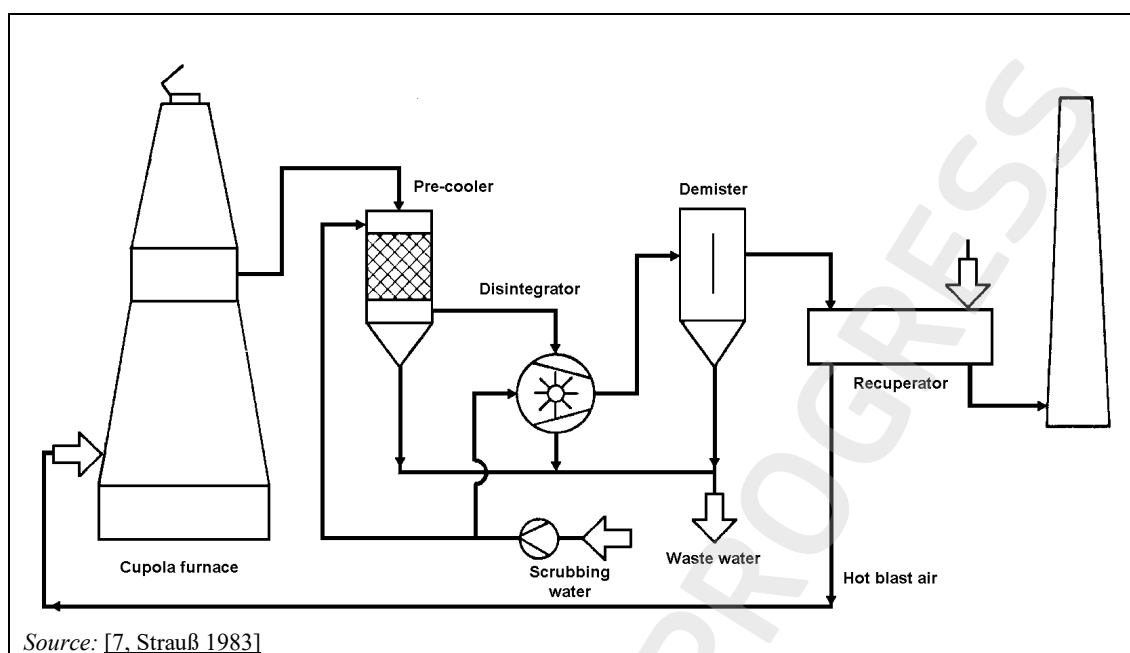


Figure 3.11: Process flow diagram of a hot blast cupola with heat recovery

In another example plant (Gießerei Heunisch GmbH, DE), substitution of solvent-based coatings with water-based ones made the recovery and utilisation of excess waste heat economically advantageous. In 2009, a thermal oil heat system to recover excessive heat from the off-gases was installed at the cupola furnace. To use the waste heat, a secondary circuit (recovery circuit) was constructed between the upper end of the zero-pressure collector of the primary circuit (cooling circuit at the cupola furnace) and by a cycle line (DN-125 mm) and - via the roof – to the drying area of plant. In the event that there might be additional consumption points for the waste heat, additional sockets could be integrated in the circuit. The hot oil in the secondary circuit reaches a temperature of about 210 °C. To use some of this waste heat for a paint shop, five thermal oil heat exchangers were installed in the drying tunnel. The basic characteristics of the new system are presented in the table below.

Table 3.9: Basic characteristics of the new waste heat recovery system

Start date of operation	4th Quarter of 2009 (actual system) 2nd Quarter of 2010 (extension of waste heat utilization)
Operation time	Monday to Friday in a three-shift operation
Area requirements	1 700 m ³
Performance - flow rate castings	6 500 kg/h
Installed electric power	335 kW
Installed capacity of natural gas burner	2 250 kW
Power consumption	1 728 028 kWh in 2010
Gas consumption	118 078 m ³ /y compared to 1 315 400 kWh in 2010
<i>Source: [133, DE UBA 2014]</i>	

Gas consumption for drying is reduced by around 30 % from about 25.5 m³/h to 18.2 m³/h. It is noted that the cupola operated in two shifts while the paint shop in three shifts. In the case of operating the cupola in three shifts, the period of waste heat recovery is longer and the heat recovery potential rises.

Space heating and/or heating the water for the casting cleaning facility

In an aluminium foundry, the fuel-fired furnaces are connected to a heat exchanger system, which heats the premises and the water for the casting cleaning facility. When closing the direct line to

the chimney, the exhaust gases flow through a by-pass to the heat exchanger, which transfers the process heat to the water circuit.

In this furnace, high resource efficiency and good insulation were realised to be able to make use of as much melt heat as possible. At the same time, low amounts of exhaust gas are generated due to the special design of the combustion chamber. The principle of reverse airflow is used, hence gases formed during the melting process are not directly discharged through the chimney, but remain longer in the oven (Figure 3.12).

At the example plant JURA CAST GmbH (see example plants below), the annual production capacity of the aluminium foundry is about 300 000 castings parts mainly for automobile and truck manufacturers, international engineering as well as for medical technology. This medium-sized company currently employs around 200 staff.



Source: [133, DE UBA 2014]

Figure 3.12: Exhaust systems of four furnaces connected with heat exchangers to transmit the heat of the hot gases from the melting process to the heating circuit

With two heat exchangers, one for the large melting furnace and one for the three small systems, a 30 000-litre storage reservoir is heated, which supplies 80 % of the company building area with heat. In addition, the washhouse system for finished castings is heated from this reservoir. The large melting furnace has two burners, each with 1 000 kW power, the flow of heat energy after the melting process is about 35 % to 40 % to the heat exchanger. The heat exchanger is able to transfer about 75 % of the incoming heat into the reservoir.



Source: [133, DE UBA 2014]

Figure 3.13: Largest furnace lowered into the ground

In addition, in the concrete case of the example plant the cleaning system was simplified. Since the furnace is embedded about 70 cm deep in the ground, it is easy to clean without pedestals, and other resources from both sides (see Figure 3.13). All areas are reachable over the large holes while cleaning. To empty all the melt, the furnace tilts into a recess in the floor, in which there is a transport ladle. This is moved subsequently hydraulically upwards.

Off-site waste heat utilisation

The Georg Fischer Automotive AG in Singen produces ductile iron castings for cars and trucks. A total of 200 000 tonnes of metals are cast per year from a hot blast cupola furnace. The CO-rich off-gas is post-combusted and temperatures up to 900 °C are achieved. The off-gas must be cooled before entering the cleaning system.

Waste heat is discharged to a nearby food processing plant using a thermal oil circuit. Georg Fischer Automotive AG plant replaced the existing recuperator by a 2.5 times more efficient one in 2008. The excess heat is used to heat thermal oil, which is pumped through a 400-metre-long pipeline system in the boiler house of the food processing plant. The 280 °C hot thermal oil is used there in a heat exchanger to produce food-grade steam. The food processing plant expects to have about 67 % savings in natural gas consumption previously used to produce food-grade steam.

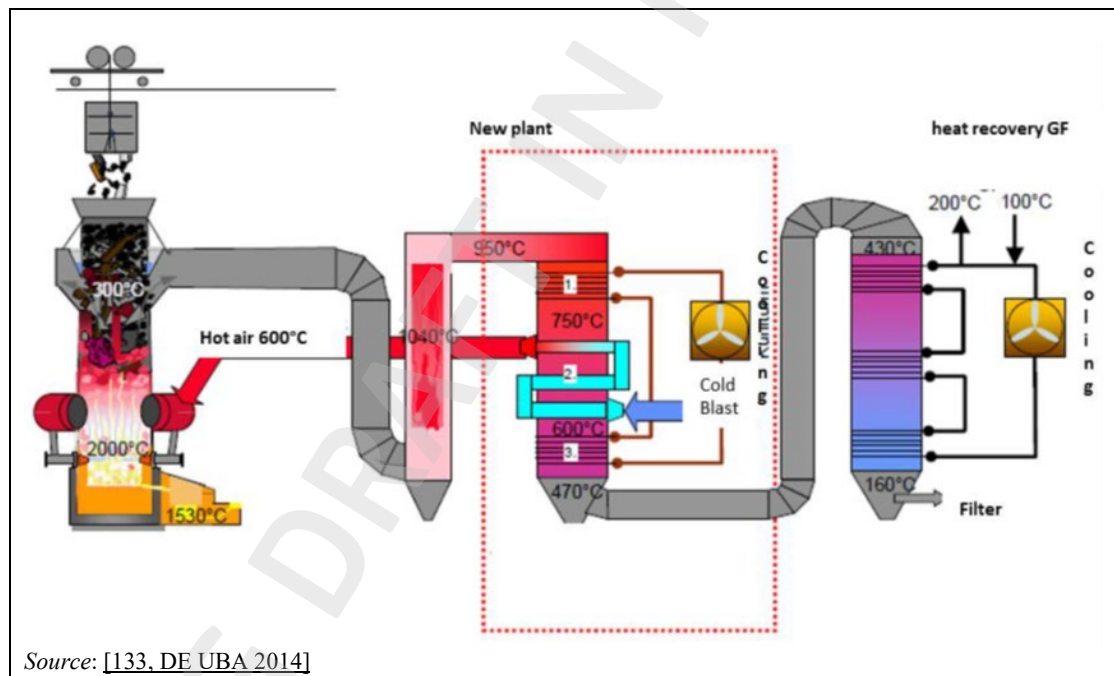


Figure 3.14: Schematic of an off-site heat recovery application in a cupola furnace using a thermal oil circuit

Table 3.10: Comparison of energy data before and after reconstruction of recuperator

	Situation before reconstruction	Situation after reconstruction
Maximum energy for recovery	25 MW	30 MW
Used energy		
Hot blast	7 MW	7 MW
Hot water	6 MW	6 MW
External use	0 MW	10 – 14 MW
Total	13 MW	23 – 27MW

Source: [133, DE UBA 2014]

ORC applications

Several applications of ORC in foundries have been reported (see the Example plants section below).

Cross-media effects

None.

Technical considerations relevant to applicability

Applicability may be restricted by the lack of a suitable heat demand.

This technique applies to new installations and should be taken into account when designing the process. For existing plants, the technique can be applied during major refurbishment of the plant, however, small add-on units can generally be accommodated in existing plants.

It is necessary for the excess energy of the foundry furnace to meet the needs of the end user. A short distance between production and use of heat is crucial. The maximum distance must be determined case by case.

Economics

The first two stated examples (for Plants G and H) were installed as part of a major rebuilding of the installation. It is therefore not possible to extract specific cost data.

For the third example (Gießerei Heunisch GmbH, DE, on-site waste heat utilisation), the following figures were reported:

- The additional investment costs for the integration of waste heat to the drying area were approximately EUR 1.4 million (2013 data). These costs have been considered only on a pro rata basis.
- By using waste heat for the paint drying process, the production costs can be reduced compared to the paint drying process using exclusively natural gas burners by approximately 20-25 %.
- Maintenance and repair costs are in the order of EUR 20 000/y (2013 data).

For the example of off-site waste heat utilisation (Georg Fischer Automotive AG):

- capital expenditures for the foundry plant were about EUR 3.5 million (2013 data);
- the food processing plant investment was around EUR 1.5 million.

In the theoretical case of costs for primary energy of 5 cents/kWh, the amortisation time of the overall investments will be less than 3 years.

For the example plant JURA CAST GmbH (space heating and/or heating the water for the casting cleaning facility), the investment costs for heat exchangers, piping, structural interventions, connection to the central heating system were about EUR 100 000.

Driving force for implementation

- Increasing energy efficiency of industrial processes.
- Economic and environmental benefits.

Example plants

- Widely used. In the SF data collection, 20 plants reported heat recovery from induction furnaces and 11 plants reported heat recovery from cupola furnaces.
- The first two example plants mentioned (Plants G and H) are located in Germany.
- Thermal oil circuit: Gießerei Heunisch GmbH, Germany.
- Off-site waste heat utilisation: Georg Fischer Automotive AG, Germany.

- Space heating and/or heating the water for the casting cleaning facility: JURA CAST GmbH, Germany
- ORC applications:
 - Schulte and Schmidt, Brasov, Romani [192, Pocolaa et al. 2017]
 - FMGC foundry, France [187, Baret 2014]
 - German foundry: [207, J. Lechner 2016]
 - DE049 [169, TWG 2021].

Reference literature

[7, Strauß 1983], [12, Kran, H.-P. et al. 1995], [100, TWG 2002], [133, DE UBA 2014], [169, TWG 2021], [187, Baret 2014], [192, Pocolaa et al. 2017], [207, J. Lechner 2016]

3.2.1.3.13 Preheating of combustion air

Description

Reuse of part of the heat recovered from the combustion flue-gas to preheat the air used in combustion. This may be achieved for example by using regenerative or recuperative burners (see below). A balance has to be achieved between maximising heat recovery from the flue-gas and minimising NO_x emissions.

Technical description

To improve the thermal efficiency of furnaces, the exhaust gases from the furnace may be used to preheat the combustion air. Thermal efficiency increases with increasing preheated air temperature and decreasing waste gas temperature. Potential fuel savings achieved by combustion air preheating may be case-specific.

Several systems can be employed such as the regenerative and the recuperative burner, or central recuperators and rotary regenerators. These are described in more detail below.

Regenerative burners

Regenerative systems use two sets of heat exchangers, containing for example brick chequer material or ceramic balls. When one burner is fired, the furnace gases are channelled via the other burner. The exhaust gases pass through a regenerator which contains a bed of refractory or ceramic materials. The refractory materials are heated by the exhaust gases and store the energy, which is then used to preheat the combustion air. When the refractory materials are fully heated, the firing burner is turned off and the regenerated burner is put into operation. Typical reversal times are in the range of 20 s to 100 s.

New regenerative low-NO_x burners have been developed, combining the regeneration with coupled gas and air staging, internal POC (products of combustion) recirculation and flameless technologies.

A special type of regenerative burner is the integral bed burner which has a more compact design as the regenerative bed is incorporated in the body of the burner. These types of burners are especially suitable for retrofitting furnaces where space constraints may be a problem and for small furnaces.

Recuperative burners

A recuperator is a heat exchanger fitted in the exhaust gas outlet, which allows heat to be transferred continuously through the heating surfaces to the incoming combustion air. Various equipment designs are available. Self-recuperative burners have integral heat exchangers for preheating combustion air.

More information on the regenerative and recuperative burners can be found in the BREF for the Ferrous Metal Processing Industry [168, COM 2022]

Central recuperators

Using a central heat recuperator, an important part of the calorific energy of waste can be absorbed and transmitted to another fluid. Using central recuperators, savings in fuel consumption up to 60 % can be obtained. Typical designs are radiation or convective recuperators for example.

In the case of a radiation recuperator, an inner tube carries the hot exhaust gases while an external annulus carries the combustion air from the atmosphere to the air inlets of the furnace burners. The hot gases are cooled by the incoming combustion air, which now carries additional energy into the combustion chamber. This is the energy which does not have to be supplied by the fuel; consequently, less fuel is burned for a given furnace loading. The saving in fuel also means a decrease in combustion air and therefore stack losses are decreased not only by lowering the stack gas temperatures but also by discharging smaller quantities of exhaust gas. With a radiation recuperator, a substantial portion of the heat transfer from the hot gases to the surface of the inner tube takes place by radiative heat transfer.

In the case of convective recuperators, the hot gases are carried through a number of parallel small-diameter tubes, while the incoming air to be heated enters a shell surrounding the tubes and passes over the hot tubes one or several times in the direction normal to their axes. Typically, these types of recuperators are more compact and have a higher effectiveness than radiation recuperators, because of the larger heat transfer area made possible through the use of multiple tubes and multiple passes of the gases. [217, UNEP 2006]

Rotary regenerators

In a rotary regenerator, the waste gases and the combustion air travel in opposite directions whilst a continuously rotating element cuts through both streams. The rotating element is a porous structure consisting of a mass of thin plates of metallic or ceramic material. The best performance is obtained using a fine pore size with high surface area to volume ratio. The heat transfer is obtained by a wiping action. Both sides of the surface are alternately swept by hot gases and air. Rotary regenerators constitute a variation of heat wheels (see [217, UNEP 2006]).

Achieved environmental benefits

Reduction of energy consumption.

Environmental performance and operational data

See [168, COM 2022].

Cross-media effects

Thermal NO_x generation may be increased [168, COM 2022].

Technical considerations relevant to applicability

Generally applicable.

Economics

[168, COM 2022], [210, TWG 2022]

Driving force for implementation

Reduction of energy consumption.

Example plants

No information provided.

Reference literature

[168, COM 2022], [169, TWG 2021], [177, COM 2009], [217, UNEP 2006]

3.2.1.3.14 Waste heat utilisation in induction furnaces

Description

Waste heat from the induction furnace cooling system is recovered using heat exchangers for drying raw materials (e.g. scrap), space heating or hot water supply.

Technical description

A significant proportion of the electrical energy which is supplied to an induction melting furnace is converted into waste heat. About 20-30 % of the total energy input to the plant is dissipated through the cooling system. The furnace cooling circuit not only deals with the electrical losses in the induction coil, but also protects the coil from heat conducted through the furnace lining from the hot metal in the crucible. The heat in the furnace cooling system is used in some installations for space heating, the heating of shower water and for drying raw materials.

- *Drying of raw materials:* Where metallic charge materials are added to a molten heel in an induction melting furnace, the presence of water in the scrap can potentially be very dangerous. Although scrap may be stored under cover at the foundry, it is possible that it may be wet when delivered by the scrap dealer. The heat in the furnace cooling water can be extracted in an air/water heat exchanger and a fan can be used to convey the warmed air to the bases of the stockyard bunkers. A diagrammatic layout of such an installation is shown in Figure 3.15.

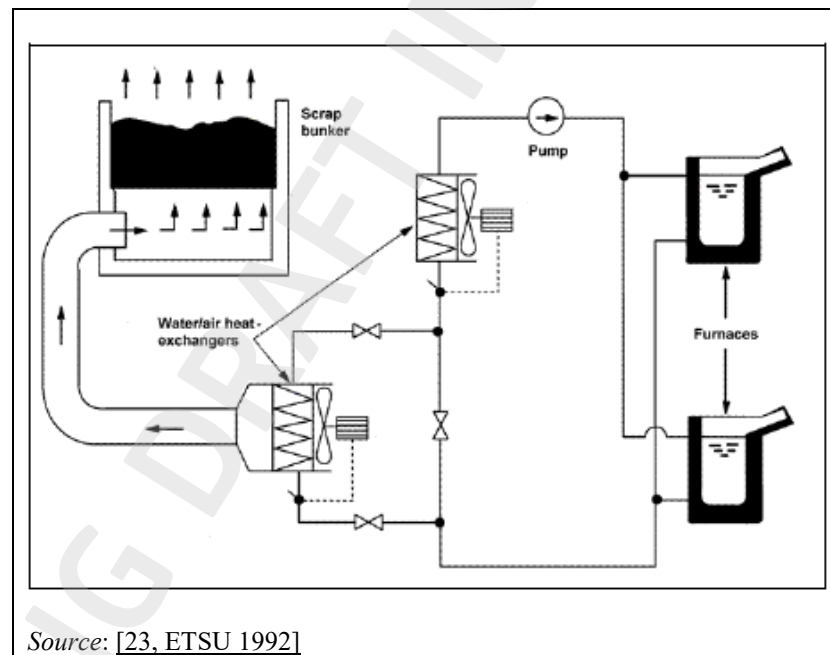


Figure 3.15: Use of waste heat for scrap drying

- *Space heating and hot water supply:* A similar system to the one discussed above may be used to blow hot air into the foundry hall for space heating. Alternatively, a water/water heat exchanger is used to heat a water circuit for radiators or for hot water supply.

Since the temperature of the cooling water in an unpressurised system is normally unlikely to exceed 60-70 °C, radiators will need extra-large surface areas in order to transfer heat efficiently. Alternatively, the temperature of the water can be boosted by some other heat source, such as supplementary gas or oil burners or an electrical heater. Some alternative heating system may be required to take over when the furnaces are not operating, for example early in the morning to raise the temperature of the work areas to a comfortable level.

The normal furnace cooling facilities must be kept operating during the summer period and at other times when the space heating facilities are not extracting an appropriate quantity of heat from the furnace cooling system. It is essential to ensure the integrity of the furnace cooling system. The whole installation must be designed to be fail-safe, to protect the integrity of the furnaces at all times. Also, water returning to the furnaces must not be too cold (i.e. not below 30 °C). Temperature-operated alarms should be provided and emergency bypass pipework with easily accessible manual control valves should be installed, to ensure that the heat recovery facilities can be isolated quickly from the primary cooling circuit in the event of any problems.

Achieved environmental benefits

Increased energy efficiency.

Cross-media effects

No cross-media effects have been reported.

Environmental performance and operational data

A heat recovery system using the cooling oil of induction furnaces was installed in a Belgian foundry. The foundry operates two induction holding furnaces in combination with a cupola furnace. The inductors of the electrical furnaces are cooled using thermal oil. The thermal oil gets heated up to 200-300 °C and loses its heat over an outside oil/air heat exchanger. Before installation of the heat recovery system, 1 MW of heat was dissipated into the air. An alternative system was installed to use the waste heat for space heating. The heated air is introduced into the core shop. This allows the recuperation of a third of the dissipated heat and replaces the original gas-fired heating system. The implementation was possible at low cost because the oil/air heat exchanger is installed next to the core shop. Space heating in other parts of the foundry may be considered later, but will require more piping (and will subsequently thus involve further losses).

Before heat recovery can be applied, a number of criteria must be met:

- A worthwhile application for the waste heat must be reasonably nearby and the times at which this recovered heat can be utilised must match the times at which the furnace is operating. However, typically the heat available is fairly low grade. The temperature for the cooling water must not exceed 70 °C.
- The relatively low temperatures involved mean that heat exchangers need to be much larger than those which are normally encountered.
- The furnace water must not be returned to the furnaces at a temperature lower than about 30 °C; otherwise, this may give rise to condensation problems.
- Maintaining the integrity of the cooling circuits is absolutely essential. The cooling circuit is provided to protect the coil – if it fails in its task the results can be disastrous.

The above aspects, particularly the question of furnace integrity, discourage most furnace operators from even contemplating the utilisation of heat from the cooling circuit.

Applicability

Generally applicable.

Economics

A foundry attempting to make use of the heat from the cooling circuit needs to fully evaluate the benefits and then compare them with the cost of the additional equipment and the safety of the furnace and operators.

Driving force for implementation

Increasing energy efficiency at the foundry.

Example plants

Space heating using hot air: Proferro foundry [BE022 in SF BREF data collection], Oudenaarde (BE).

Metso Paper Jyväskylä Foundry (FI).

Cast iron foundries (e.g. DE061, ES085, FI102, DE042, AT010, DE067, CZ026, SE150, DE069) and NFM foundries (e.g. FR116, AT003, DE072, DE066, DE048) [169, TWG 2021].

Reference literature

[23, ETSU 1992], [169, TWG 2021]

3.2.1.4 Material efficiency

3.2.1.4.1 Storage and handling of residues, packaging and unused process chemicals

3.2.1.4.1.1 Appropriate storage of various residue types

Description

This includes the following:

- Fabric filter dust is stored on impermeable surfaces, in enclosed areas and in closed containers/bags.
- Other residue types (e.g. slag, dross, spent furnace refractory linings) are stored separately from each other on impermeable surfaces in covered areas protected from surface run-off water.

Technical description

The storage area for the various residue types is structured and managed according to the residue/waste type in order to avoid their potential mixing and to facilitate the subsequent management processes, e.g. recovery, reuse, recycling, disposal.

Achieved environmental benefits

- facilitation of subsequent residues management,
- reduction of groundwater and soil contamination.
- in addition, reduction of diffuse emissions to air (see Section 3.2.1.5).

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

- Legal requirements.
- Local conditions.

Example plants

Widely used.

Reference literature

[169, TWG 2021]

3.2.1.4.1.2 Reuse of internal scrap**Description**

Reuse of internal scrap directly or after treatment. The degree of reuse of internal scrap depends on its content of impurities.

Technical descriptionFerrous metal foundries

Internal scrap is produced from the knock-off of feeders and runners, in quality control and in finishing operations. The relative amount of internal scrap produced can be calculated from the metal yield as defined and described in Section 3.2.1.4.2. In order to minimise residue production, internal scrap is returned to the scrap metal feed of the furnace.

For steel foundries, 100 % use of return metal is uncommon, due to the amount of dissolved gas. Operators consider 60 % to be the maximum amount of return metal (feeders, scrap castings, etc.) in the charge metal. Swarf and turnings may cause excessive molten metal oxidation.

Internal scrap recycling/reuse may also be limited in the case of nodular base iron melting, as a high amount of silicon (about 1 % in most cases) is added in the liquid iron during the metal treatment. In some cases remelting the whole internal scrap is not possible because the final silicon would be too high (typically 2.5 – 3 % in the castings).

In the case of grey or nodular iron, lead or bismuth are very noxious for the properties of the metal after solidification. If there has been a pollution incident the returns (internal scrap) must not be recycled.

Magnesium foundries

The two main techniques for internal recycling of metal in magnesium casting foundries are as follows:

'In cell' recycling

Clean feeders can be directly melted in the melting furnaces. Because of oxides and other inclusions, the possible amount of recycling is limited. Specialised equipment for exact analytical and metallographical control is necessary.

'In house recycling'

Here the scrap is treated and recycled at a separate recycling-plant on-site at the foundry. Two techniques may be applied:

- *Fluxless remelting*: Remelting of Mg scrap under a covering gas in a hearth type furnace; applicable only to class 1 scrap. Advantages are the low additional investment and low energy consumption.
- *Salt remelting*: Remelting of Mg scrap under a salt cover. Is applicable to the processing of all scrap classes except used fluxes and sludge (not treated). If only class 1 – 2 scrap is used, HP (high purity) magnesium alloys may be produced.

Both techniques can be used to produce Mg ingots or molten metal for liquid charging.

Both in fluxless and salt-covered remelting, dross (the floatings on the melt) and sludge (the sinkings in the melt) are generated, as well as residues retaining a residual metal content (70 – 80 % Mg for sludge, 60 – 90 % Mg for dross). For recovery of the metal content, three options exist:

- salt remelting (in the same or a separate furnace);
- remelting in the aluminium industry;
- utilisation in the desulphurisation of iron or steel.

If the scrap is re-melted in a fluxless melting furnace, the salt remelting of dross and sludge involves the operation of a separate furnace.

The remelting of mixed class scraps is performed using salt remelting. The mixed scrap needs pretreatment. Table 3.11 gives a survey of the input-outputs of a pretreatment installation.

Table 3.11: Inputs and outputs for a magnesium scrap treatment plant

Inputs	Equipment	Outputs	End-of-pipe technology
- Oily or wet Mg-turnings (> 2 % oil/water) - Electricity	Centrifuge	- Mg-turnings (< 2 % oil/water) - Oil/water-emulsion	
- Centrifuged and all other turnings - Electricity	Turning-press (T = 400 °C)	- Pressed turning - Exhaust air	Particle separator for the vaporised oil
- Feeders, bad castings - Dross (without salt, from the foundry process) - Electricity	Shredder (if necessary)	- Shredded material - Dust	
<i>Source: [100, TWG 2002]</i>			

The recovery of metal from the remelting salt residue is done using dry crushing and screening with magnetic separation or by using a wet washing system. The wet system produces a magnesium fraction and a sludge, which, after dewatering, may be used in fertiliser industry.

Achieved environmental benefits

- The main benefit is the optimised recycling of metal.
- Minimisation of residues through recycling of raw materials.
- Internal recycling has the added benefit of eliminating transport to an external recycling plant. The metal efficiency of the recycling is increased by type-specific melting.

Environmental performance and operational data

Magnesium foundries

Experimental mass flow diagrams for the remelting of class 1 scrap are given in Figure 3.16 and Figure 3.17. These include the internal remelting of sludge and dross.

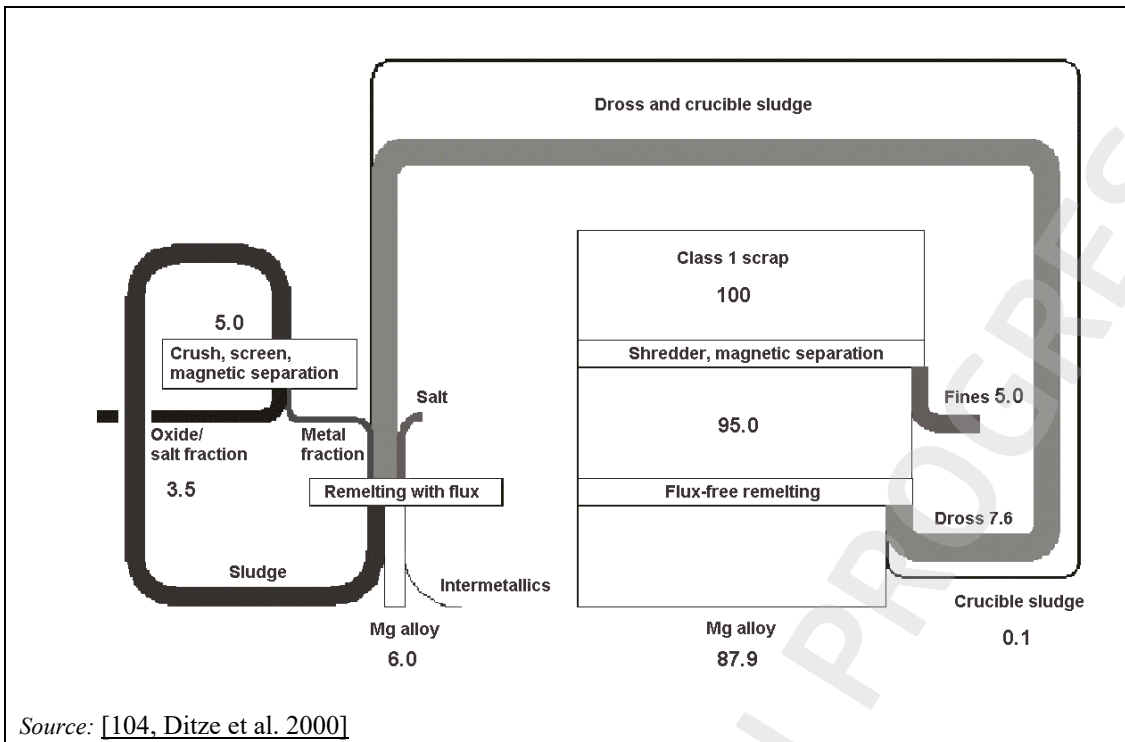


Figure 3.16: Mass flow diagram for the fluxless remelting of magnesium class 1 scrap

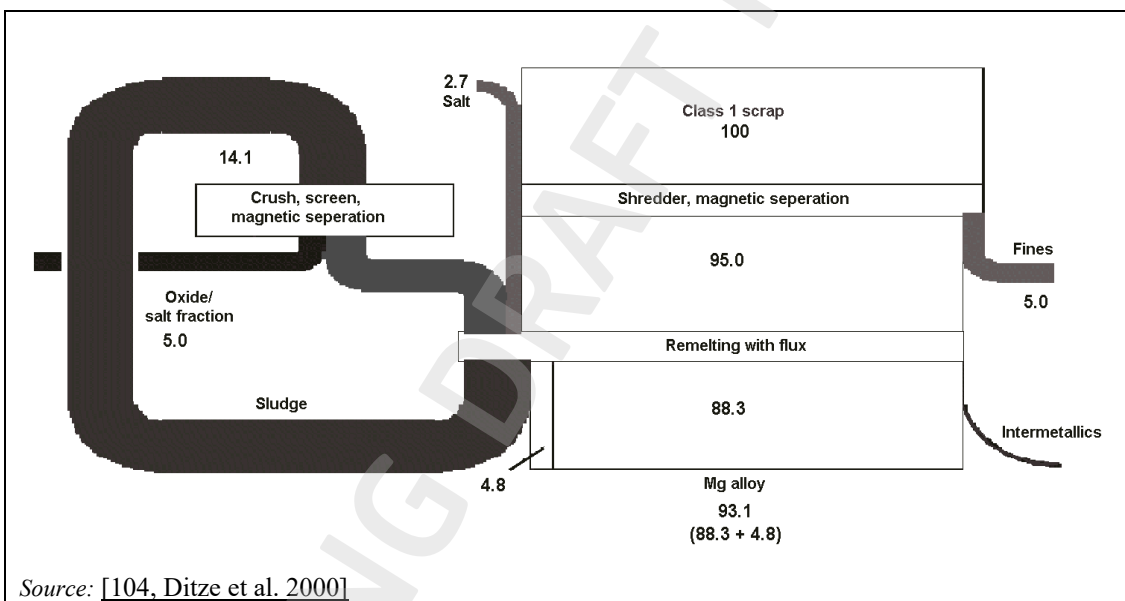


Figure 3.17: Mass flow diagram for the salt remelting of class 1 magnesium scrap

Operational data from a 2 000 tonne/yr salt remelting plant for mixed treated scrap (3 furnaces with a capacity of 600 kg each) give consumption levels of salt: of 3.4 kg/tonne scrap and natural gas: of 26.5 Nm³/tonne scrap.

The wet treatment of the salt fraction produces a magnesium fraction (43 %) and a sludge (57 %). The sludge is dewatered using a membrane filter press and the water is re-circulated into the process.

Cross-media effects

None in the case of ferrous metal foundries.

For magnesium foundries, fluxless re-melting involves the use of sulphur containing protective gases.

Technical considerations relevant to applicability

This technique applies to all new and existing installations.

Economics

In the case of ferrous metal foundries, the technique does not involve any additional costs.

In the case of magnesium foundries, the following information is available.

Costs for external recycling are estimated to be approximately EUR 1 200/tonne, depending on the type of transport used, the transport distance and the local market. The costs for in-house recycling are EUR 500/tonne, a difference of EUR 700/tonne. For a single plant with 1 500 tonnes/yr recycling material this means a potential saving of more than one million euro per year.

The given data are general and have to be adapted individually for each enterprise. Depending on the products and the processes used, the expenses needed for separation of the waste have to be taken into account. The waste has to be collected specifically for every alloy and every procedure.

Further factors of major influence are:

- depreciation (approximately 10 % in a depreciation period of 5 years);
- personnel costs (35 – 40 %);
- cost for new material (approximately 30 %) to substitute the material loss (estimated 7 %);
- costs for energy, maintenance, spare parts, salt, disposal (20 – 25 %).

The amortisation of a flux-based facility with two furnaces is in the range of 8 to 11 months. The amortisation of a continuous facility with 500 kg magnesium per hour will likely take a few months more.

Driving force for implementation

- Minimisation of residues, optimal use of metal.
- Legal requirements.

Example plants

The technique is applied in all European ferrous metal foundries.

For magnesium foundries: TCG Unitech, Kirchdorf/Krems (A) uses an in-house recycling facility.

No fluxless remelting IED plants have been reported in Europe, although the melting technology is used in Europe.

Reference literature

[100, TWG 2002], [104, Ditze et al. 2000], [118, Rauch et al. 2003], [169, TWG 2021], [210, TWG 2022]

3.2.1.4.1.3 Reuse/recycling of packaging

Description

Process chemicals packaging is selected to facilitate its complete emptying (e.g. considering the size of the packaging aperture or the nature of the packaging material). After emptying, the packaging is reused, returned to the supplier or sent for material recycling. Preferably, process chemicals are stored in large-size containers.

Technical description

The packaging types used for process chemicals are adapted to the conditions of use and include intermediary bulk containers (IBCs), big bags, containers, metal recipients, plastic or paper bags.

IBCs, buckets, containers and recipients

Packaging for chemicals like IBCs, buckets, containers and recipients for ready-to-use solutions, mixtures of active substances is emptied without the use of water: by gravity and by scraping the inner surface when possible.

Thereafter, the emptied packaging is stored in an appropriate manner in a dedicated storage area, until it is taken over by a qualified processing company or by the chemicals supplier.

Sacks and big bags

Sacks or big bags with chemicals in powder form are emptied under negative pressure. Thereafter, emptied sacks and big bags are stored in an appropriate manner, until they are taken over by a qualified processing company or by the chemicals supplier. Emptied sacks are packed in polyethylene sacks and sacks and big bags are stored in enclosed conditions.

In addition, purchased chemicals and additives are stored in large containers. Used containers are returned to chemicals/additives suppliers.

Achieved environmental benefits

Prevents waste generation, reduced emissions to soil and ground water and further stimulates recycling/reusing.

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

- Savings in chemical purchase.
- Reduction of waste generated.

Example plants

This technique is commonly applied in European foundries.

Reference literature

[38, Vito 2001], [169, TWG 2021], [210, TWG 2022]

3.2.1.4.1.4 Return of unused process chemicals

Description

Unused process chemicals (i.e. which remain in their original containers) are returned to their suppliers.

Technical description

The unused chemicals (in their original packaging) are preferably returned to the supplier before their expiration date, when possible, for possible resale and use. This is achieved especially by using innovative business models like chemical leasing, closed-loop chemicals management, etc.

Achieved environmental benefits

Reduction of the generation of waste chemicals.

Environmental performance and operational data

Return of unused chemicals to their suppliers may depend on parameters such as the distance between the site and the supplier and the acceptance of the supplier to take back the unused quantities.

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable.

Economics

No information provided.

Driving force for implementation

Cost savings.

Example plants

Widely used.

Reference literature

[169, TWG 2021], [210, TWG 2022]

3.2.1.4.2 Operational material efficiency in the casting process

Metal yield (or operational material efficiency – OME) is defined as the ratio of good casting to the total metal melted and calculated as the total yearly amount (expressed in t) of final castings without defects divided by the total yearly amount of liquid metal output.

3.2.1.4.2.1 Improving casting yield and decreasing scrap generation**Description**

Measures are taken to maximise the efficiency of the casting process and to decrease the generation of scrap, e.g.:

- applying best practices in melting and pouring operations to reduce for example melting losses, excessive pigging, scrap generation rates;
- applying best practices in moulding and core-making to reduce scrap generation resulting from deficiencies in moulds and cores;
- optimising gating and rising systems;
- using insulated exothermic feeders.

Technical description

As stated above, OME is defined as the ratio of good casting to the total metal melted. The difference between the two values is due to metal losses (e.g. melting losses, spilt metal, grinding losses) and return metal (e.g. pigged metal, runners, scrap castings). An improvement of the metal yield involves reducing the metal loss and amount of return metal.

Improving metal yield is possible using one or more of the following measures:

- *Applying an efficient method*: proper design of runners, risers, ingates, pouring basin and optimised box yield (castings/metal poured in a mould). A valuable tool in designing is the use of computer aided simulation of casting, pouring and solidification (see also Section 3.2.1.4.2.2).
- *Applying good procedures in melting and pouring operations*: in order to reduce melting losses, excessive pigging, scrap rates, etc.
- *Applying good practice in the moulding and core-making departments*: in order to reduce scrap due to deficiencies in the mould- and core-making operations.
- *Applying direct remelting and or avoiding sprue materials* [169, TWG 2021]

Achieved environmental benefits

Increasing the metal yield results in a lower consumption of energy, sand and additives per unit of good casting. The overall efficiency of the process is increased.

Environmental performance and operational data

A statistical analysis of the data reported for OME is presented in the following table.

Table 3.12: Statistical analysis of the data reported for OME (expressed in %)

	Iron foundries	Steel foundries	NFM foundries
Average	51	53	56
Median	58	57	60
20th percentile	5	41	39
80th percentile	80	69	85
Number of values	73	23	45
<i>Source: [169, TWG 2021]</i>			

The following table provides a guide to the typical yields obtained for different types of iron casting production.

It is noted that OME depends on the type of metal, type of casting, the production facilities and the market which has to be served.

Table 3.13: Typical metal yields for different iron casting types

Casting type	Yield (%)
Heavy grey iron, simple shape	85 – 95
Medium sized grey iron jobbing or small batch	65 – 75
Mechanised repetition, general quality small to medium sized grey iron engineering and municipal castings	65 – 75
Mechanised repetition, high quality small to medium sized grey iron engineering castings, relatively simple design	60 – 65
Mechanised repetition, high quality small to medium sized grey iron engineering castings, complicated heavy cored design	55 – 60
Medium sized nodular iron jobbing or small batch	50 – 60
Small or very small grey iron repetition	45 – 55
Mechanised repetition of malleable iron and small nodular iron castings	40 – 50
<i>Source: [21, ETSU 1990]</i>	

Cross-media effects

Thinner castings may result in a lower yield.

Technical considerations relevant to applicability

The technique is applicable in all existing ferrous and non-ferrous foundries.

Economics

Improving the metal yield is possible through simple low-cost practical measures and controls. The benefits may be high since every percentage improvement results in a corresponding reduction of melting energy consumption and a reduction in the consumption of sand and chemicals.

The introduction of a computer-aided simulation for pouring and solidification requires investment and training costs.

Driving force for implementation

- Optimisation of process efficiency.
- Legal requirements.

Example plants

Metal yield considerations are part of good operational practice in the majority of European foundries.

Reference literature

[21, ETSU 1990], [47, EU Thematic Network Foundry Wastes 2001], [169, TWG 2021], [210, TWG 2022]

3.2.1.4.2.2 Use of computer-aided simulation for casting, pouring and solidification

Description

A computer simulation system is used to optimise the casting, pouring and solidification process, to minimise the number of defective castings and increase foundry productivity.

Technical description

The simulation of mould filling improves the quality, the recovery and productivity. The yield during a manufacturing process is the net weight generated, based on the spent gross casting weight.

As an example, the use of the new casting process simulation technique, compared with the previous model, leads to an improvement in yield of about 18.5 %. The example case refers to the manufacturing of a front wheel fork in light alloy, which is manufactured by tilted die-casting.

Achieved environmental benefits

- Reduced consumption of metallic materials.
- Reduced dust and gaseous emissions from melting, casting / cooling / emptying and casting treatment from reduced use of material.
- Less energy consumption and related CO₂ emissions, particularly during the melting.

Environmental performance and operational data

Both hardware and software for the simulation of cooling characteristics and properties of cast iron or cast parts are needed.

Cross-media effects

None.

Technical considerations relevant to applicability

Applicable for all industrial casting materials and casting processes.

Economics

Licence fees for the annual use of standard software is approximately EUR 25 000. The software is material-specific or process-dependent and can be extended with additional modules. Alternatively, it is possible to use casting simulation as a service.

Economic benefits are:

- the increase in yield and reduction of rejection rate and the moulding cycle time can result in a reduction of the melting and material costs in the sum of EUR 28 000 in the first year (example), leading to a return of investment in approximately 1 year;
- an increase in the metal yield results in less consumption of energy, sand and additives per tonne of good casting.

Other exemplary cases for the application of simulations [[133, DE UBA 2014](#)]:

- The equipment manufacturer John Deere, Moline III. has reduced the scrap rate of the grey-iron part from 10.3 % to 1.4 % and saved USD 66 936/year by modifying the part and gating system. The company also boosted its casting yield from 58 % to 64 % for an additional saving of USD 66 600/y.
- Simulation results led pump manufacturer Otto Junker in Germany to cast a steel pump housing that had direct-pour top risers instead of the typical side risers. This lowered the amount of liquid metal needed by 81 %, reduced the moulding time by 79 % and minimised the time needed to burn off the risers by 87 %. The company reduced its total production costs for the part by 12 %.
- A South American iron foundry increased its casting yield for a ductile-iron differential case housing from 62 % to 67 % by using simulation to develop a non-traditional gating system. The design lowered the overall scrap rate from 17 % to 7 %, saved 700 000 kWh/yr to produce 24 000 parts and reduced total costs by USD 500 000.
- Heidelberger Druck (Germany) relocated a mould gate based on simulation results and thereby significantly reduced the amounts of repair welding to perform on a cover. Temperature losses in the original part had led to incomplete filling of a rib. Simulation enabled the engineers to visualise how the material flow was affected by moving the gate to different locations.

Driving force for implementation

- Increase in the ability to process and avoid casting defects.
- Increase the yield by reducing the amount of recycled material.
- Reduction in wall thickness and therefore reduction of the setting time and the moulding cycle time by 10 %.

Example plants

In Germany, about 180 simulation systems from various providers are in use.

Reference literature

[[133, DE UBA 2014](#)]

3.2.1.4.2.3 Production of lightweight castings using topology optimisation

Description

Use of topology optimisation (i.e. casting simulation by means of algorithms and computer programs) to reduce the product mass while meeting the product performance requirements.

Technical description

Topology optimisation uses the principles of the ‘bionic’ concept. The term ‘bionics’ is a composition of the words biology and technology, and describes the implementation of requirements from nature to technology. The central goal is the production of components such as castings with a minimum mass of material.

With the help of the bionic concept, typically implemented by computer programs for topology optimisation, the castings can be improved for all applications like castings for automotive, engineering and many more.

An example is the manufacturing of machining tools, which is subject to the highest design and manufacturing challenges. By using advanced optimisation algorithms and computer programs, more lightweight castings can be produced having even better mechanical properties compared to their predecessors.

The specified design goal, high stiffness combined with low manufacturing costs, can be taken into account with natural growth structures (for example, the growth patterns of trees). For the development of a bionic product, the German VDI guideline 2221 ('Methodology for Developing and Designing Technical Systems and Products') may be used and this can find applications in die-casting, particularly in lightweight design. [198, Beismann et al. 2018]

Achieved environmental benefits

- Reduced flows of metallic feedstock in the total production process including raw material storage, melting, casting / cooling / emptying and in casting treatment.
- Reduced dust and gaseous emissions in these manufacturing sectors (at constant number of castings).
- Less energy use and CO₂ emissions, especially during melting and transport.

Environmental performance and operational data

A case example of topology optimisation is using a special calculation tool - the 'finite element method' (FEM). The FEM software allows the user to find weaknesses in a constructive computer-aided design and an objective evaluation of design variants. So far, designers used it only as a tool to improve functionality in an iterative approach by repeated modifications of the CAD model, which was very time-consuming. By combining FEM software with advanced optimisation algorithms, it became possible to generate functionally convincing design proposals automatically by masking areas during the topology optimisation of the work piece which are not or only minimal stressed. Output is a structure, which provides minimal distortion with a given weight.

The software improves and accelerates finding of convincing workpiece designs which is seen as even more important due to increasing deadline constraints.

After the detailed design of the workpiece, the mould can be optimised. Analogous to growth processes in nature, it eliminates strength-related vulnerabilities by automatically applying some material in heavily used areas.

Cross-media effects

None.

Technical considerations relevant to applicability

Applicable to all cast components - regardless of casting materials and casting processes. Close communication with the customers is advised especially when low mass castings will be developed and applicability may depend on customer's willingness to involve the foundry in the design process.

Economics

- Reduced raw part costs by saving material.
- Reduced melting costs.
- Reduced cost for core and mould production.
- Increased value of components in cases where value of components depends on weight and or costs per piece.
- Competitive advantages over competing materials and manufacturing processes (welding, forging, polymer concrete).

Driving force for implementation

- Reduction in weight of castings. In general a range of reduction between 10 % and 35 % is expected.
- Maximum component stiffness by minimum material use.
- Accelerated finding of concepts for design of workpieces.
- Reductions of unit costs.

Example plants

- CLAAS GUSS is using the software Hyperworks.
- Under the trade name BIOCAST[®], Heidenreich and Harbeck AG is developing material-efficient premium cast parts with the help of bionic optimisation tools.
- GF Automotive is producing mechanically highly stressed components for the automotive industries with bionic guidelines that are based on the principle of growth of trees.

Reference literature

[133, DE UBA 2014], [198, Beismann et al. 2018], [210, TWG 2022]

3.2.1.4.3 Reduction of material consumption

3.2.1.4.3.1 Separate spraying of release agent and water in high-pressure die-casting

Description

Water and release agents are applied separately to the mould using an additional row of nozzles mounted on the spray head. Water is sprayed first, leading to a significant cooling of the mould before the application of the release agent, which results in reduced emissions and consumption of release agents and water.

Technical description

In aluminium high-pressure die-casting, the permanent moulds are cooled and sprayed with release agent prior to casting to prevent the casting adhering to the mould. The conventional technique for release agent use is that a mixture of release agent and water is applied to the hot mould in one go, by means of several linearly arranged nozzles. Some of the water evaporates, cooling the mould and leaving the release agent in place, whilst another part of the mixture runs off the mould, leading to a loss of release agent and water. The evaporation may also cause the formation of a mist.

In an alternative process, water and release agent are applied separately. For this purpose, a row of nozzles was added to the spray head for the separate application of release agent. These nozzles can be actuated individually via a computer (see the figure below).

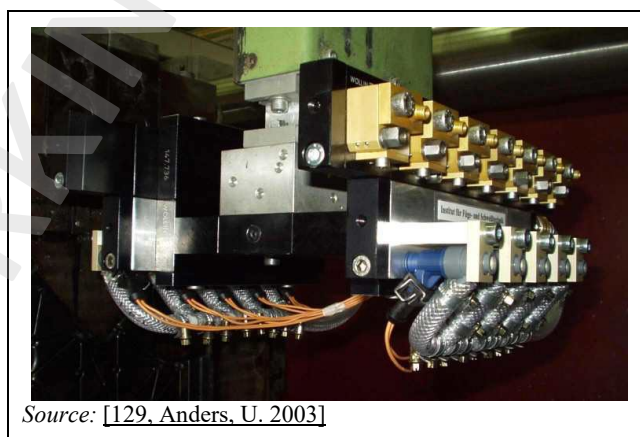


Figure 3.18: Spray head with separate nozzles for water and release agent

Water is sprayed on first, cooling the mould by approximately 20 °C, followed by spray application of the release agent. The preliminary cooling causes less release agent to evaporate and improves its adhesion to the mould. This reduces the consumption of release agent by some 25 %. Thermographic measurements showed that the technique cools moulds more strongly and more evenly. Tests proved that it involves no leakage of release agent which otherwise would have had to be collected and disposed of.

Release agent is applied only to those parts of the mould which come into contact with the molten aluminium. This can reduce the consumption of release agent by another 30 %.

The use of computer-assisted actuation of the nozzles for the release agent has made the previously used existing array of nozzles for compressed air redundant. This function is now taken over by the nozzles for the release agent.

An advantage with small series and frequent mould changes is that the spraying programme can be saved on the computer and can thus be reproduced quickly after a mould change.

Achieved environmental benefits

The consumption of release agent can be reduced by 25 % by the separate application of water and release agent. Separate actuation of the nozzles makes it possible to achieve a further saving of up to 30 %, depending on the geometry of the casting, as the release agent is applied only to those parts of the mould which come into contact with the casting.

Water consumption can be reduced by about 15 %. There are no losses of water or release agent to be disposed of. No gaseous emissions due to evaporation of release agent are generated.

Environmental performance and operational data

No information provided.

Cross-media effects

None. No increase in energy costs is expected.

Technical considerations relevant to applicability

Generally applicable.

Economics

Economic advantages result from the considerable savings in release agent and water, and from the elimination of disposal costs.

Further advantages result from the major time savings achieved in the mould change, due to the fact that spraying programmes can be saved and re-run.

The investment costs for this technique are higher than those of the conventional process. On the plus side, different moulds can be sprayed individually with the same spray head.

Driving force for implementation

- Considerable saving of material and water.
- The loss of release agent-water mixture, which needs to be collected, is avoided.
- Short time-scales required for machine set up and adaptation.
- High reproducibility of the results (consistent quality).

Example plants

CZ025, DE031, FR114, FR115, PT142, SE148.

Reference literature

[129, Anders, U. 2003] [169, TWG 2021]

Description

Measures to minimise the consumption of release agent and water include:

- use of an automated spraying system;
- optimisation of the release agent's dilution factor;
- application of in-die cooling;
- closed-mould application of release agent;
- measuring the consumption of release agents;
- measuring the die surface temperature to indicate hotspots in the die.

Technical description

A water-based solution of release agent is sprayed on the open HPDC die before closing it. This allows cooling and coating of the die. Some simple process measures allow the minimisation of the release agent and water consumption. These will also prevent the formation of a mist. These measures include the following:

- *Automated spraying process:* Robotisation of the spraying process allows a careful control of the amount of release agent used and adaptation of the amount used to the local needs of the cast piece.
- *Optimise dilution factor:* The release agent dilution factor should be chosen such that the spraying action has the required balance between coating and cooling of the die.
- *Apply in-die cooling:* The cooling action may be partially taken over by internal cooling using an integrated water circuit.
- *Closed-mould application of release agent:* A release agent is applied to the closed die-casting mould in a vaporised form. The high temperature results in a condensation and deposition of a release agent film. This technique is an alternative to the spraying of a water-based solution of the release agent onto the open die. It allows the water usage to be reduced and also reduces the consumption of release agents. The active substances for the process, i.e. getting the casting out of the die, are very similar to the open-mould technique: paraffin wax, aliphatic carbons, polysiloxanes, polyglycol. Water spraying, however, also causes the necessary cooling of the die surface. The alternative technique therefore requires enhanced temperature management (mainly by a cooling effect), by means of an internal die cooling system. This may be obtained by reducing the thermal oil temperature. Combined water spraying and closed-mould release agent application is possible in places where the moulds cannot achieve complete thermal equilibrium by means of internal cooling systems alone.
- *Measuring the consumption of release agents:* The objective is to use the release agent in accordance with its actual purpose and to spray only minimal quantities. Automated systems are available that, among others: track the automatic flow measurement per cycle (and spray circuit), track the target / actual comparison of flow rate values, generate a notification in case of deviation above the permissible value, signal a cycle stop in case of deviation.
- *Measuring the die surface temperature to indicate hotspots in the die:* The quality of die casting is largely determined by the process parameters, such as the temperature.

Achieved environmental benefits

- Minimisation of water and chemicals consumption.
- Prevention and/or reduction of (diffuse) emissions.
- Reduction of generated waste water and reduced emissions of steam containing oily particles.

Environmental performance and operational data

For the closed-mould application of release agent, some operational examples in aluminium foundries have been reported. A 50 – 80 % reduction in the spraying time was reported as well as an 80 % reduction in sleeve-parting agent consumption. [100, TWG 2002]

Cross-media effects

Generally no cross-media effects were reported for most of the techniques. For the closed-mould application of release agent, an increased effort to cool the dies is required. In simple cases, this may involve a lowering of the thermal oil temperature, but for more complex dies, it may involve the application of an additional cooling circuit.

Technical considerations relevant to applicability

Generally applicable.

Economics

No information provided.

Driving force for implementation

- Foundry strategy to reduce waste water production and to reduce the consumption of water and chemicals.
- Legal requirements.

Example plants

Most of the techniques are applied in major HPDC plants, e.g. in the manufacture of car parts. For the closed-mould application of released agent, some operational examples in aluminium foundries have been reported.

Reference literature

[88, Hüttenes-Albertus 2002], [100, TWG 2002]

3.2.1.4.3.3 Optimisation of binder and resin consumption

Description

Measures to optimise binder and resin consumption include:

- use of a sand quality which is consistent with the binder system;
- good management of sand storage and sand testing (purity, grain size, shape, moisture);
- temperature control;
- mixer maintenance and cleaning;
- checking mould quality (to prevent and if necessary repair moulding defects);
- optimising binder addition process;
- optimising mixer operation.

Technical description

The minimisation of chemicals consumption can be achieved through optimisation of the process controls and material handling. In this section process measures are discussed.

Overuse to compensate for poor process control is the most common way in which binder chemicals are wasted. For instance, key parameters that relate to good binder management include:

- *Sand consistency*: Use of a sand quality which is consistent with the binder system. Good management of sand storage and sand testing (purity, grain size, shape, moisture) are of the main importance. A low content of fines and maximum amount of re-used sand will reduce the amount of resin needed.
- *Temperature control*: The sand temperature must be maintained in a narrow range, with regular checks and adjustment of the amount of hardener addition. Positioning the sand heater just before the mixer allows close temperature control.
- *Mixer maintenance and cleaning*.
- *Mould quality*: Checking, solving and preventing moulding defects.

- *Addition rates:* The appropriate binder addition depends on the binder type, the surface area of the sand and the size of the casting.
- *Mixer operation:* Optimisation of the mixer performance involves monitoring and control of its operation.

The following table lists the mixing process variables that are easy to measure using readily available instrumentation. Interfacing the controls with an alarm system allows the operator to be alerted to any ‘out-of-specification’ condition. This needs to be corrected by cleaning, maintenance and recalibration before a major problem develops.

Table 3.14: Process variables and how they indicate mixer performance

Process variables	Comments	Instrumentation
Sand flow	Can vary as a result of obstructions at the discharge gate that reduce/stop the sand flow or worn/loose stop nuts that produce a faster flow	Impact plate flowmeters
Sand temperature	Determines the speed of hardening and the amount/type of hardener required	A process control instrument can be used to adjust hardener additions to compensate for changes in sand temperature
Power consumption	Provides an indicator of mixer cleanliness	Motor load monitor
Resin and hardener flowrate	Can vary as a result of worn pumps, viscosity changes with temperature, blockages or leaks in pipework and nozzles, sticking of non-return valves, etc.	Positive displacement, electromagnetic or coreolis flowmeters
Operating hours	Useful for assessing performance against capital and maintenance costs	
<i>Source:</i> [28, ETSU 1998]		

For foundries that require greater sophistication, a range of fully automated mixer control systems are available. These systems use microprocessor technology to provide automatic corrective control of mixed sand production and need only limited operator involvement. The additional benefits achievable with automated control systems are mainly due to the much reduced dependence on the operator and the more rapid correction of variations in conditions. The latter is also performed without having to stop production.

Achieved environmental benefits

Optimisation of the binder and resin use results in a minimisation of the consumption of chemical additives.

Volatile organic compounds make up to 50 – 60 % by weight of the binder components. The amount depends on the binder system type. Most are emitted during sand mixing and metal pouring. A reduction in the use of binder results in a corresponding reduction of VOC emissions.

Environmental performance and operational data

In most cases, reductions of 5 % in binder levels and 1 % in scrap moulds are easily achieved using modern mixer control systems. Many foundries have realised savings that have been considerably higher. Reductions in binder addition of 5 % to 25 % have been reported for various foundries, as well as almost eliminating scrap moulds production.

The installation of an automated mixer control system in an iron foundry using cold-setting resins allowed the foundry to reduce the resin addition rate from 10 kg/minute (1.22 % resin to sand weight) to 8.89 kg/minute (1.09 %), which correspondingly resulted in a 10 % saving in the

amount of catalyst used. The number of defective moulds fell by over 60 % and cost savings of over GBP 37 000/year (1995 UK prices) were achieved.

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable. This technique applies to all new and existing foundries using chemically bonded sands. Mixing monitoring control equipment can be retrofitted to existing plants.

Economics

For a tonne of mixed sand, the binder addition is typically only 1 – 3 % by weight, but in terms of cost, the binders account for 30 – 60 % of the total raw material cost. It is estimated that cost savings of 5 – 10 % could be achieved through better management of binder materials.

Incorporating all the equipment suggested in Table 3.14 in a mixer system costs around GBP 10 000 (1997 UK prices). However, due to the significant improvement in process control, this capital investment will have a relatively short payback time. Although the cost of installing an automated control system is approximately twice that for simple on-line monitoring, substantial cost savings are possible.

Some example economic data are given in Table 3.15. These refer to the iron foundry described under Operational data.

Table 3.15: Annual savings, cost and payback for example plant mixer control (1995 prices)

Cost type	EUR
Saving due to 60 % reduction in defective moulds	6416
Saving due to 10 % reduction in resin use	29966
Saving due to 10 % reduction in catalyst use	9050
Total saving in material cost	45433
Annual running cost	320
Estimated annual maintenance cost	24
Net cost saving	45088
Purchase cost of unit	24166
Payback period	7 months
<i>Source: [31, ETSU 1996]</i>	

Driving force for implementation

- Optimisation of operational costs and minimisation of VOC emissions.
- Legal requirements.

Example plants

Good binder management measures are used in the vast majority of the foundries using chemically bonded sand.

Reference literature

[28, ETSU 1998], [31, ETSU 1996], [100, TWG 2002], [120, TWG 2003], [210, TWG 2022]

3.2.1.4.3.4 Minimisation of mould and core sand losses

Description

Production parameters of the various product types are stored in an electronic database that allows easy changeover to new products with minimised losses in time and materials.

Technical description

Modern mould and core-making machines allow the production parameters of the various product types to be saved in an electronic database. This allows easy change-over to new products, without the loss of time and materials from finding the right parameters by simply using trial and error. For new products, the settings for similar products may be used to shorten the optimisation time.

Achieved environmental benefits

Reduction of the amount of waste sand and energy, through minimisation of the test run period.

Environmental performance and operational data

This technique is especially useful for the production of small series with high production throughput. An errorless change-over requires good control and continuity of the sand quality.

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable.

Economics

The investment cost for a core shooting machine depends on the core volume, and range from EUR 150 000 (5 l) to EUR 400 000 (100 l). Operational costs are 5 – 10 % of investment costs per year (2001 data).

Driving force for implementation

Optimisation of processes that require frequent change of core or mould type.

Example plants

This technique is applied in several foundries around Europe.

Reference literature

[38, Vito 2001]

3.2.1.4.3.5 Use of best practices for cold-setting processes

Description

Practices include the following (depending on the binding system used):

- Temperature control: the temperature of the sand is kept as constant as possible and low enough to prevent emissions caused by evaporation. For phenolic- and furan-acid catalysed, polyurethane and ester silicate systems, the optimum temperature range is between 15 °C and 25 °C. For resol-ester systems, the optimum temperature range is between 15 °C and 35 °C.
- for furan-acid catalysed systems:
 - minimise the content of free (monomer) furfuryl alcohol in the resin (e.g. less than 40 wt-%); and
 - reduce the sulphur content of the acid catalyst by substituting a portion of the sulphonic acid with a strong sulphur-free organic acid.

Technical description

In cold-setting processes, temperature control of the sand should be kept as constant as possible and the optimum temperature ranges should be selected. This is summarised below together with additional parameters to consider for all the main cold-setting systems:

- *Phenolic*: The temperature of the sand is kept as constant as possible, i.e. at around 15 – 25 °C, which is low enough in order to prevent emissions caused by evaporation. Direct contact

between the resin and catalyst has to be avoided as the reaction is exothermic and can be violent.

- *Furan*: The temperature of the sand is very important for this process and is kept as constant as possible, around 1 – 25 °C; in order to control the setting time of the binder and to minimise catalytic additions. Direct contact between the resin and catalyst needs to be avoided as the reaction is exothermic and can be violent.
- *Polyurethane (phenolic isocyanate)*: The sand temperature is kept between 15 and 25 °C, to maintain process control and to minimise emissions. Best practice is to work with three pumps and to mix the catalyst and the phenolic resin with isocyanate and sand directly in the mixer [100, TWG 2002].
- *Resol-ester* (alkaline phenolic ester hardened): The temperature of the sand is controlled and kept at an optimal level of 15 – 35 °C. The process is less sensitive to temperature fluctuations than other self-hardened systems. The velocity of hardening is managed by the choice of the hardener type [120, TWG 2003].
- *Ester silicate*: The sand temperature is controlled within the range 15 – 25 °C. As moulds and cores pick up moisture, they need to be used as quickly as possible after achieving full strength. Prolonged storage can only be done in dry conditions.

Specific measures for furan-acid catalysed systems

Furan resins are made from furfuryl alcohol (FA) and can be modified with urea, formaldehyde or phenol. Generally, the higher the content of furfuryl alcohol in the resin, the lower the viscosity of the resin. Since the classification of furfuryl alcohol as a carcinogenic compound in Regulation EC No 1272/2008, the content of free (monomer) furfuryl alcohol in resin should be limited theoretically to less than 25 wt-%.

Based on the data collected via the questionnaires, although several plants did report a FA content > 70 wt-% (i.e. PT140, FI103, DE067, DE058, DE055, DE044, DE042, CZ156, AT018, AT017), many plants also reported a FA content within the range of 30 – 40 wt-% (i.e. BE023: 40 %, DE070: 31 %, ES088:33 – 40 %, FR119: 35 %, IT134: 30 %, PL137: 30 – 40 %), and one plant (DE039) also reported a FA content below 25 wt-% (according to the supplier of the resin) after having substituted another resin previously used at this plant containing more than 50 wt-% FA. The information indicates that it seems possible to employ resins with a lower FA content, which should in turn reduce TVOC emissions.

In order to limit the emissions of sulphur compounds during pouring, new types of acid catalysts have been developed. Essentially, sulphur is introduced into the moulds via the acid catalyst (paratoluenesulphonic acid) employed in furan-acid catalysed systems. The most efficient way to reduce sulphur inputs into the mould consists of reducing the amount of paratoluenesulphonic acid added or partially replacing it with other compounds (e.g. sulphur-free organic acids).

Achieved environmental benefits

Reduction of VOC and sulphur emissions during pouring.

Environmental performance and operational data

Historically, the furfuryl alcohol content in furan resins used in the foundry process ranged from 50 wt-% to 95 wt-%. New resins have been developed where the furfuryl alcohol content has been limited to slightly above 50 wt-%. [191, Holtzer et al. 2015], [199, Holtzer et al. 2013]

More recently, furan resins with low formaldehyde content (percentages of formaldehyde of less than 0.1 wt-%, based on the weight of the resin) and low furfuryl alcohol content (less than 25 wt-%.) have also been developed. [200, Zennaro et al. 2019]

Binders developed by different manufacturers for foundries using low-sulphur catalysts composed of a mixture of non-sulphur strong organic acids and aliphatic or aromatic toluenesulphonic acid, and H₂SO₄ are effective (possibility of reducing the sulphur content of the acid catalyst by about 50 %).

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable.

Economics

The price of using low-sulphur catalysts in furan binders is higher than using paratoluenesulphonic acid only.

Driving force for implementation

Legal requirements.

Example plants

Widely used.

Reference literature

[100, TWG 2002], [120, TWG 2003], [191, Holtzer et al. 2015], [199, Holtzer et al. 2013], [200, Zennaro et al. 2019], [210, TWG 2022]

3.2.1.4.3.6 Recovery of amines from acid scrubbing water

Description

When acid washing is used (e.g. using sulphuric acid) to treat the cold-box off-gases, amine sulphate is formed. The amines are recovered from the treatment of amine sulphate using sodium hydroxide. This may take place on site or off site.

Technical description

When acid washing the cold-box exhaust gas, amine sulphate is formed (see Section 3.2.1.4.3.6). This amine may be recovered through neutralisation with sodium hydroxide, followed by distillation.

As shown in Figure 3.19, the salt that is formed from tertiary amine (e.g. DMEA, DMIPA and triethanolamine (TEA)) in the acid scrubber, and the scrubbing acid (e.g. sulphuric acid) are retransformed by reaction with a strong base (e.g. caustic soda solution), thereby forming free amine and e.g. sodium sulphate. The amine is expelled with water vapour and is then cleaned and concentrated in a column, to an extent that allows it to be re-used. The sodium sulphate solution (together with polluted scrubbing solution) can be recovered or may be disposed of.

If the amine is not recycled, the scrubbing concentrates can be treated in a biological waste water treatment plant with nitrogen elimination.

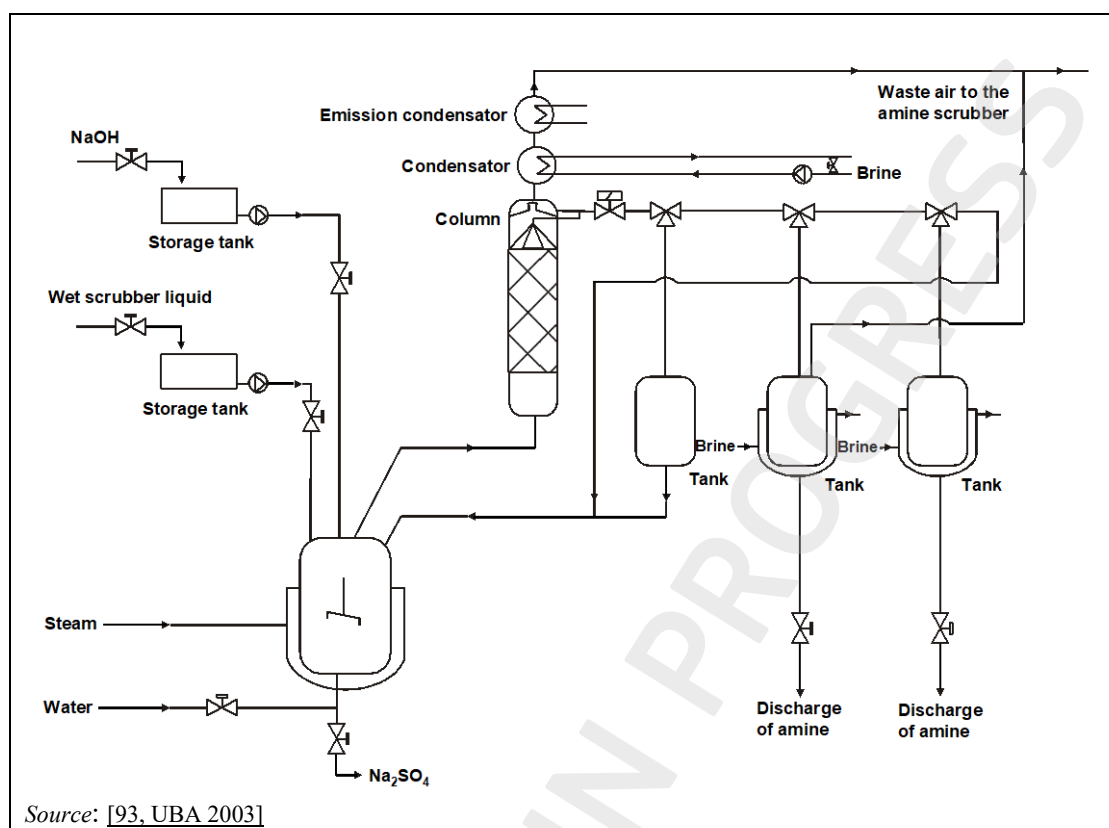


Figure 3.19: Amine recycling plant

Achieved environmental benefits

Recovery of a chemical compound, which may be reused.

Environmental performance and operational data

This technique is applicable to all amine-containing scrubber liquors from core-making exhaust. The implementation is associated with economic factors (e.g. transport costs), since sufficient quantities of amine scrubber liquid need to be available. In general, the treatment is applied in a centralised location, treating the effluents of several foundries. Since the operation is subject to an explosion hazard, any necessary measures to prevent explosion risks should be taken (see also Technical considerations relevant to applicability below).

Cross-media effects

- If the operation is performed in a centralised plant, it involves transport of the scrubber liquid to the treatment unit.
- Consumption of sodium hydroxide and generation of a sodium sulphate solution which may require disposal.

Technical considerations relevant to applicability

Applicability may be restricted due to safety considerations (explosion hazard).

Economics

No information provided.

Driving force for implementation

- Recovery of chemical compounds.
- Disposal costs for industrial waste.

Example plants

- Centralised recycling plants: Voerde (DE).

Reference literature

[93, UBA 2003]

3.2.1.4.3.7 Use of best practices for gas-hardening processes

Description

Practices include the following (depending on the hardening process used):

For phenolic urethane resins (cold-box process):

- The consumption of amines is minimised by optimising the diffusion process within the core, typically through simulation and optimisation of the gas flow.
- The sand temperature is maintained as constant as possible, between 20 °C and 25 °C, to minimise gassing time and amine consumption.
- The moisture of the sand is maintained below 0.1 % and the gassing and purging air is dried.
- Core boxes are well sealed to allow the amine catalyst gas to be extracted and the cores are thoroughly purged to prevent amine releases during the storage of cores.

For resol-ester resins:

- The sand temperature is maintained as constant as possible, between 15 °C and 30 °C.
- Curing of the alkaline phenolic resin is achieved using methyl formate that is gasified by air typically heated up to 80 °C.
- Core boxes and gassing heads are sealed correctly and the venting of the core box designed to give a slight backpressure so that the curing vapour is held long enough for the reaction to take place.

For CO₂-hardened resins (e.g. alkaline phenolic, silicate):

- The exact volume of CO₂ gas necessary for curing the resins is used by employing a flow controller and a timer to achieve the best strength and storage time.
- For silicate resins, liquid breakdown agents are employed (e.g. soluble carbohydrates) to increase gassing speed.

For SO₂-hardened resins (e.g. phenolic, epoxy/acrylic):

- The gassing period is followed by purging with either the same inert gas (e.g. nitrogen) used for curing or air, to remove the unreacted excess sulphuric dioxide from the sand.
- Core boxes are well sealed and the cores are thoroughly purged to prevent gas releases during the storage of cores.

Technical description

- *Cold-box*: Amine vapours need to be captured at the core-making machine. Any excess amine is captured through the core box. Additionally, it may also be necessary to ventilate the core storage area. When possible, hoods are placed over the moulding or coring machines as well as over the temporary core storage area.

Amine consumption can be minimised to the extent that its consumption matches the production needs of the sand cores, since the cost of the raw material and its treatment is high. Minimisation of amine consumption is helped by optimising the amine distribution process within the core, typically through a simulation and optimisation of the gas flow [100, TWG 2002].

The sand temperature has to be maintained as constant as possible, between 20 °C and 25 °C, otherwise a too low temperature will involve a longer gassing time, thus resulting in a larger amine consumption. A too high temperature drastically reduces the lifetime of the prepared sand.

Water is detrimental to this process. The moisture of the sand has to be maintained below 0.1 %, and the gassing and purging air must be dried.

Note: Amines are flammable and explosive in some proportions with air. Considerable care is required in their storage and handling, and the supplier's instructions need to be observed at all times.

- *Resol (alkaline phenolics methyl formate hardened):* It is advisable to ventilate the working area, at least in order to prevent any danger of fire. Methylformate consumption needs to be minimised to such an extent that its consumption matches the production needs of the sand cores. The sand temperature has to be maintained higher than 20 °C, in order to prevent the condensation of methylformate. Methylformate vapours are heavier than air; this should be kept in mind when designing the exhaust system.

Note: Methylformate is flammable when its concentration in air reaches 6 to 20 % and explosive in some proportions with air. Considerable care is required in storage and handling, and the supplier's instructions need to be observed at all times.

- *Resol-CO₂:* The resin has low contents of unreacted phenol and formaldehyde, and their emission levels, even during the gassing and purging periods, are very low. It is advisable to ventilate the working area. [120, TWG 2003]
- *SO₂ hardened phenolic or furan:* The working area has to be ventilated, and the emissions collected at the emission point by totally hooding the moulding or coring machines and by applying venting.

These collected gases must be treated before emission. This is easily completed by a scrubber containing a sodium hydroxide solution. The pH and the concentration of the scrubbing solution have to be continuously supervised. The scrubbing solution needs to be occasionally replaced to remove concentrated salts, it then requires disposal as a hazardous waste.

Sulphur dioxide consumption needs to be minimised to the extent that its consumption matches the production needs of the sand cores.

Normally, the purging cycle lasts 10 times longer than the gassing cycle.

- *SO₂ hardened epoxy/acrylic (free radical curing).* As for gassing and purging, collection and treatment are described in the SO₂ hardened furan resins section. The best gassing conditions for achieving cores with good characteristics require:
 - the sand to be dry before use;
 - the blowing or shooting air to be dried too;
 - the concentration of sulphur dioxide in CO₂ or nitrogen to be from 5 % to 100 %, depending on the resin used (minimal for acrylic, maximal for epoxy/acrylic);
 - the purging cycle to last 10 times longer than the gassing cycle.

Achieved environmental benefits

Reduction of consumption of resins and of associated emissions.

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

- Reduction of resins consumption and associated emissions.
- Legal requirements.

Example plants

Widely used.

Reference literature

[100, TWG 2002], [120, TWG 2003]

3.2.1.4.3.8 Use of alternative moulding/core-making processes

Description

Alternative moulding/core-making processes using no or a reduced amount of binders include:

- lost foam casting process;
- ceramic shell moulding;
- vacuum moulding.

The Lost Foam casting technique is described in Section 3.2.1.4.3.9 and additional information on the post-combustion of off-gases from Lost Foam casting may be found in Section 3.2.1.11.2.1.

More information on the ceramic shell moulding technique is available in Section 3.2.1.4.3.10. Vacuum moulding is described in Section 3.2.1.4.3.11.

3.2.1.4.3.9 Lost Foam casting

Description

The Lost Foam casting process starts with the 3D-CAD design and production of a precision moulded foam pattern, made from expanded polystyrene (EPS) or PMMA, produced by automated injection moulding machines. The foam patterns of the parts to be cast are then assembled together into clusters. The clusters are subsequently invested in unbonded sand. Upon pouring, the molten metal causes the pyrolysis of the expanded polystyrene and fills the emptied space.

Technical description

The general principles of Lost Foam casting have been described in Section 2.2.5.9.1. Due to the absence of binders, the technique produces a reduced amount of solid waste and emissions compared to sand casting methods.

The technique allows the production of pieces with tighter tolerances, less feeder and riser channels and better as-cast features. This all results in less machining and clean-up time.

Lost foam foundries include a foam workshop, a melting shop and a casting shop. They do not have an extensive core-making shop and finishing shop. The foam shop involves foaming machines, steam generators and coolers and ambient air dryers.

The Lost Foam models are made of polystyrene (EPS) or PMMA, with small amounts of pentane, glue and a mineral coating. Since both EPS and pentane are pure hydrocarbons, organic carbons are formed upon pyrolysis of the model. In order to minimise emissions of the organic decomposition products of EPS, post combustion of the off-gases is performed.

The technique uses unbonded sand, which results in no binder-related emissions upon pouring and shake-out and which may be internally re-used without major treatment. EPS pyrolysis results in a slow build-up of organic material in the sand. This may be prevented by de-dusting and partial renewal of the circulating sand. A 5 % renewal is sufficient to maintain sand quality. The evacuated sand may be thermally regenerated for internal re-use.

Achieved environmental benefits

Since unbonded sand is used, the technique shows no binder-related emissions upon pouring. However pyrolysis of the EPS or PMMA results in organic decomposition products, which necessitate post combustion.

The use of energy in the Lost Foam process is significantly lower than in conventional casting methods. This is mainly due to the reduced energy uses for post casting operations, melting and sand preparation. The production of cores for conventional moulding methods is relatively more energy intensive than the production of the foamed model.

A foundry located in France which participated in the SF BREF data collection (Stellantis aluminium foundry, FR115) is producing raw cylinder heads using both the conventional gravity casting process and the lost foam process. Since this foundry is operating both types of production processes, the environmental benefits of using the lost foam casting process compared to the more classical gravity casting process were clearly identified. The following benefits were obtained (when using the lost foam casting compared to the gravity casting process) [230, Desmots 2020]:

- *Dust*: about 20 % reduction in dust emissions.
- *TVOC*: 70 % reduction in TVOC emissions, but there is a need to install thermal oxidation to treat the off-gases generated during pouring.
- *Formaldehyde*: 25 % reduction in formaldehyde emissions.
- *Water consumption*: 50 % reduction in water use.
- *Residues generation*: in lost foam casting, no aluminium chips are generated in finishing, which is not the case in the gravity casting process where chips need to be recycled.
- *Increased yield*: the ratio of good casting to the total liquid metal (operational material efficiency) is 66 % in lost foam casting compared to 51 % in gravity casting.
- *Chemicals use*: no chemicals with a hazard statement are used and no pre-machining lubricants are required in the lost foam process.

Environmental performance and operational data

This technique applies to the serial production of small and medium sized products in ferrous and non-ferrous metal. Maximum casting sizes are 1 000 x 1 000 x 550 mm. The technique finds most of its implementation in aluminium foundries and has a 2 % share of aluminium casting.

The technique results in lower residue production compared to a sand foundry of equal capacity. Flue-gases need more intensive cleaning (post-combustion) and (after cleaning) result in higher organic compound (BTEX, formaldehyde) stack emissions.

Comparative consumption levels for the production of a comparable compressor casing using sand casting and Lost Foam casting are given in Table 3.16. This shows the higher amount of return material in the melt and the lower weight of the casting. For the Lost Foam method, the total amount of moulding sand is greatly increased, while no cores are used.

Table 3.16: Operational data for the production of a similar cast iron compressor casing, using various methods

Input material	Green sand	Chemically bonded sand	Lost Foam
Cast iron	98.0	98.0	96.1
Foundry returns	30.0	30.0	38.1
Weight casting	68.0	68.0	58.0
Moulding-sand	256.8	233.0	1101.4
Core sand	122.0	150.7	n.a.

Input material	Green sand	Chemically bonded sand	Lost Foam
Weight foam model + feeder	n.a.	n.a.	0.212
All data in kg n.a: not applicable Source: [44, de Wilde et al. 1999]			

Emissions data (e.g. dust, TVOC, benzene and formaldehyde) including relevant abatement techniques for aluminium and cast iron foundries that have implemented the lost foam casting process are summarised in Section 2.3.2.10.1.

Cross-media effects

The technique represents a reduction in energy consumption and a decrease in mould making and casting finishing operations (see Environmental performance above). The off-gases show increased values of BTEX and formaldehyde, but emissions only occur during pouring and they can be more easily captured and treated (see Section 3.2.1.11.2.1).

Technical considerations relevant to applicability

Applicability of the Lost Foam casting process to existing plants may be restricted due to the required infrastructure modifications.

Since the technique implies a basic change in the mould making procedure and infrastructure, it applies primarily to new installations. Application in existing foundries requires a conversion of the foundry process with regard to the moulding, pouring and finishing operations and a review of these stages for each of the castings produced. To introduce Lost Foam for a given casting requires funds, manpower and the necessary time and flexibility, as well as the co-operation of the customer.

Economics

Economic data for an aluminium Lost Foam installation are given in Table 3.17. Investment costs include equipment, installation, start-up and training.

Table 3.17: Economic data for an aluminium Lost Foam foundry

Investment costs	Description	EUR
Model making equipment	Model making machine Steam generator Coating installation	1 300 000
Casting equipment	Automatic casting machine	2 540 000
Off-gas cleaning	Dry dedusting Thermal regenerative treatment	608 000
Sand preparation	Sieving, cooling, transport	160 000
<i>Total</i>	<i>Investment, installation, start-up, training</i>	<i>4 608 000</i>
Operational cost		EUR/tonne good casting
Consumption	EPS-granules, glue, coating, steam, combustibles	202
Foundry details: aluminium castings, 5 500 tonne/y production good castings, 6 864 tonne/y production molten metal, 1997 data. Source: [35, Spillner, A. 1997]		

The aluminium foundry Stellantis (FR115) was able to carry out a very detailed economic analysis for the implementation of the lost foam casting process in comparison to a more conventional gravity die casting process given that both production routes are employed at this plant. The results are depicted in Figure 3.20. This study shows that for the production of aluminium raw cylinder head castings, the use of the lost foam casting process significantly reduces the overall investment costs (e.g. -18 % for the total investment cost) and the plant footprint (i.e. -50 % of surface area required compared to gravity casting) [230, Desmonts 2020].

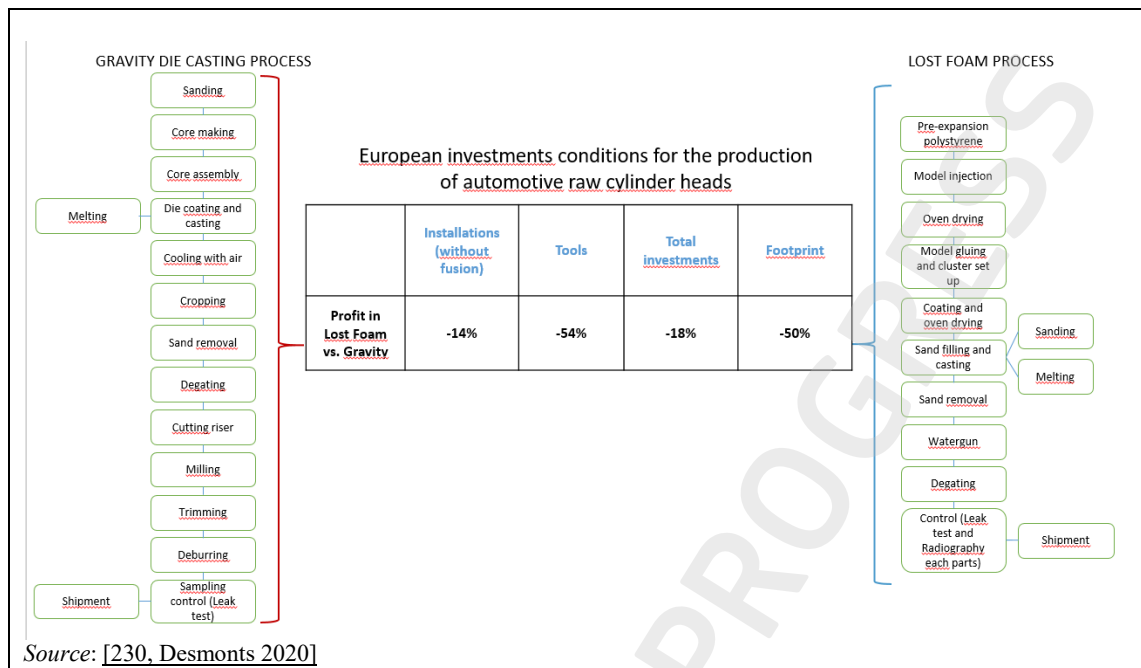


Figure 3.20: Economic comparison of the lost foam casting process versus the gravity casting process for production of aluminium cylinder head castings

Driving force for implementation

- To reduce wastes from sand casting and to reduce energy consumption.
- Legal requirements.

Example plants

Plants FR115, DE078, IT129 and IT130.

Reference literature

Cast iron: [44, de Wilde et al. 1999]

Aluminium: [35, Spillner, A. 1997], [49, Inasmet and CTIF 2002], [230, Desmonts 2020], [169, TWG 2021]

3.2.1.4.3.10 Ceramic shell moulding

Description

A polystyrene model is covered with a thin ceramic shell made of ethyl silicate and refractory sand. The shell is hardened using ammonia and sintered burning away the polystyrene model. The metal is then poured into the shell.

Technical description

This kind of ceramic shell moulding is a patented process (Replicast®) in which a polystyrene model is covered with a ceramic shell (2-3 mm thickness), based on ethyl silicate and refractory sand. The shell is hardened using ammonia and sintered at 1 000 °C. The sintering cures the shell and burns away the polystyrene model. The metal is then poured into the shell.

The sintering furnace is equipped with post-combustion to reduce emissions.

The technique allows a casting design with no parting lines, cores and draft angles and reduced feed metal. This reduces the need for finishing and machining operations.

Achieved environmental benefits

The technique results in a minimisation of dust emissions from moulding and finishing, as compared to sand moulding. The emissions of VOC are eliminated as no gas is emitted for the inert ceramic mould. Additionally the amount of waste (dust, metal) is reduced. The reduction of feeder systems results in a higher yield of castings per melt.

Environmental performance and operational data

Operational data from the owner of the technique are reported in Table 3.18 for the casting of valves, as compared to sand casting.

Table 3.18: Relative weight reduction for ceramic shell casting of valves as compared to sand casting

Property	Relative weight reduction (%)
Finished weight of castings	20 – 26
Feed metal	24 – 60
Poured metal	24 – 50
<i>Source: [117, Castings Technology International 2003]</i>	

Cross-media effects

None.

Technical considerations relevant to applicability

Applicability of ceramic shell moulding may be restricted by product specifications (e.g. high surface finish).

The technique applies for the fabrication of castings which need a high surface finish, in low-carbon alloys such as ultra low carbon stainless steel and nickel-based alloys with a finished weight of up to 550 kg. This patented type of ceramic shell process may only be used in accordance with the terms and conditions of the licence granted.

Driving force for implementation

Regulation of VOC emissions and high disposal costs for residual wastes.

Legal requirements.

Example plants

- CMS srl, Urbisaglia (IT): 2 automated shelling lines, producing steel valves up to 150 kg finished weight.
- Saint-Gobain SEVA, Chalons-sur-Saone (FR): steel and super alloy components for glass industry.

Reference literature

[38, Vito 2001], [117, Castings Technology International 2003]

3.2.1.4.3.11 Vacuum moulding

Information on the vacuum moulding process is available in Section 2.2.5.6.

Applicability

Applicability of vacuum moulding may be restricted in the case of large moulding boxes (e.g. above 1.5 m x 1.5 m).

3.2.1.4.4 Sand reconditioning and reclamation

3.2.1.4.4.1 Optimised reconditioning of green sand (breaking, separation, cooling)

Description

The green sand reconditioning process is controlled by a computer system to optimise raw material consumption and green sand reuse, e.g. cooling (evaporative or fluidised bed), addition of binders and additives, moistening, mixing, quality control.

Technical description

One of the major advantages in using green sand moulding is that the sand from the moulds can be reconditioned after pouring for multiple re-use. The addition of a minimum percentage of new sand is performed in order to maintain the quality of the moulding-sand. The amount of new sand added is determined by the input of core sand and the losses in the process. For coreless moulding, the average sand renewal ratio is 2 – 5 %. In casting processes using cores, sand renewal occurs through the introduction of the core sand into the loop. In any case, surplus sand is removed from the sand circuit after the shake-out screen or from the storage silos. The general treatment is depicted in Figure 2.31. This internal recirculation of green sand with minimal treatment is referred to as primary regeneration. This regeneration basically has three aims: (1) to break the sand into its original grain size or small particles, (2) to remove the fines, and (3) to cool the sand before blending with new sand.

Various techniques are applied for the breaking and separation:

- *Vibration*: The vibratory grid, or screen equipment, is the most widely used technique for primary reclamation purposes. The sieved sand is removed for subsequent treatment, e.g. for cooling, size classification, and thermal reclamation, and the residual material is collected for disposal.
- *Drum*: Sand from the knock-out operation is loaded into a rotating drum fitted with both lifting and travelling bars. As the sand travels along the drum, the rotating and lifting action causes the sand particles to grind against each other and break down to individual grains. The sand grains fall through screens at the end of the drum, while oversize and tramp materials are removed for landfill disposal.
- *Shot blast*: The mould and casting is loaded directly into the shot blast machine. The action of the shot blast results in the complete disintegration of the mould and also cleans the surface of the casting. The sand and shot are subsequently separated. However, this technique is not very common.

During cooling of the castings, the sand gets heated-up. In order to reach good sand mixing conditions, the sand needs to be cooled down to 40 – 45 °C. Evaporative coolers are used with turbulent and fluidised beds, as well as heat-exchangers. If shake-out is done using the vibrating transporters or revolving drums, the cooling can occur at the same time.

If a fluidised bed cooler is used, the drying air may be heated using gas or electricity. The average treatment time in the bed is 10 minutes. In general, the sand enters the fluidised bed with a humidity of 2 – 3 % and a temperature of 250 – 300 °C. Temperature and humidity control may be performed before the fluidised bed cooler with a subsequent addition of controlled amounts of water. This allows minimisation of the amount of fines that are removed during the fluidised bed drying. The fines contain bentonite that may be re-activated. The level of humidity of the return sand needs to be kept between 2 % and 2.2 % at 35 °C. Consequently, during storage, the bentonite contained in the cooled and wet sand starts to activate and, during the mixing, the water and bentonite that need to be added are reduced, as is the cycle time.

A good homogenisation of the sand allows a constant sand quality and better and easier sand preparation. Homogenisation systems consist of the use of a few small silos instead of one big one, or in the re-circulation of the sand in the silo.

In systems using chemically bonded cores, the mixing of the core sand may have a negative effect on the sand quality, depending on the binder type and the amount of core sand mixed. The negative effects are more significant with acidic and alkaline cores, than compared to neutral systems (SO₂-epoxy, PUR-cold-box). During shake-out, core sand and moulding sand will inevitably get mixed. Uncured cores and non-broken cores, however, may be left out or taken out of the sand before feeding back to the primary regeneration.

Achieved environmental benefits

Reduced usage of primary materials (sand and bentonite), reduced amount of material for disposal.

Environmental performance and operational data

While the level of new sand addition is governed by a number of factors, the usual range is 10-20 % of the poured metal weight. However, it is more convenient to consider new sand additions as a percentage of sand throughput. For most foundry processes, a 5 % addition is considered sufficient, but many foundries work at lower rates.

For a green sand monosystem, regeneration ratios of 98 % may be achieved. Systems with a high degree of incompatible cores, may achieve a regeneration ratio of 90 – 94 %.

Cross-media effects

Sand regeneration uses electricity, therefore it increases the overall electric energy consumption of the installation. Since mechanical techniques are mainly applied, this increase is low.

Sand cooling and the separation of fines leads to dust-laden exhaust gas. The exhaust needs to be filtered to prevent dust emissions. The collected dust is sent to disposal or reused (see Section 3.2.1.4.4.14).

Technical considerations relevant to applicability

Generally applicable. This technique is applicable to all green sand foundries, in new and existing installations.

Economics

The potential cost benefit of reclamation for a foundry that does not currently reclaim its sand is summarised in Table 3.19.

Table 3.19: Cost benefits from primary reclamation

Description	Cost (EUR/tonne of sand)
Average price of silica sand	32.64
Average cost of waste sand disposal	14.56
Total cost of sand purchase and disposal	47.2
Estimated depreciation cost to recoup equipment expenditure in one year	18.24
Average operating cost	7.76
Anticipated cost saving in first year	21.2
Anticipated cost saving in subsequent years	39.44
(UK estimation 1995)	

The investment for a mixer, dosing unit and process control unit is in the range of EUR 0.05 – 1 million. The investment for the size reduction of core-breaks is EUR 0.1 million, although this is only applied if the size reduction cannot be done in an available mechanical or pneumatic regeneration unit. Operational costs (on a yearly basis) can be estimated at 5 – 10 % of the investment cost.

Driving force for implementation

- Many foundry operators state the reduction in costs as the sole reason for starting various sand reclamation programmes. Regulations encourage a reduction in the amount of dumped material, through an increase in disposal costs.
- Legal requirements.
- Local conditions.

Example plants

Primary reclamation is used by virtually all green sand foundries, though the degree of sophistication of the reclamation plant varies widely; from a simple manual operation to one fully automated with computer-controlled equipment.

Reference literature

[29, ETSU 1995], [30, ETSU 1995], [37, FEF 1999], [38, Vito 2001], [42, IHOBE 1998], [47, EU Thematic Network Foundry Wastes 2001], [49, Inasmet and CTIF 2002], [169, TWG 2021]

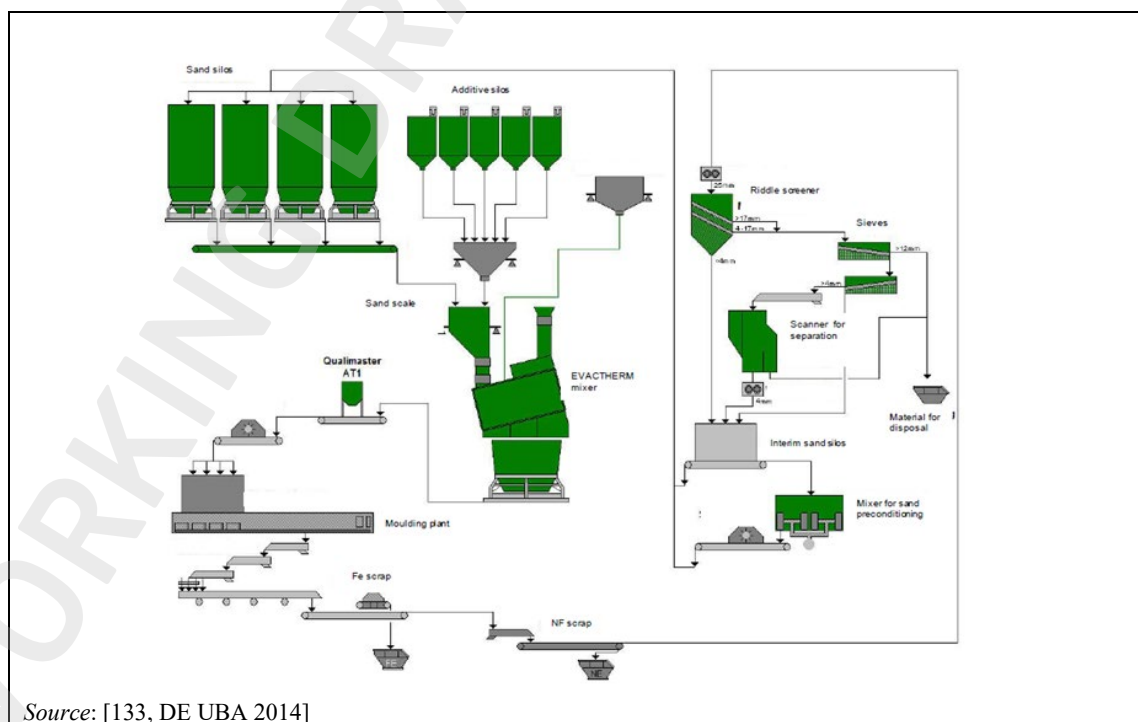
3.2.1.4.4.2 Low-waste green sand reconditioning

Description

Green sand reconditioning in aluminium foundries is carried out using a scanner for identifying impurities in green sand based on brightness/colour. These impurities are separated from green sand using an air blast pulse.

Technical description

In foundries, process-related factors cause an accumulation of impurities in the moulding material in sand casting. In standard sand regeneration systems these impurities (core sand, insulating material, metal scrap) cannot be separated sufficiently from the moulding material. Significant agglomeration of impurities creates a necessity to dispose of comparatively high amounts of moulding material and refresh the system with new silica sand and clay binder. A new sand regeneration technique achieves a more complete separation of impurities from the moulding material (Figure 3.21).



Source: [133, DE UBA 2014]

Figure 3.21: New green sand regeneration plant at an aluminium foundry (key components in green)

Key components are mixers, silos, riddle screeners and a scanner for separating impurities from green sand based on the brightness/colour of the material (Figure 3.22).

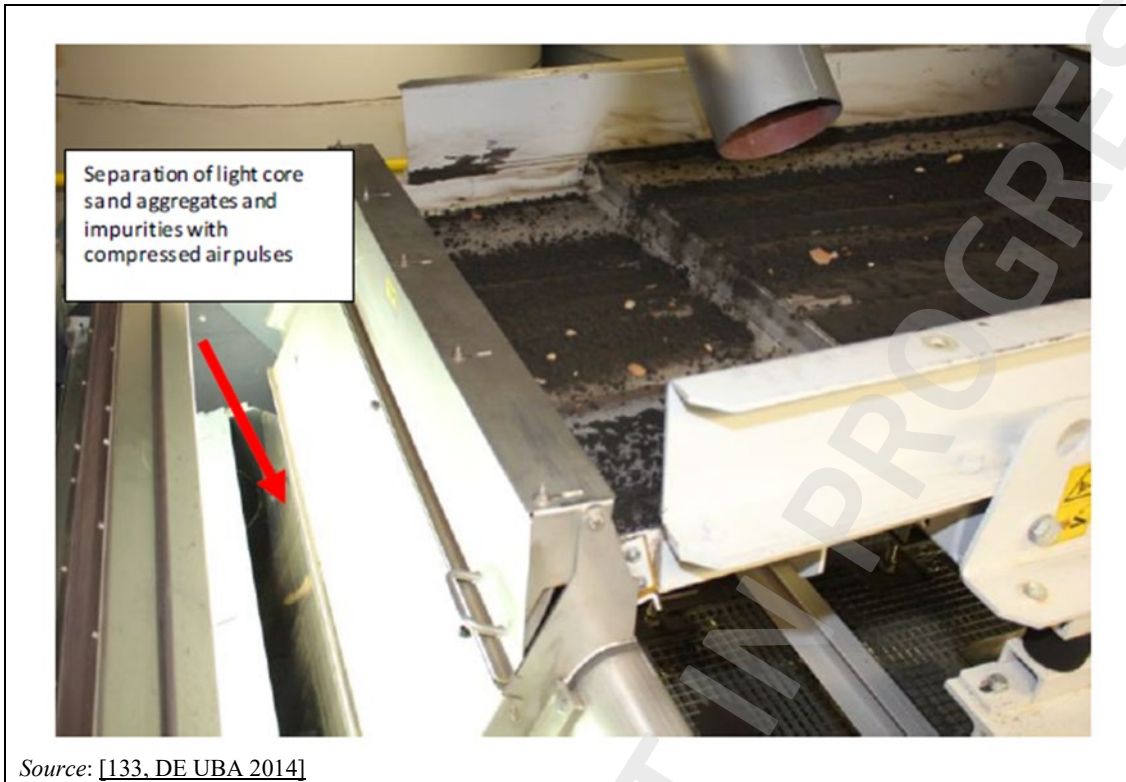


Figure 3.22: Device for optical detection and separation of impurities from green sand

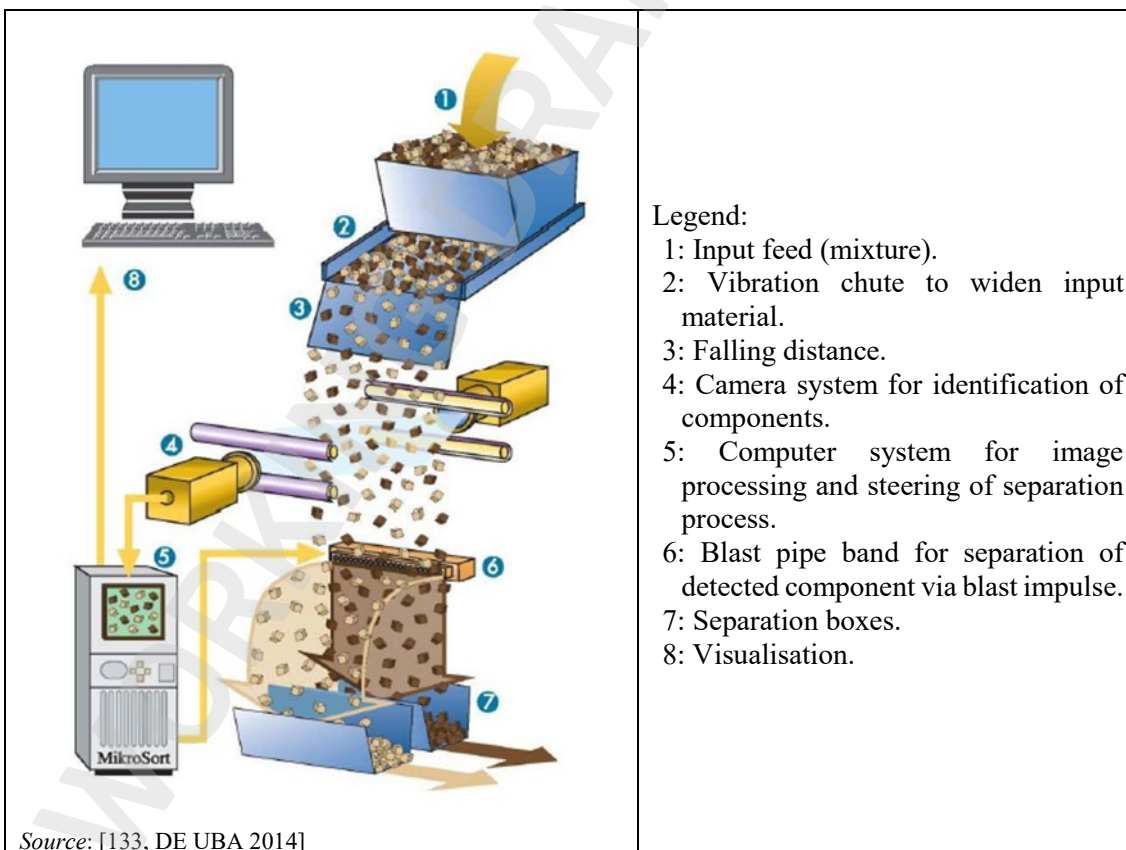


Figure 3.23: Process scheme of the device for optical detection and separation of impurities

Organic bonded sands are kept separately from inorganic bonded sands.

Achieved environmental benefits

- Minimisation of waste sand.
- Reduction of raw material consumption (resource conservation for silica sand and bonding clay).
- Significant reduction of heavy-duty transport.

Table 3.20: Reduction potential using low-waste green sand reconditioning

Parameter	Potential in case of full capacity operation for the example plant
Reduction of used sand for disposal	12 650 t/y
Reduction of raw material consumption: silica sand	13 800 t/y
Reduction of raw material consumption: clay binder	92 t/y
Reduction of CO ₂ emissions due to reduction of transport	140 t/y
<i>Source: [133, DE UBA 2014]</i>	

The following operational data were reported.

Table 3.21: Operational data (in case of full capacity operation for the example plant)

Maximum licensed operating hours:	8 760 h	
Operating hours:	6 570 h	
Capacity sand preparation plant:	70 t/h	460 000 t/y
Without new technique:		
- amount of new sand:	ca. 3 %	13 800 t/y
- amount of disposed sand:	ca. 3 %	13 800 t/y
With new technique:		
- amount of new sand:	0.25 %	1 150 t/y
- amount of recycling sand (no disposal):	0.25 %	1 150 t/y
Reduction of new sand consumption:	12 650 t/y	
Reduction of disposal of contaminated sand:	13 800 t/y	
<i>Source: [133, DE UBA 2014]</i>		

Environmental performance and operational data

See Achieved environmental benefits above.

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable.

Economics

The following economic data were reported.

Table 3.22: Economic aspects of green sand preparation

Total investment:			4.44 millions €
Cost reduction per year: ca.			1.18 millions €:
- New sand costs	12 650 t	45 €/t	569 250 €/y
- Disposal sand costs:	13 800 t	43 €/t	593 400 €/y
- Total sand costs:			1 162 650 €/y*
- Bentonite costs:	92 t	228 €/t	21 000 €*
<i>Source: [133, DE UBA 2014]</i>			

Driving force for implementation

- In addition to resource efficiency improvement, technical advantages were also achieved by means of the new sand preparation system, which are of great importance in foundry production:
 - significant reduction in the consumption of bentonite binders and water in the moulding material;
 - fine-grained moulding sand composition achieved, resulting in smooth surfaces in the castings.
- Reduction of surface defects from impurities accumulated in the moulding material.

Example plants

Ohm&Häner Metallwerk GmbH & Co KG, Drolshagen, DE.

Reference literature

[133, DE UBA 2014]

3.2.1.4.4.3 Preparation of clay-bonded sand by vacuum mixing and cooling

Description

Mixing and cooling processes are combined into a single process step by operating the sand mixer under reduced pressure, which results in cooling by the controlled vaporisation of the water.

Technical description

The mixing and cooling process are combined into a single process step. This is achieved by operating the sand mixer under reduced pressure, which results in cooling by the controlled vaporisation of the water. The special mixer needs to be hermetically closed. It has a pressure casing and is connected to a vacuum system. The layout of the system is given in the following figure.

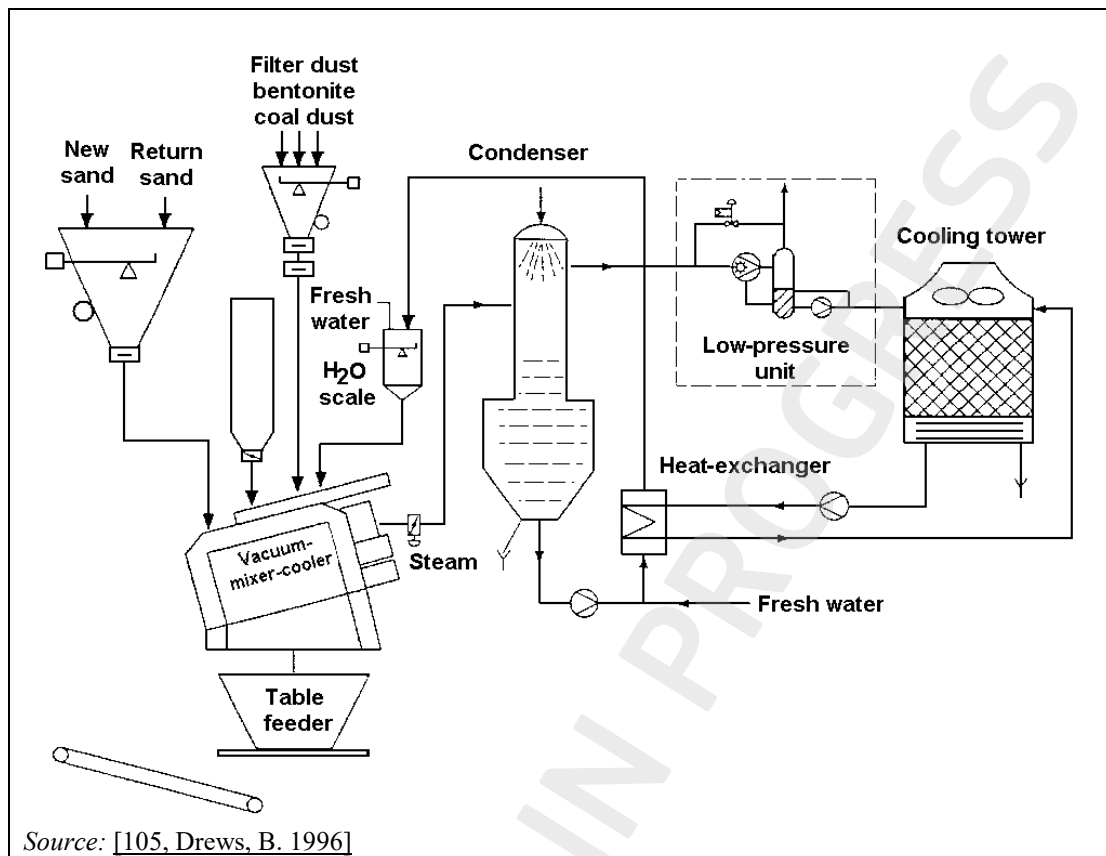


Figure 3.24: Moulding-sand preparation plant with vacuum mixer-cooler

As compared to a normal mixing plant (Figure 2.31), this technique does not require a separate cooler and associated equipment. The vacuum plant therefore is a more compact size. Since the total airflow is reduced, the vacuum installation has a smaller central dust extraction filter. The size and energy consumption of the filter are 50 % of that of a conventional plant. The reduction of the airflow, results in a reduced removal of active bentonite and thus in an overall reduction of additive consumption. Due to the enclosed operation, the technique is not affected by outside climatic conditions.

The use of steam in the absence of air leads to a quick activation of the bentonite, resulting in a very quick attainment of the optimal compressive strength for the bonded sand.

Water is added in two separate stages:

- water to moisten the return sand to the prepared sand moisture content;
- water to cool the sand by vaporisation to the required temperature of 38 – 40 °C.

The disadvantage of the system is the operation and management of the vacuum system. The process also affects the sand technical properties (e.g. compressive and tensile strength, permeability), which diminish after 72 h ('the 72 h effect'). This can be prevented by re-mixing for about 90 s.

Achieved environmental benefits

Reduction of the total airflow results in a reduced off-gas volume and amount of dust for disposal, as well as a reduced consumption of binder as compared to conventional cooling and mixing plants (although this also depends on the efficiency of the regeneration plant). Additionally, the system uses less energy.

Environmental performance and operational data

See technical description above.

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable.

Economics

The commercial limits of application appear to be processes where sand cooling is required and which have a capacity of > 60 tonnes of sand per hour.

Driving force for implementation

- Reduction of dust for disposal and minimisation of additives consumption. Limitation of space.
- Legal requirements.
- Local conditions.

Example plants

In Japan, a vacuum mixing and cooling plant has been in operation since 1993, with a prepared sand throughput of 100 m³/h.

Various installations are also currently running in Italy, France, Germany and England.

Reference literature

[49, Inasmet and CTIF 2002], [105, Drews, B. 1996], [112, Gerl, S. 2003]

3.2.1.4.4.4 Mechanical reclamation of cold-setting sand

Description

Mechanical techniques (e.g. breaking of lumps, segregation of sand fractions) using crushers or mills are used to reclaim cold-setting sand.

Technical description

Simple mechanical techniques are used for the reclamation of cold setting monosands (e.g. furan sand) and uncured core sand. These techniques include the breaking of lumps, segregation of the sand grains and cleaning by intergranular friction, with consequent dedusting and cooling down to operational temperature. Various types of crushers and mills are used, e.g. impact crusher, jaw crusher, ball mill.

Achieved environmental benefits

A reduction of the amount of sand for disposal and of the consumption of new primary sand.

Environmental performance and operational data

For furan cold-setting monosands, reclamation ratios of more than 90 % are reported. The technique can be used for all cold-setting sand, excluding silicate sand. The reclaimed sand can be reused in the same moulding cycle, with small additions of new sand to level off quality losses.

Cross-media effects

The reclamation of sand requires additional energy and causes additional dust emissions and residual dust for disposal.

Technical considerations relevant to applicability

May not be applicable to silicate-bonded sand.

Economics

No information provided.

Driving force for implementation

- Avoidance of costs associated with the disposal of residues.
- Avoidance of need to purchase new sand.
- Legal requirements.
- Local conditions.

Example plants

Simple mechanical reclamation of cold-setting sand is applied in many foundries around Europe, and reported in the SF data collection by the following plants: FI102 and PT141

Reference literature

[57, Umweltbundesamt 2002], [100, TWG 2002], [169, TWG 2021]

3.2.1.4.4.5 Cold mechanical reclamation of clay-bonded or chemically bonded sand using a grinding wheel

Description

Use of a rotating grinding wheel to remove clay layers and chemical binders from used sand grains.

Technical description

This is a widely applied commercial grinding system (see Figure 3.25). The system was originally developed to reclaim mixed bentonite-organic sands. In this system, a horizontally rotating grinding wheel is used to remove the hard oolitic bentonite layer from the sand. The grinding can also remove chemical binders from sand grains. Around the grinding wheel is a slowly rotating paddle wheel, which continuously moves the sand onto the grinding wheel. Above this, a dedusting unit extracts the dusts and the fines. To be fit for processing, the sand must be dry. A pre-drying step, using a fluid bed or other dryer, is required to bring the moisture content down to below 0.2 %.

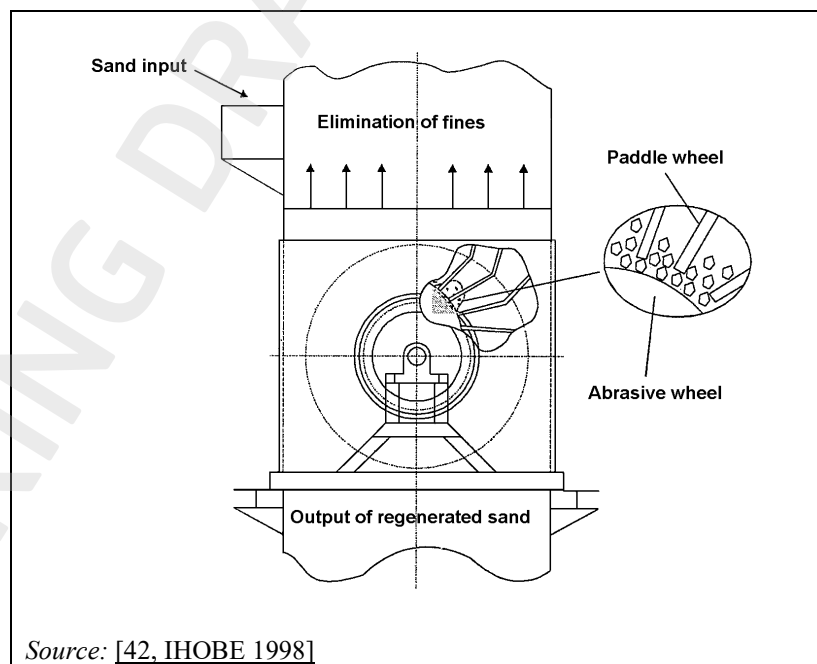


Figure 3.25: Cold mechanical regeneration using grinding

The off-gas stream of the regenerator is dedusted using a cyclone and a bag filter. The filter dust contains residual active bentonite and coal dust. It may be recirculated into the core-making,

thereby allowing a reduction in the use of lustrous carbon. Furthermore, the moulds demonstrate better technical quality (wet tensile strength, flowability), due to the remaining bentonite content, which furthermore leads to a reduction in the amount of scrap moulds and a reduction in finning on the castings.

Achieved environmental benefits

- A reduction of the amount of sand for disposal and of the consumption of new primary sand.
- A reduction in the consumption of lustrous carbon, in the case of green sand.
- An increase in moulding sand properties, resulting in a reduction in the number of scrap moulds and in the number of rejects in finished castings.

Environmental performance and operational data

For clay-bonded sand, the maximum reclamation rate is 65 – 75 %. This corresponds to the quartz grain content of the material. For a chemically bonded sand, the amount of recyclable quartz sand is 90 – 95 %.

The total sand circuit flow and the need for new sand depends on the amount of cores (and core sand) used. Therefore, data on the sand circuit are very process-specific. Figure 3.26 gives data for a plant in the Netherlands.

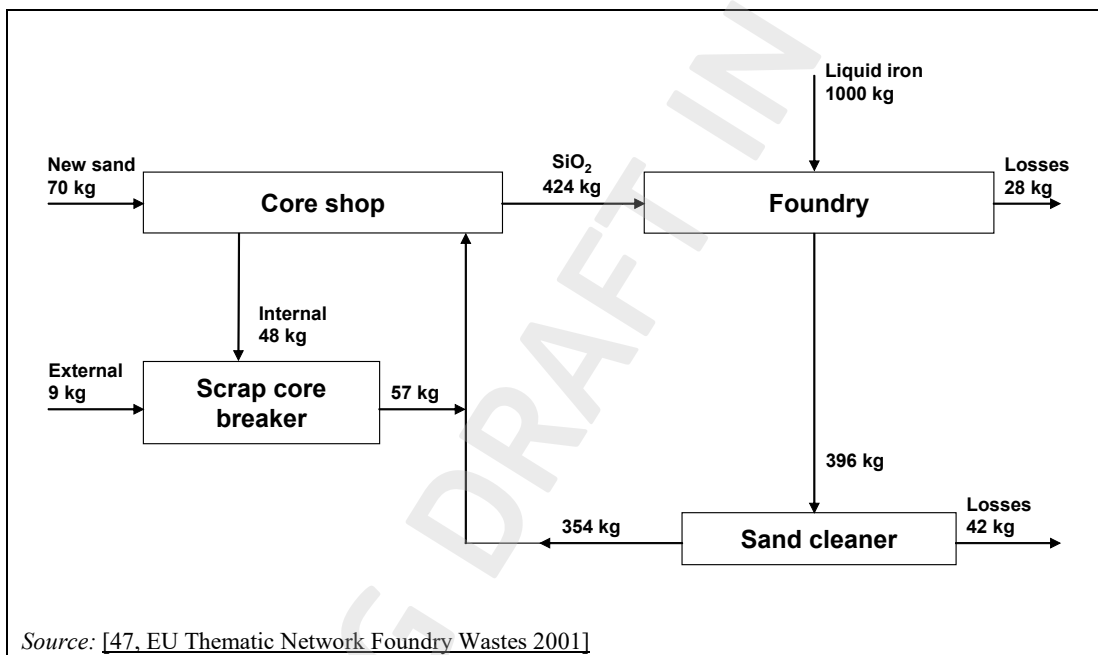


Figure 3.26: Operational data on the sand circuit of a Dutch green sand foundry

In general, waste green sand consists of about 80 % quartz sand grains and about 20 % fines (bentonite, coal dust, etc.). Out of 100 % waste sand, about 70 % is transferred back to the core-making as reclaimed sand. The degree of efficiency with regard to quartz is about 88 %.

The filter dust contains approximately 40 % active bentonite, which has a loss of ignition (LOI) of 17 % and contains 43 % fines. Reuse of the dust in the sand plant results in a reduced requirement for lustrous carbon by up to 30 %. Results of the improved sand quality at the example foundry show the amount of scrap moulds were practically halved.

The cyclone dust (20 % of reclaimed green sand weight) contains 25 – 30 % bentonite and high levels of organics, but its chemical composition falls outside the required specification to allow its re-use as a secondary construction material. In the Netherlands, a specific application in cover layers on disposal sites is allowed. In other regions, this fraction will need disposal of. However, legislation limiting the organic content of material for disposal, may limit the disposal options.

The grinding of the sand causes accelerated wearing of the sand grains. This and the recirculation of the filter dust cause shifts in the grain size distribution of the sand. The overall sand composition therefore needs good control and follow-up.

Cold mechanical reclamation is mainly applied for removing bentonite layers from green sand and for removing chemical binders in no-bake systems. The grinding technique is the most widely applied cold mechanical treatment. Vibration and impact systems are also used for chemically bonded sands but produce sand of only low or average quality. These techniques are more appropriate for the conventional sand loop (primary reclamation). The secondary reclamation of green sand has limited implementation.

Regarding clay-bonded sand, foundries use this technique when producing automotive parts by using green sand moulds with urethane cold-box cores. Because of the shape of the castings, at the shake-out stage they are able to select a mixture of used sand with a great amount of core sand and a small amount of green sand. This kind of used sand regenerated with a grinding wheel can be used for core making.

Regarding chemically bonded sand, mechanical reclamation is a typical process but there are several kinds of alternative reclamation techniques in use.

Cross-media effects

The reclamation of sand requires additional energy and causes additional dust emissions and residual dust for disposal. However, the use of reclaimed sand in the moulding process allows a reduction in the amounts of lustrous carbon used.

Technical considerations relevant to applicability

Generally applicable.

Economics

The investment cost for a 50-tonne/day unit, including drying, cooling, reclamation unit, cyclone and bag filter is around EUR 1 135 000. Data from Germany (1996) state an investment cost of EUR 600 000 for a 1.5 tonne/h unit.

The consumption levels are as follows (based on yearly average figures):

Electricity:	39	kWh/tonne;
Natural gas:	3	Nm ³ /tonne (depending on the moist input of the sand);
Compressed air:	36	Nm ³ /tonne;
Wear parts:	1.18	EUR/tonne;
Manning level:	0 %;	
Maintenance:	routine.	

Cost curves for the mechanical reclamation of organic bounded sand are given in Figure 3.27. Fixed costs vary according to the total capacity and investment. Variable costs can be up to around EUR 11/tonne, although the actual costs depend on the specific installation and local conditions. The total costs (fixed plus variables) range from EUR 12-40/tonne of reclaimed sand, depending on the size and type of equipment.

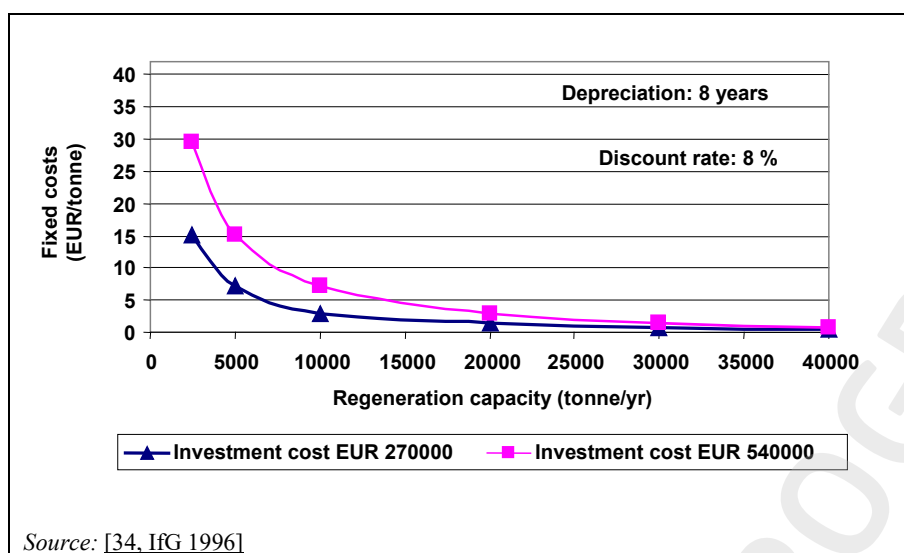


Figure 3.27: Fixed costs in euro per tonne of regenerated sand, for the mechanical reclamation of sand with cold-setting binders

Driving force for implementation

- High disposal fees aiming to reduce the amount of residues for disposal.
- Legal requirements.
- Local conditions.

Example plants

- De Globe, Weert, the Netherlands, 60 tonnes per day plant using two lines, in operation since 1995
- Eisenwerk Brühl, Brühl; D (1.5 tonne/h), 1999
- Giesserei Fritz Winter GmbH & Co KG, Stadtallendorf, D (9.5 tonne/h)
- Mercedes-Benz AG, Mannheim, D (9 tonne/h)
- Reported in the SF data collection by plants: DE054, DE055, DE067, DE068, DE073, DE074, IT1125, IT126, IT128, IT130, IT131, IT132, IT134, IT157, PL135 and PT140.

Reference literature

[34, IfG 1996], [38, Vito 2001], [42, IHOBE 1998], [45, De Globe B.V. 1999], [47, EU Thematic Network Foundry Wastes 2001], [55, Gemco 1999], [169, TWG 2021]

3.2.1.4.4.6 Cold mechanical reclamation of sand using an impact drum

Description

Use of an impact drum with a spinning internal axis, equipped with small blades, for abrasive cleaning of sand grains. When applied on a mixture of bentonite and chemically bonded sand, a preliminary magnetic separation is carried out to remove parts with magnetic properties from the green sand.

Technical description

This mechanical regeneration technique is based on intergranular grinding of the sand and gives the best results for chemically bonded monosand. The sand is fed into a drum with a spinning internal axis, equipped with small blades. Sand grains are impacted against the drum wall and against each other. This impact produces a mechanical abrasive cleaning action. Fines are removed with the exhaust gas. The impact drum operates in a batch wise regime. The installation of two units allows continuous operation.

When applied on a mixed bentonite-organic sand, the regeneration is preceded by a magnetic separator, to remove green sand. Due to the presence of unreacted bentonite, the green sand shows

a very weak magnetism, which allows a magnetic separation to be carried out. The regeneration system allows the introduction of a limited amount (15 %) of uncured core sand (core breaks from production). The combination of magnetic separation and impact drum cleaning allows an optimised chemically bonded sand regeneration from a mixed sand flow, with re-use of the regenerated sand in core-making.

Achieved environmental benefits

Internal re-use of core sand, therefore limiting the amount of material for disposal and the need for raw materials.

Environmental performance and operational data

The regeneration drum has a batch wise regime, with a 20 minute treatment time for each 1.5 tonne sand charge. The energy consumption of the full installation (including magnetic separation, exhaust treatment, sand transport) is 55 kWh/tonne of treated sand, of which 35 % may be attributed to sand transport and feeding. The installation uses compressed air at 48 Nm³/tonne sand.

The regenerated sand is of the following quality:

- average grain size: 0.30 – 0.33 mm;
- share of fines: 0.4 – 1 %;
- pH: 8.7;
- loss on ignition: 0.25 – 0.5 %.

Cores made with 100 % regenerated sand have acceptable properties. In practice, 10 – 70 % of regenerated sand is used for new cores, the actual amount depending on the core type.

Dust generation in the installation is 10 % of the regenerator input. This dust is collected using a cyclone (90 %) and a bag filter (10 %).

The combined separation-regeneration technique can be applied for the treatment of mixed green sand and chemically bonded sand. Reclamation is performed on the chemically bonded sand flow and may include uncured core sand. The technique may be applied in new and existing installations.

Cross-media effects

The regeneration of sand requires additional energy, and causes additional dust emissions and residual dust for disposal.

Technical considerations relevant to applicability

Generally applicable.

Economics

Investment costs for a 3 tonne/h unit with one impact drum, magnetic separation, exhaust gas dedusting and transport and a feeding system are EUR 1.3 million. Operational costs for this unit are EUR 10/tonne. These include energy consumption, wear and tear of parts, maintenance and disposal of residues. This represents a net benefit of EUR 37/tonne, compared to the costs of new sand purchase and used sand disposal (both incl. transport) (2002 data).

For a 380 tonne/day unit in France, an operational cost of EUR 15/tonne was quoted. For this plant this represents a net benefit of EUR 18/tonne, compared to the costs of new sand purchase and used sand disposal (both including transport) (2002 data).

Driving force for implementation

- High disposal fees aiming to reduce the amount of residues for disposal.
- Legal requirements.
- Local conditions.

Example plants

This technique is used in the following plants:

- PSA, Sept-Fons (FR): 6 magnetic separators and 2 grinders, working alternatively.
- GF, Leipzig (DE): 2 magnetic separators and 1 grinder.
- Döktas – Turkey: 5 magnetic separators and 2 grinders.
- Reported in the SF data collection by plants: AT013, AT016, BE019, BE022, BE023, CZ024, DE036, DE037, DE060, DE072, ES088, FI103, FR105, IT124 and IT130.

Reference literature

[84, Spitz et al. 2002], [40, Kirst, J. 1999], [57, Umweltbundesamt 2002], [169, TWG 2021]

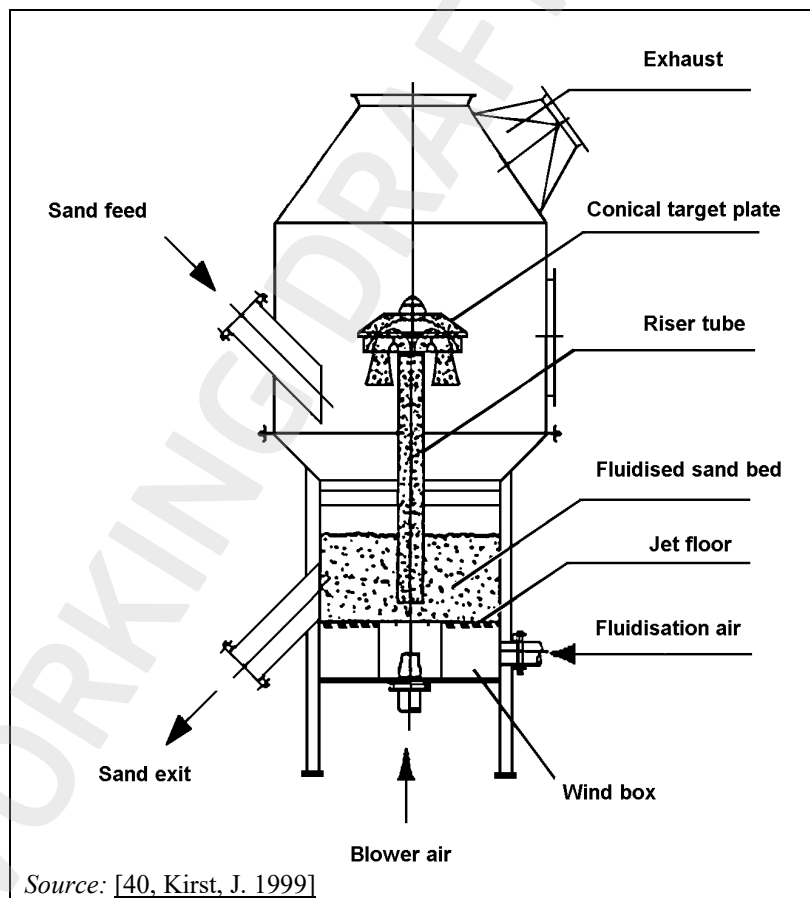
3.2.1.4.4.7 Cold reclamation of sand using a pneumatic system

Description

Removal of binders from the sand grains using abrasion and impact. The kinetic energy is provided by a compressed air stream.

Technical description

In a pneumatic system, binders are removed from the sand grains using abrasion and impact. The kinetic energy is provided by a compressed air stream. This results in a simultaneous dedusting. The advantage of this type of system is that the direction and velocity of the sand can be controlled. Due to the low energetic efficiency of air compression, the energy consumption is higher compared to the purely mechanical treatment. The principle of the reactor is depicted in Figure 3.28.



Source: [40, Kirst, J. 1999]

Figure 3.28: Cold mechanical regeneration using a pneumatic system

The reactor uses a fluidised bed with a central raiser tube. The sand is blown into the tube using compressed air and impacts on either a rubber deflector plate or a conical target plate. From there, the sand falls down again and the cycle starts over again. The cleaning happens through intergranular abrasion, abrasion against the impact plate and through 'pure' impact. The shape of the plate determines the main cleaning mechanism: impact (bell-shape) or abrasion (conus). The generated dust is removed with the airflow over a bag filter. Treatment is performed as a batch system or through a series of coupled pneumatic units. In this case, the cleaned sand is sucked out of the reactor through a deflector below the impact plate.

Achieved environmental benefits

Reduction of the amount of sand for disposal and of the consumption of new primary sand.

Environmental performance and operational data

A waste sand mix of green sand with chemically bound core sand having the following characteristics: 8 – 12 % fines content, 3 – 5 % LOI, < 2 % humidity; produces a regenerate with the following characteristics:

- regenerate yield, based on SiO₂ content of waste sand: 70-80 %;
- ultra fines content (< 0.063 mm): max. 2 % ;
- fines content: < 2 %;
- loss on ignition: < 0.5 %;
- average grain size: unaltered.

The technique uses a modular installation build-up, using 0.8 – 1.2 t/h basic units. The supplier mentions an electric energy consumption of 15 – 20 kWh/t (excluding dedusting equipment). German operational data give an electric energy consumption of 41 kWh/t for a 8 t/h unit and 62 kWh/t for a 0.75 t/h unit. Reported sand regeneration efficiencies based on sand input range from 65 % to 85 %. Spanish data give a total energy consumption of 120 kWh/t of regenerated sand for a 1.2 t/h unit.

The pneumatic system can be used for the reclamation of organic mixed and monosands and mixed sand containing bentonite. It also finds application as a pre- or post-treatment in combined mechanical-thermal-mechanical treatment. Here, the main use is the removal of residual dust from the sand grains and cooling. The regenerated sand from simple mechanical reclamation may be used in mould making (using 100 % reclaimed sand) or mixed with new sand in core-making (using 40 – 60 % regenerated sand).

Furthermore, the technique may be applied for the reclamation of core sand of the CO₂-water glass type from aluminium foundries. This is discussed separately below.

Cross-media effects

The reclamation of sand requires additional energy and causes additional dust emissions and residual dust for disposal.

The general evaluation of internal reclamation versus external re-use and the corresponding cross-media effects are discussed separately below.

Technical considerations relevant to applicability

Generally applicable.

Economics

Investment costs for a single 0.8 – 1.2 tonne/h unit are EUR 330 000. Operational costs are estimated at EUR 22/tonne, which gives a total regeneration cost of EUR 36.5/tonne of sand (1998 data).

Driving force for implementation

- High disposal fees aiming to reduce the amount of residues for disposal.

- Legal requirements.
- Local conditions.

Example plants

This type of equipment is built by various suppliers: e.g. KGT Jet Reclaimer, Künkel-Wagner GmbH Turbo Dry, Kernfest Webac AB. The technique is used in several plants in Western Europe and China. Reported in the SF data collection by plants: AT017, AT018, DE038, DE044, DE056, DE058, DE068, DE069, DE077, ES088, ES095, ES098, FI103, FR104, IT121, IT126, IT128, IT129 and SE153.

Reference literature

[14, CAEF 1997], [34, IfG 1996], [37, FEAF 1999], [38, Vito 2001], [40, Kirst, J. 1999], [42, IHOBE 1998], [169, TWG 2021]

3.2.1.4.4.8 Thermal reclamation of sand

Description

Use of heat to burn binders and contaminants contained in chemically bonded and mixed sand. This is combined with an initial mechanical pretreatment to bring the sand to the correct grain size and remove any metallic contaminant. In the case of mixed sand, the share of chemically bonded sand should be high enough.

Technical description

Thermal reclamation uses heat to combust binders and contaminants. All thermal processes need an initial mechanical step in order to bring the sand to the correct grain size and to screen out any metallic contaminants. This pretreatment may also involve a (partial) abrasion of bentonite and dust removal. The heating of the sand is usually achieved by means of a fluidised bed furnace, operating at temperatures mostly between 700 °C and 800 °C. Rotary kilns or multiple-hearth furnaces are also used. Heat may be provided by gas combustion, electric heaters or by short wave infra-red emitters. The throughput of these systems ranges from 250 kg/h to more than 5 t/h.

The emerging gases are combusted in order to eliminate carbon monoxide and any VOCs that may be present. This may be done in the freeboard of the furnace, if it is large enough, by adding complementary air or by gas-fired afterburners. If the temperature of the combustion gases is not high enough or if the time during which the gases are at a high temperature is not sufficient, a separate afterburning device is added. In all cases, emissions can be considered as insignificant.

The exhaust gases are filtered, mostly by means of fabric filters. Therefore cooling is needed, which may be done using water injection, heat exchange/recovery or by mixing with air naturally entering through openings/slits etc. The cooling may incorporate a preheating of the fluidisation air.

Achieved environmental benefits

Reduction of the amount of sand for disposal and a reduction in the consumption of new primary sand.

Environmental performance and operational data

The sand is usually heated to temperatures of 700 – 850 °C. Theoretically, this requires 200 kWh/t. In practice, energy uses of 150 – 350 kWh/t are reported, depending on the energy recuperation and the calorific value of the sand.

Operational data from three thermal reclamation plants treating various types of sand and of various capacities are given in Table 3.23.

Table 3.23: Operational data of 3 German reference foundries applying thermal sand regeneration

Property	Units	Plant		
		Foundry K	Foundry L	Foundry M
Reference plants		Foundry K	Foundry L	Foundry M
Type of sand		Cold-box core units	Green sand moulding, Cold-box cores	Handforming in furan bonded sand
Regeneration unit supplier		CEC/VAW	Richards	Siempelkamp
Technique		Multiple hearth furnace (500 °C) with sieving and classification	Fluidised bed furnace (780 °C), mechanical size reduction and dedusting	Fluidising combustion chamber with magnetic pre-separation, simultaneous processing of sand and dust from mechanical furan sand regeneration
Sand throughput	t/h	12 – 16	1.0	2.0 used sand, 0.5 dust
Capacity	t/yr	28600	3840	5000
Regeneration ratio, based on used sand throughput	%	95	95 (99 ⁽¹⁾)	95
Application of regenerated sand		Core-making	Core-making	Mould and core-making
Quality criteria for regenerated sand		Dust <1 % AFS 60 – 70 LOI <0.1 %	Identical to new sand F33	LOI <0.5 % pH 6.0 – 6.5 Mould strength upon addition of 1 % binder and 0.3 % harder: 350 N/cm ² after 24 h
Consumption of electrical energy	kWh/t	119	65	
Consumption of natural gas	m ³ /t	24.5	38	
Residue production	t/year	660	Dust: 10 Bentonite sand: 1700	200
Final destination of residues		Mining cavities	Cement production	Construction industry/disposal site
Waste gas flow	Nm ³ /h	7000	16509	6560
Waste gas temperature	°C	75	60	35
Type of filter		Post combustion and fabric filter	Fabric filter	Lime injection + fabric filter
Emission levels ⁽²⁾				
- dust	mg/Nm ³	0.1	4.9	0.4
- C _{total}		2.2	5.7	10
- CO		2.3	1.6	0
- O ₂		14	n.d	20.95
- PCDD/F	% ng TEQ/N m ³	0.006	n.d	n.d.
(1) The higher recuperation rate (99%) is reached if only in-house core sand is regenerated. A rate of 95 % applies for mixed internal and external core sand				
(2) Emission levels are calculated average values from continuous monitoring data over a period of several hours, during sampling for dust or PCDD/Fs				
Source: [57, Umweltbundesamt 2002]				

The performance of the reclamation technique and the quality requirements for the regenerated sand are evaluated on a location-specific basis. Specific data may be found in the references: [85, Stephan, J. 1996], [86, Stephan, J. 1997], [87, Stephan, J. 2000].

Thermal systems are normally used for chemically bonded sand systems and mixed sand systems, providing the share of chemically bonded sands (cores) is high enough. Nevertheless, a distinction can be made:

- Some binders may leave inorganic salt residues at the grain surface. When the temperature increases above the melting point, these spread out over the sand surface and may cause the sintering of the sand grains upon cooling. Known examples are resol resin and silicate resin-bonded sands.
- The thermal recycling of furan resins causes the emission of SO₂ if sulphonic acids are used as a hardening agent. The temperature of the exhaust system must be sufficiently high enough to prevent sulphuric acid condensation. If the emission is high, a wet flue-gas cleaning may be needed. Phosphor (from the phosphoric acid used as a hardener) does not evaporate but remains on the surface in salt form. This may lead to P accumulation upon recycling. If the P concentration rises above 0.5 – 0.7 %, a metallurgical reaction may occur, causing the rejection of the casting.

The degree of implementation of thermal reclamation is low compared to mechanical regeneration.

Cross-media effects

Thermal reclamation requires fuel and generates emissions of dust and combustion related compounds (NO_x, CO; and in the case of oil: SO₂).

The high energy consumption and complexity of the installation are balanced by a low wearing of the sand grains and the recovery of the dust in a thermally inert form.

Thermal reclamation of furan bonded sand with paratoluenesulphonic acid as a hardener, requires flue-gas cleaning: i.e. fabric filter, post-combustion of CO and/or the adsorption of SO₂.

Technical considerations relevant to applicability

May not be applicable in the case of used sand containing residues from inorganic binders.

Economics

Investment costs vary according to the size and type of equipment and are given in Figure 3.29. The data relate to thermal systems with a mechanical pre- or post-treatment step, as well as for intensive mechanical reclamation (e.g. grinding units). Small scale installations have a capacity of 0.75 t/h or 1 500 t/y. A medium size foundry will produce between 2 500 t/y and 5 000 t/y. For a small-scale unit, the capital cost (with 8 years amortisation and 8 % interest rate) would be EUR 55/t. These costs do not include expenses for energy, personnel nor for the disposal of residues (all data from 1996).

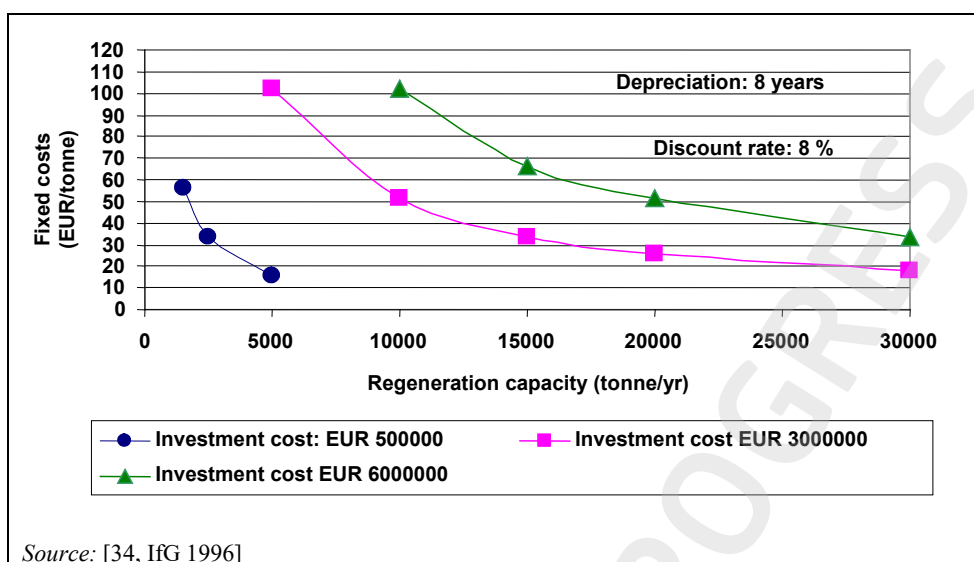


Figure 3.29: Fixed costs in euro per tonne of regenerated sand for thermal regeneration and high level mechanical regeneration of mixed sands

Driving force for implementation

- High disposal fees aiming to reduce the amount of residues for disposal.
- Legal requirements.
- Local conditions.

Example plants

Reported in the SF data collection by plants: AT011, DE065, FR104, FR106, FR112, FR114, IT129 and PT139.

Reference literature

[3, Schneider, B. 1993], [14, CAEF 1997], [33, ERM Lahmeyer International GmbH 1999], [42, IHOBE 1998], [46, Metaalgieterij Giesen B.V. 1996], [85, Stephan, J. 1996], [86, Stephan, J. 1997], [87, Stephan, J. 2000], [169, TWG 2021]

3.2.1.4.4.9 Combined reclamation (mechanical-thermal-mechanical) for mixed organic-bentonite sands

Description

After pretreatment (sieving, magnetic separation) and drying, sand is mechanically or pneumatically cleaned to remove part of the binder. In the thermal step, organic constituents are burned and inorganic constituents are transferred to the dust or burned onto the grains. In a final mechanical treatment, these grain layers are removed mechanically or pneumatically and discarded as dust.

Technical description

In mixed organic-bentonite sands, cured bentonite and organic binders are present on the sand grains. The dust is composed of active and cured bentonite, coal dust (only for iron foundries), quartz fines and organic binder residues. Mixed sands occur mainly in iron foundries and represent some 75 % of the total used sand production. The reclamation can be performed using mechanical, pneumatic, thermal or combined systems.

The sand is pretreated (sieving, magnetic separation) and dried, in order to reduce the water content to < 1 %. After this, the sand is mechanically or pneumatically cleaned in order to remove part of the binder. In the thermal step, organic constituents are burned, and inorganic constituents are transferred to the dust or burned onto the grains. In a final mechanical treatment, these layers

are removed mechanically or pneumatically and discarded as dust. A typical layout for a system using pneumatic treatment and fluidised bed thermal treatment is depicted in Figure 3.30.

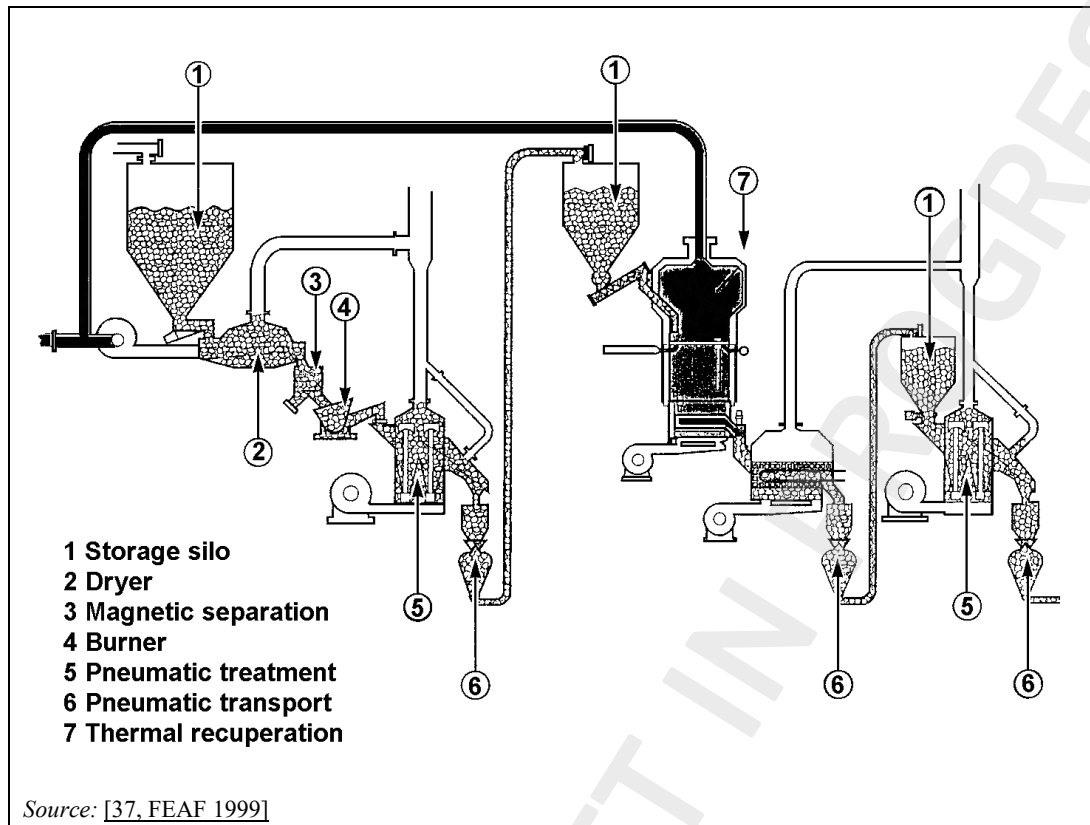


Figure 3.30: Mechanical-thermal-mechanical sand reclamation unit

Achieved environmental benefits

Reduction of the amount of sand for disposal and of the consumption of new primary sand.

Environmental performance and operational data

Operational data for a mechanical-thermal-mechanical treatment are given in Table 3.24.

Table 3.24: Operational data of a mechanical-thermal-mechanical treatment system (pneumatic - fluid bed - pneumatic)

Parameter	Units	Foundry N	Foundry O	Foundry P
Sand flow	(tonne/h)	1	2	3
Maximum humidity of the sand input	(%)	1	1	1
Total installed electric power	(kW)	150	215	400
Natural gas	(Nm ³ /h)	31	62	155
Thermal treatment - average airflow (fluidisation + combustion)	(Nm ³ /h)	700	1200	3000
Treatment temperature	(°C)	800	800	800
Average treatment time	(min)	20	20	20
Flue-gas flow	(Nm ³ /h)	200	300	500
Cooling - type		Fluidised bed with water circulation		

Parameter	Units	Foundry N	Foundry O	Foundry P
- water flow in the circuit	(m ³ /h)	15	30	75
Sand temperature at exit	(°C)	30 – 40		
Total energy consumption:				
- electric		100	90	70
- gas		260	260	260
Compressed airflow	(Nm ³ /h)	150	210	330
Efficiency of the installation		70 – 80 %		
Reclaimed sand quality:		Unchanged		
- granulometry		Unchanged		
- loss on ignition		≤0.1 %		
Re-use of the reclaimed sand:		100 %		
- mould making		100 %		
- core-making		70 – 80 %		
<i>Source: [37, FEAF 1999]</i>				

German data for a 85 000 tonne/y (13 – 15 tonne/h) installation provide the following off-gas composition:

- SO₂: 118 mg/Nm³;
- NO_x: 150 mg/Nm³;
- total C: 10 mg/Nm³;
- CO: 30 mg/Nm³.

This reclamation technique is used for mixed sands containing bentonite. The economical and technical success of the regeneration depends on the selection of the sand to be regenerated. It is not suitable to reclaim the whole sand volume. Sand which is not thermally damaged can be reused directly for new sand preparation. Its reclamation is not suitable, because active binders and additives would be removed. A selection and separation has to be made during shake-out, before homogenisation. The technique cannot be applied for core sands which disrupt bentonite characteristics (binders of acid nature) or which change green sand characteristics (e.g. water glass sand).

The reclaimed sand can be used for core-making in the original process, for cores with low or medium geometrical demands. The applicability for core-making is related to the initial amount of chemically bonded sand. The applicability in other binder systems must be tested in each case. Furthermore, these sands may be applied without restrictions for the replacement of losses in green sand moulding cycles. Restrictions may apply in processes that use water glass or methyl formate bonded sands.

Cross-media effects

The reclamation of sand requires additional energy and causes additional dust emissions and residual dust for disposal.

The general evaluation of internal reclamation versus external reuse, and the corresponding cross-media effects, are discussed separately below.

Technical considerations relevant to applicability

May not be applicable for core sands containing acidic binders (because it may alter bentonite characteristics) or in the case of water glass (because it may alter green sand characteristics).

Economics

Costs for a three-step installation (mechanical-thermal-mechanical) using pneumatic cleaning as the mechanical step (3 tubes in 1 chamber, KGT type Jet Reclaimer) with a capacity of 2.5 tonnes/h are as follows: operational costs (consumption, personnel, maintenance) – EUR 21/t, investment costs (8-year amortisation) – EUR 30/t, thus yielding a total regeneration cost of EUR 51/tonne.

The consumption levels are as follows (1999 data):

- Electricity: 50 kWh/t;
- Natural gas: 18 Nm³/t (depending on the moisture content of the sand);
- Compressed air: 60 Nm³/t;
- Wear parts: 5 EUR/t.

Driving force for implementation

- High disposal fees aiming to reduce the amount of residues for disposal.
- Legal requirements.
- Local conditions.

Example plants

Gusswerke Saarbrücken (DE), thermal-mechanical system. This plant treats 13 – 15 t/h of mixed 30 % organic, 70 % inorganic bonded sand. The organic bonded sand is a 50/50 mixture of Croning and cold-box sand. The reclamation yield on the basis of the amount of used sand treated is 78 %. The reclaimed sand is applied for core-making (100 % Croning; 70 – 100 % cold-box).

The mechanical primary reclamation, separation of chromite (from cores) and quartz sand (both chemically bonded) and thermal/mechanical treatment of quartz sand was demonstrated on a pilot scale in Germany (1993). Separation of both sand types was needed because sintering and eutectics formation occurred in the mixed sand. The plant later closed down due to other economic reasons.

Reported in the SF data collection by plants: AT009, AT013, DE037, DE047, DE073 and ES091.

Reference literature

[4, Schachtner et al. 1993], [17, Winterhalter et al. 1992], [37, FEAF 1999], [40, Kirst, J. 1999], [42, IHOBE 1998], [57, Umweltbundesamt 2002], [120, TWG 2003], [169, TWG 2021].

3.2.1.4.4.10 Thermal-mechanical sand reclamation using drum furnaces

Description

Thermal-mechanical sand reclamation using two drum furnaces, the first for thermal reclamation of sand and the second for mechanical processing using steel balls.

Technical description

Thermal regeneration of foundry waste sand has been used as a technology since the 1980s. The technology has never become a standard solution for foundries and it can be estimated that thermal regeneration is only used in a few hundred foundries worldwide, compared to the high number of foundries. The thermal sand regeneration is dominated by the fluidized bed technology, where the sand to be regenerated is heated by hot air in a closed reactor. Thermal sand regenerators based on fluidized bed technology are available from many technology suppliers.

There are problems with fluidized bed technology, particularly related to its usability. The technology is said to easily cause the sintering of the sand in the reactor, causing the sand grains to stick together and disrupting the process. According to studies, several foundries using thermal sand recovery based on fluidized bed technology are not satisfied with the technology's performance.

The new thermal-mechanical process is based on a combination of two drum furnaces. In the first drum, the sand to be regenerated is heated using propane, natural gas, or biogas up to a maximum of 800 °C at which the sand binder is completely burnt off the sand. In the cooling drum, the sand is mechanically processed using steel balls in the drum. The balls enhance the removal of the binder residues from the sand and as it passes through the drum the sand cools. The coarse material in the reclaimed sand is then sieved out using a dense mesh in the drum.

Thermal-mechanical technology, based on the use of two drum furnaces, is energy-efficient and easy to use. The major difference between a drum furnace and a fluidized bed reactor is that the heating of the sand is based on contact of the sand with the hot surface of the rotating drum and also with the hot air inside the drum as the sand falls from the top to the bottom of the drum as the drum rotates, instead of being heated only by hot air. Before the sand is fed into the combustion drum, the sand passes through a magnetic separator that separates any magnetic metal residue. Depending on the type of sand to be reclaimed and the binder system used, additives can be added to the sand to raise the melting point of the salts in the sand.

The drum furnace-based reclaimer can be considered to be mechanically very reliable as the sand flow in the furnace is based on the rotational movement of the furnace and the angle of inclination of the drums. The reclamation unit is placed, for example, on an asphalted field, on top of a concrete slab, where it stands on steel legs. The equipment is designed so that it can be serviced and the essential components can be replaced quickly and easily. The equipment and components used are standard parts, available from a number of alternative suppliers. This facilitates unit construction and component sourcing.

The most important aspect of the technology of the reclamation unit and its result is the know-how in running the operating parameters supported by an intelligent automation system. The process is equipped with several measuring instruments that collect data on all key system parameters such as the temperature of the drum furnaces, the temperature of the sand and flue gas, the power of the gas burner, the amount of sand fed into the process, and, for quality assurance purposes, even the sand color. The process is controlled from a control panel connected to the unit, from which it is possible to adjust all the main process parameters. For example, when the combustion drum reaches the target temperature, the gas supply is reduced to maintain the target temperature. The data collected by the measuring devices is stored in the cloud service, from which it is possible to analyse measurement data over different periods as required. The operation of the automation system is a critical part of overall technology for process control, reliability, energy efficiency and the quality of the end product, i.e. the reclaimed sand.

In thermal reclamation, organic impurities are burned, and adhering binder residues as well as loosely bound dust particles are blasted off the sand grain by the abrupt increase in volume of the sand grains during the quartz phase transition at 573 °C. The blown-off residues are separated in the dedusting process.

Achieved environmental benefits

Approximately 100 million tonnes of waste sand is produced annually by foundries globally. Only a small amount of it is being recycled. Through thermal reclamation, 97% of waste sand can be recycled and reused. That would drastically reduce the need for new landfills for the waste sand and the need for new virgin sand. Foundries produce around 10 million tonnes of sand-related CO₂ emissions annually, from which 70% is associated with excavation and processing of new sand and an additional 30% is associated with transportation. By adopting circular economy approach, there is the potential to reduce up to 80% of these CO₂ emissions.

The baseline scenario assumes that the emissions are caused by the (i) extraction and processing of virgin sand, (ii) logistics, and (iii) landfilling of sand. The emissions from the excavation and processing of the used virgin sand are based on scientific, peer-reviewed, and recent LCA research and can be considered reliable. The avoiding of new sand extraction and processing is equivalent to approximately 75 kg CO₂ per tonne of sand, which can be avoided. Furthermore, the avoided emissions from the logistics of virgin and waste sand are equivalent to approximately of 25 kg

CO₂ per tonne of sand (assuming an average 500 km transportation (road/rail) distance from virgin sand deposit to the foundry). Avoided emissions from landfilling of sand are equivalent to approx. 15 kg CO₂ per tonne of sand. Therefore, the total avoided emissions potential is equivalent to 115 kg CO₂ per tonne of sand.

Environmental performance and operational data

Reclamation equipment is connected closely to the foundry's process, no full-time operator is needed, and the unit operates fully automatically and independently. Operations needed:

- Weekly refill of central lubrication system by the foundry operator;
- 24/7 remote surveillance;
- Modular design (equipment is delivered ready for installation), the scope of construction on site is very limited. In case of need, additional modules can be installed or removed from operation due to low seasonal work;
- CE marked;
- Stand-alone equipment – no impact on the safety of other equipment installed on-site;
- Low installation costs, fast installation (only gas and electric connection required);
- Space requirement 13,5m x 7,5m or 20m x 3,5m;
- Silo height 11m, feed material single grain, magnetic separation;
- Capacity 1 – 2.5 tonnes/h (green sand), up to 4 tonnes/h (resin bonded)
- Typical average gas consumption is 10 – 15kg = 130 – 190 kWh/tonnes of natural gas depending on the binder content;
- Electrical power requirement 96 kW (nominal) ~ 30 kWh consumption in operation = 10 – 15kWh/tonne;
- Compressed air need for the dust filter: 5,5 Nm³/h (max. 45Nm³/h);
- Compressed air sand conveying 9 – 11 Nm³/h;
- Low particulate emissions < 1 mg/Nm³;
- Low NO_x and SO₂ emission values.

Cross-media effects

The main sources of the environmental footprint are associated with manufacturing and delivering the equipment.

Technical considerations relevant to applicability

Binder systems for foundry sands are divided into two main categories. The resin-cured sands and so-called green sands, where the curing agent is bentonite clay. In resin sands, the two most commonly used types of resin are phenolic and furan resin. The green sand-based binder system is predominant in iron and steel foundries, accounting for an estimated 70% of the casting sand used in iron and steel foundries. The process is suitable for all of those sand types.

Economics

Cost for virgin sand and dumping fee: 100 – 300€/ton. The cost varies between the countries in Europe.

No major investment is required (foundation for the unit).

Driving force for implementation

Cost saving, price increase for dumping used foundry sands in landfills

Improvement of Carbon Footprint.

Easy to acquire, low investment cost.

High reclaimed sand quality.

Equipment and proposed process match the German long-term governmental Resource Efficiency Program “ProgRess” (Deutsches Ressourceneffizienzprogramm “ProgRess”), Circular Economy Act (sand can be recycled for unlimited quantity of rounds), Federal Nature Conservation Act (in the scope of sand mining). Similar regulations and programs exist in other EU/non-EU countries. Wide choice of gas burners (including sustainable biogas) available on the market.

Positive impact on ISO 14001 system of foundry

Example plants

Three regeneration units at Nuutajärvi, each of which has the capacity to regenerate foundry sand for the customers. The technology and service model has been in commercial use in Finland since January 2019 at the following installations: Peiron Oy, Valmet Technologies Oy, Raahen Valimo Oy and Suomivalimo Oy.

Reference literature

FI submission in [237, TWG 2023]

3.2.1.4.4.11 Combined sand reclamation and heat treatment of aluminium castings

Description

After pouring and solidification, mould/casting units are loaded into the furnace. When the units reach a temperature $> 420\text{ }^{\circ}\text{C}$, the binders are burnt, the cores/moulds disintegrate, and the castings undergo heat treatment. The sand falls to the bottom of the furnace for final cleaning in a heated fluidised bed. After cooling, the sand is reused in the core sand mixer without further treatment.

Technical description

This new process uses an automatic system to carry out three foundry steps simultaneously in one automatic system:

- thermal decoring / sand – casting separation;
- thermal sand regeneration;
- casting heat treatment.

The following figure shows a schematic of the system.

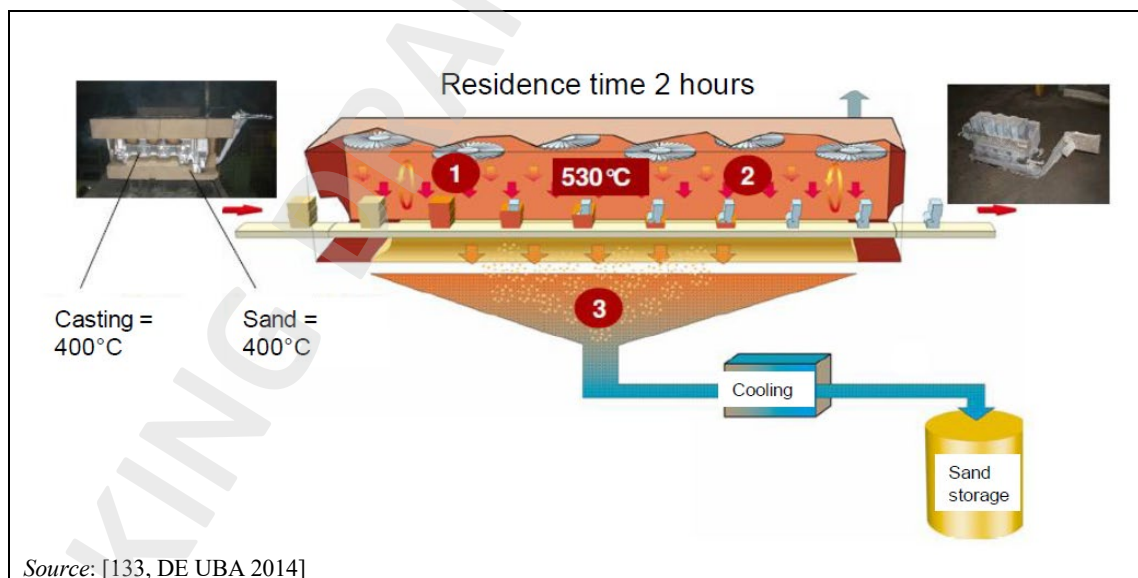


Figure 3.31: Schematic of the system: 1: separating; castings and sand; 2: annealing; 3: sand reclamation

Immediately after pouring and solidification, the castings are loaded into the furnace for heat treatment. Foundries load the castings within 15 minutes and moulds within 20 – 25 minutes into the furnace. No cooling, no mechanical sand removal and/or decoring, and no riser cutting steps are needed.

The binder is burned as a fuel: only the presence of heat above $420\text{ }^{\circ}\text{C}$ and oxygen causes the organic binder to burn and the mould/core will disintegrate. Special axial fans create a pressure

drop across the castings (negative pressure) which results in turbulence inside the castings. This allows rapid sand removal from horizontal internal passages such as water jackets, oil passages and other thin cores.

The sand falls to the bottom of the furnace for final cleaning in a heated fluidised bed and will be released to the sand collecting vibratory conveyor underneath the furnace. Sand will be cooled for pneumatic transport back to the core shop. No further treatment is needed before being reused in the core sand mixer. Levels of loss-on-ignition (LOI) of the reclaimed sand are less than 0.07 %.

Castings are thermally processed (casting heat treatment) at temperatures between 485 °C and 535 °C (as specified by customer) and quenched after treatment.

Systems are available as:

- roller hearth furnace (batch type and continuous);
- deep fluidised bed (DFB) ('continuous' batch type); or
- chain type furnace (continuous).

Waste gases are thermally treated in an afterburner at 820 °C to burn nitrogenous gases. Hot exhaust runs through a heat exchanger, preheating fresh air for the fluidiser, air knives, and burners, before being directed to the bag filter.

This technique finds a number of applications, for example:

- castings in aluminium alloy;
- castings with sand;
- core and mould sand with organic binders;
- castings made in any process where sand (silica, zircon, etc.) is used for forming;
- the outer and/or inner contour of the casting (e.g. gravity die-casting process, low-pressure die casting process, precision sand moulds, Croning, no-bake);
- casting heat treatment capacities between ~30 and 180 castings/hour;
- sand removal and reclamation capacities up to > 35 t/hour.

Achieved environmental benefits

Reduced waste and reduced resource consumption by sand recycling

- It is a closed circuit 'core shop – pouring – thermal decoring – sand reclamation – core shop'. About 97 % of the used sand loaded with the castings into the system's furnace will be transported back to the core shop as clean, regenerated sand.
- All sand from the foundry can be regenerated. Waste sand from the core shop, broken cores can be loaded into the furnace for reclamation as well.
- Only the loss (only about 3 % per hour; broken grains, and fine particles) will be separated and need to be replaced.
- Reduced waste amounts.
- Another environmental benefit is the reduction of truck transport between sand providing facility and foundry and/or between foundry and landfill.

Use of recovered heat

- Loading of hot castings into the furnace; heat for melting the metal is also used for sand reclamation and heat treatment.
- No cooling of castings; avoiding using energy in the cooling process (e.g. electric blowers).
- Organic binder creates heat when burned. This heat inside the furnace is used for sand reclamation and heat treatment.
- Binder chemicals are burned inside the furnace.
- Some foundries use the heat of exhaust gases for providing hot water or heating the building.

Waste gas treatment

- Minimised emissions.

Emissions

- Emissions of CO₂ are reduced.

Table 3.25: Emission levels corrected to 12 % O₂ measured using the combined sand reclamation / heat treatment technique

	Maximum authorised emission concentrations (mg/Nm ³)	Emissions reported using the combined sand reclamation / heat treatment technique (mg/Nm ³)
CO	80	60.9
VOCs	20	7.9
NO _x	250	230
Dust	10	6

Source: [133, DE UBA 2014]

Environmental performance and operational data

Capacities casting treatment: Existing systems treat between 33 and 180 engine block and cylinder head castings per hour, based on customer specifications. The furnaces (as a modular construction) are engineered to specified thermal systems. Depending on the number of castings/hour, size of castings/moulds, temperature, heat up and soak time, etc., the furnaces will be designed as a number of modules.

Capacities sand reclamation: The installations provide the capacity to reclaim between 1 tonne and 30 tonnes of used sand per hour. The hopper-shaped bottom of the furnace is also designed to buffer a certain amount of sand during production stops in the sand system downstream of the furnace, meaning the furnace can continue to heat treat castings.

Energy consumption: Utilities estimate the consumption of gas, electricity, and compressed air based on the customer's process specification. Gas consumption for example depends very much on the temperature of castings during loading, treatment time and temperature, quantity of sand and binder content, etc. The share of recovered energy can be about 47 %. In general, operating such a system can reduce the energy consumption by 25 – 30 %.

Cross-media effects

It may be considered as an indirect disadvantage when risers and feeders are heat treated as well before being cut off. It may use more energy in the furnace. On the other hand, loading of hot risers and feeders increases the heat loaded into the furnace.

'Heat treated' risers and feeders can be cut off more easily. This saves costs for cooling.

Technical considerations relevant to applicability

Generally applicable.

Economics

Savings can be achieved by:

- reduced treatment time (energy);
- reduced space requirements;
- reduced personnel costs;
- less equipment, no stand-alone machinery;
- less handling operations, less damage;
- reduced emissions;
- recovery of energy;
- less inventory (work in progress).

Additionally reported reductions by one example plant were:

- labour costs by 46 %;
- energy costs by 25 %;
- gas consumption by 64 %;
- operating costs by 55 %.

Reported share of energy:

- gas: 42 %;
- electric power: 11 %;
- energy recovery 47 %;

No data on investment costs are available.

Example plants

- In total 37 of such 3-in-1 roller hearth and chain type systems have been installed worldwide and are used mainly for the treatment of engine block (gasoline and diesel) castings (low-pressure die casting), precision sand mould and gasoline and diesel cylinder head castings (gravity die casting, low-pressure die casting, precision sand mould).
- Hydro Aluminium Dillingen (now Nemak Dillingen) in Germany with four lines for producing engine blocks and heads with a total production capacity of about 480 castings/hour.
- Daimler Benz Mettingen, Germany, equipped with two lines for producing cylinder heads.

Reference literature

[133, DE UBA 2014]

3.2.1.4.4.12 Wet reclamation for green sand, silicate- or CO₂-bonded sands

Description

Sand is mixed with water to produce a sludge. The removal of grain-bound binder residues is performed through intensive inter-particle rubbing of the sand grains. The binders are released into the wash water. The washed sand is dried, screened and finally cooled.

Technical description

After metal removal, the sand is mixed with water to produce a sludge for easily separating the binder and to allow subsequent wet screening (1.6 mm). The removal of grain-bound binder residues is performed in the wet reclamation unit, through intensive interparticle rubbing of the sand grains. The binders are released into the wash-water. The washed sand is dried to a final moisture content of maximum 0.3 %, dry screened (at 1.2 mm), and then cooled. This may be followed by an additional magnetic iron extraction and a final dust collection. The binder residue is separated from the suspension and treated to allow its safe, disposal.

The main advantage of the process over mechanical and thermal processes is that it allows real time process monitoring. Through pH control, continuous follow-up of the process is possible, allowing corrective real-time action if needed and producing a continuous quality reclaimed sand. The technique allows removal of the binder layer through wet mechanical action, combined with chemical action when needed, without wearing the sand grains.

The process mainly aims to lower both the oolitisiation degree of used sand (LOI maximum 1 %) and the acid content.

Information from industry states that besides the waste water generation issue (see Cross-media effects below), wet reclamation usually has a poor yield (recovery rate of only up to about two thirds of the reclaimed used sand). [134, CAEF 2020]

Achieved environmental benefits

Reduction of the amount of sand for disposal and of the consumption of new primary sand.

Environmental performance and operational data

No information provided.

Cross-media effects

The wet process generates a sludge for disposal and a waste water stream. A serious problem of this waste water flow is the bad sedimentation of bentonite, and its difficult removal out of waste water. Waste water from water glass sands regeneration shows the presence of alkaline ions. These ions are difficult to separate from the waste water.

Technical considerations relevant to applicability

Generally applicable.

The wet reclamation system can only be applied to green sand and silicate- or CO₂-bonded sands. Regeneration from these types of processes allows full re-use of the regenerated sand in both moulds and cores. Tests on regenerated green sand showed the possibility of producing good quality cold-box cores with an acceptable binder quantity (1.8 % in total).

Economics

Within the Italian foundry market, a centralised wet reclamation plant can offer reclaimed sand at a price lower than that of new sand.

Driving force for implementation

This system is reported to be able to cope with changes in used sand quality better than mechanical or thermal processes. This makes it suitable when considering a centralised sand reclamation plant.

Example plants

Reported in the SF data collection by plants: AT004, CZ024, DE028, DE063, DE067, DE069, FR111 and IT127. [169, TWG 2021]

Reference literature

[17, Winterhalter et al. 1992], [47, EU Thematic Network Foundry Wastes 2001], [120, TWG 2003], [134, CAEF 2020], [169, TWG 2021].

3.2.1.4.4.13 Reclamation of sodium silicate sand (water glass) using a pneumatic system

Description

Sand is heated to make the silicate layer brittle before the use of a pneumatic system (see Section 3.2.1.4.4.7). The reclaimed sand is cooled before reuse.

Technical description

Water glass sand has been traditionally difficult to reclaim. The use of a pneumatic system has allowed the setting up of reclamation plants operating with a 60 % reclamation ratio. The system works along the same principle as mentioned above (see Section 3.2.1.4.4.7). For this type of binder however, the sand needs to be heated to 220 °C before the reclamation, in order to make the silicate layer brittle. The sand should have a humidity below 0.3 % before reclamation. The reclaimed sand may be reused in the same system. In order for the ester to work properly, the reclaimed sand must be cooled to below 20 °C, before feeding back into the moulding cycle.

Water glass sand reclamation systems comprise the following process steps: breaking – drying/heating – (pneumatically) reclamation – cooling – filtration.

This technique has a lower performance than the thermal reclamation of organically bonded sands. The following limitations occur:

- lower immediate compressive strength;
- shorter applicability times of the core sand mixtures;
- stability loss upon storage of cores;
- loss of retained compressive strength, especially with the use of binders with high collapsibility.

In order to compensate for these problems, changes to the processing scheme or the binder mixes are needed.

Achieved environmental benefits

The application of water glass sand as a binder has a low environmental impact, compared to the application of organic binders. This technique allows the (partial) reclamation of the water glass bonded sand and thus reduces the need for used sand disposal and primary raw material use.

Environmental performance and operational data

A German example plant operates a pneumatical unit in a step-wise cycle. The sand is first dried by the introduction of heated air (5 min/220 °C). After this, the pneumatic cleaning is started by injecting of shots of compressed air (70 min). This is followed by a final dedusting phase, during which only fluidising air is introduced (2 min). There is no need for further cooling, since the sand cools down to a workable temperature.

The yield of reclaimed sand for one cycle operation is reported to be 85 % of the initial weight (on the basis of SiO₂). In order to produce stable cores, and taking into account the further reduction of sand quality upon a second reclamation cycle, a maximum reclamation ratio of 62 % may be achieved (leaving 38 % new sand addition).

Specific consumption levels are as follows (for a 1 500 tonne/y; 0.5 tonne/h unit):

- natural gas consumption: 104.4 kWh/t used sand;
- electricity consumption: 74.5 kWh/t used sand.

A Polish example plant (in a steel foundry) consists of the followig units: vibratory crusher – drier – impact plate regenerator – cascade dedustor – electromagnetic separator. The technical details of the installation are given in Table 3.26. The reclaimed sand is reused in the preparation of silicate-bonded moulding-sand. The silicate-sand is used as backing sand in mould making, with alkaline sand used as contact sand. The total sand balance (on a yearly basis) shows a use of 45 – 47 % regenerated sand.

Table 3.26: Operational data of a silicate sand reclamation unit

Characteristic	Value
Capacity	10 tonne/h
Recovery ratio	90 %
Content of reclaimed sand in the moulding-sand	50 – 60 %
Working power	76 kW
De-dusting system efficiency (2 bag filters)	99.4 %
Installation area for regeneration site	220 m ²
<i>Source: [98, Metalodlew s.a. 2002]</i>	

A Spanish example plant (cast steel foundry) reported a reuse of 80-88 % (with a yearly average figure of 12.5 % new sand addition) of reclaimed silicate-ester sand in a manual moulding line, used for the casting of big pieces. The reclamation system consists of: vibratory crusher – heating in an indirectly heated reactor ('quemador' with gas burner in a side chamber) – cooling in a water-cooled heat-exchange tower – impact cleaning in a rotary mixing chamber.

An Italian example plant also use special equipment for heating sand to temperatures of 140 °C to 150 °C, to enable the removal of defects and the embrittlement of the water glass coating. This is followed by mechanical treatment in a rotary wiper, dedusting and finally cooling. A schematical drawing of the rotary reclamation unit is given in Figure 3.32.

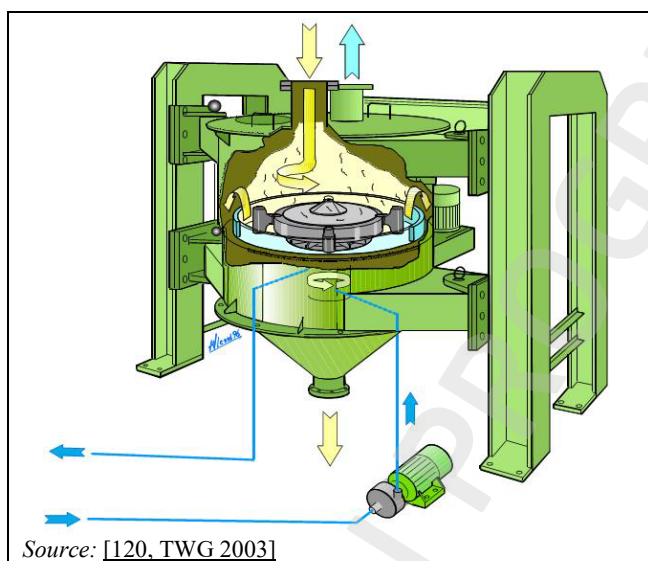


Figure 3.32: Rotary mechanical reclamation unit

The equipment has an energy consumption of 35 kW/tonne of reclaimed sand. The operational loss of sand is about 5 %. For moulding and core-making mixtures, over 90 % of reclaimed sand can be used. The achievable reclamation ratio depends on the intensity and time of reclamation and the operational sand loss. Sand losses occur during each part of the whole cycle of mixing, preparation, transportation, mould production and reclamation.

Cross-media effects

In order to heat up the sand, natural gas is combusted. The corresponding CO₂ emission is estimated to be 18 kg/tonne of used sand. NO_x emissions will also occur.

Technical considerations relevant to applicability

Generally applicable.

The applicability of reclamation for water glass sands depends on the catalyst used. With classic polyacetate glycerol esters, regeneration is no longer possible after a number of cycles. With carbonaceous esters, reclamation is possible and even easier than for silicate-CO₂ sand. If the sand cannot be cooled below 20 °C before returning to the mixer, esters with a slow reaction need to be used. These cannot be reclaimed. This situation may occur during summer in hot climates.

The reuse of the reclaimed water glass sand for the preparation of organically bound moulds or cores is problematic. The elevated content of electrolytes (binders) prohibits their use in other core binder systems. The highly basic water glass residues have a negative effect on bonding and core stability, in both neutral as well as alkaline binder systems. Applications in green sand cycles and acidic core binder systems have not yet been successfully implemented. This may be due to a reduced interest in the development of this application.

Because of the low quality of secondary regenerated sand, it is necessary during decoring and sand collection to identify the amount of regenerated sand and its origin (e.g. number of cycles), and to then discard any unusable sand.

Economics

The processing cost of this technique for the German example plant is around EUR 60/tonne. This high cost was the reason one operator closed his plant down and went back to the disposal of the water glass sand, which he could do for the lower cost of EUR 30/tonne.

The reported operational cost by the Spanish example plant is EUR 10/tonne.

Due to the high costs and relatively low reclamation ratio, depreciation of the installation in a reasonable time can only be guaranteed for plants with a capacity > 2 500 tonnes/y.

Driving force for implementation

To enable the reclamation of water glass sand, which has a good environmental performance in certain applications.

Example plants

- Akers (SE) (Plant SE153 in the data collection).

Reference literature

[42, IHOBE 1998], [56, Notzon et al. 1998], [58, Baum 2002], [98, Metalodlew s.a. 2002], [108, Martínez de Morentin Ronda, J. 2002], [120, TWG 2003], [123, Galante et al. 1997], [210, TWG 2022]

3.2.1.4.4.14 Internal reuse of core sand (cold-box or furan-acid binders)

Description

Sand resulting from broken/faulty cores, and excess sand from the core-making machines (after hardening in a specific unit), are fed to a breaking unit. The resulting sand is mixed with new sand for the production of new cores.

Technical description

Core production generates sand residues in the form of broken cores, cores with small mistakes and excess sand from the core-making machines. The excess sand can be hardened in a specific unit. Subsequently the various unused core sand flows are fed to a breaking unit. The resulting sand may be mixed with new sand for the production of new cores.

Achieved environmental benefits

Raw material efficiency (less use of new sand) and minimisation of used sand sent for disposal.

Environmental performance and operational data

Internal recirculation of 5 – 10 % of the core sand, which otherwise would be disposed of.

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable.

This technique applies for polyurethane (cold-box) and furan resin-bonded sands. Other binders do not allow the use of this technique.

The implementation of the technique necessitates changes in the process control. The optimum ratio of recirculated and new sand will need to be determined. Additionally, changes in binder addition or composition may be needed.

Economics

The technique requires an investment cost of EUR 250 000 – 500 000 for the combined treatment and breaking unit. Operational costs are about EUR 12/t (2001 data). These costs are balanced by a reduction in disposal costs and purchasing costs for new sand.

The technique is only viable for core intensive production.

Driving force for implementation

- Optimisation of the use of primary materials and reduction of the amount of waste for disposal.
- Legal requirements.
- Local conditions.

Example plants

The technique was reported by several large-scale foundries.

Reference literature

[34, IfG 1996], [38, Vito 2001]

3.2.1.4.4.15 Reuse of dust from the green sand circuit in mould making

Description

Dust is collected through the exhaust filtration from the shake-out installation and from the dosing and handling stations for dry green sand. The collected dust (containing active binder compounds) can be recycled into the green sand circuit.

Achieved environmental benefits

Reduction in the use of primary raw materials (binders, bentonite) and additives (carbon).

Environmental performance and operational data

An iron automotive foundry, using an automated moulding line with a production of 8 000 t/y castings produces 480 t/y of dust. This sand is collected, cooled and recycled into the sand mixer. The collected dust contains 23 % active bentonite and 10 % carbon. 50 % of the dust can be re-circulated without any risk of loss of quality due to fine dust.

In cases where the collected dust is a mixture of ‘active bentonite’ and ‘burned bentonite’ without a binding effect, testing of the collected dust and a careful dosing are required when mixing it in the green sand (CAEF comments in [210, TWG 2022]).

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable.

The technique may be applied in new and existing green sand installations.

Economics

The technique requires an investment of EUR 25 000 for storage and transport equipment. The amortisation period is 8 years, with a discount rate of 8 %, for a 240 tonne/yr installation, resulting in a capital cost of EUR 17/tonne of treated sand (2005 data). There are no additional operational costs since the operation of the overall installation does not change.

Driving force for implementation

To optimise the use of primary materials and to reduce the amount of waste for disposal.

Example plants

Iron automotive foundry in Germany.

Reference literature

[34, IfG 1996]

3.2.1.4.5 Reduction of generated residues and of waste sent for disposal

In general, the residues streams comprise:

- raw material dusts collected in bag or cartridge filters;
- slag from desulphurisation;
- slag/dross from melting;
- melting dust and fume collected in a filter plant;
- casting dust and fume collected in a filter plant;
- fettling dusts collected in an abatement system;
- chips and turnings from fettling;
- used abrasives from shot blasting;
- scrubber liquors and sludges and output from the effluent treatment plant;
- refractory waste from launders and ladles;
- sand;
- chemical and oil containers;
- general inert industrial waste.

Waste should be recovered and/or recycled wherever practicable. Other than sand, the most significant residues are:

- slag from the melting and metal treatment processes;
- dust collected from abatement plants;
- collected sludge;
- refractory waste.

[62, UK Environment Agency 2002]

3.2.1.4.5.1 Off-site recycling and/or other recovery of the used sand, the undersize sand, slags, refractory linings and the collected filter dust

Description

Off-site recycling and/or other recovery have priority over disposal for spent sand, undersize sand, slags, refractory linings and filter dust. Spent sand, undersize sand, slags and refractory linings can be:

- recycled, e.g. in road construction, building materials (such as cement, bricks, tiles);
- recovered, e.g. filling of mining cavities, landfill construction (such as roads on landfills and permanent covers);

Filter dust can be externally recycled, e.g. in metallurgy, sand fabrication, the construction sector.

Technical description

Used sand, undersize sand, slags, refractory linings and filter dust may find some external applications, as indicated above.

The limits of these applications are given by either technical criteria for construction materials and/or environmental criteria for the given application. Environmental criteria are generally based on leaching properties and the content of organic compounds. These may differ among various

European regions. Used sands generally show a low metal leaching potential. An exceedence of the limit values may occur for materials with a high content of organic binder or with specific additives, such as lustrous carbon.

Due to its high quartz content and appropriate granulometry, used sand may be applied as a virgin sand substitute in road construction. Application in the production of building materials (concrete, bricks, tiles, glass wool, etc.) are technically feasible but require a higher level of composition control and logistics. Industrial scale trials have been successfully applied in:

- road bases;
- filling material;
- drainage material;
- concrete elements;
- cement production (depending on the silicon need of the process; in Germany this application is of major importance);
- construction material for the reinforcement of dikes;
- vitrification of hazardous waste.

An overview table which gives more detailed information for the different sand types is given in Section 3.2.1.4.5.3.

Other fields of application are the fabrication of bricks, secondary copper smelting and zinc recuperation.

It should be stressed that discussions on the (type of) external utilisation fall beyond the scope of the current reference document. However, in general, it can be stated that the sand usually needs no pretreatment and is transported from the foundry after collection and intermediate storage. Usually in order to guarantee a continuous quality of the material, a separate collection and storage system will be developed. Furthermore, the quality of the material needs to be controlled through regular analyses.

Achieved environmental benefits

In external applications, the used sand substitute and therefore saves virgin materials. In general, the external application does not require any treatment of the sand and therefore does not generate any energy expense for the foundry.

The use of surplus foundry sand does not reduce the wear resistance of asphalt concrete. The use of surplus foundry sand together with the dust from the same foundry process is possible in Portland cement concrete production. The use of surplus foundry sand together with fly ash and steel slag is possible in mineral wool production. The use of surplus foundry sand in the composting process of biowastes does not negatively affect the environmental or technical features of the final product, i.e. the topsoil. The use of surplus green sand in mineral liners is technically and environmentally possible in the top layers of the landfill.

Environmental performance and operational data

No information provided.

Cross-media effects

In general, no cross-media effects are reported. It may be the case that residues of organic coatings are possible sources of aromatic hydrocarbons.

Technical considerations relevant to applicability

Recycling and/or other recovery may be restricted by the physico-chemical properties of the residue (e.g. organic/metal content, granulometry). It may not be applicable in the case of absence of a suitable third-party demand for recycling and/or recovery.

Economics

Costs for external utilisation depend on the local market and the transport and storage costs needed.

Investment costs for separate collection and storage are minimal. Often these can be realised through organisational measures. Operational costs for analyses and administration may be up to EUR 5 000/y. On the benefit side, there is a reduction in the costs for disposal (up to EUR 125/tonne) (2000 data).

Driving force for implementation

- High disposal fees aiming to reduce the amount of residues for disposal.
- Legal requirements.
- Local conditions.

Example plants

Multiple examples have been reported throughout Europe, e.g. by Finland, the Netherlands, Belgium, Germany, UK. An indicative list of plants reporting external recycling of spent sand in the cement industry and construction works includes the following: BE022, CZ026, DK079, FR109, FR110 and IT071. [169, TWG 2021].

Reference literature

[34, IfG 1996], [38, Vito 2001], [42, IHOBE 1998], [68, Orkas J. 2001], [70, The Castings Development Centre 1999], [169, TWG 2021].

3.2.1.4.5.2 Minimisation of slag forming

Description

Slag forming can be minimised by in-process measures, such as:

- using clean scrap;
- using a lower metal temperature (as close as possible to the theoretical melting point);
- avoiding high temperature peaks;
- preventing extended holding of molten metal in the melting furnace or using a separate holding furnace;
- making adequate use of fluxes;
- making adequate choice of the furnace refractory lining;
- applying water cooling of the furnace walls to avoid the wear of the furnace refractory lining;
- liquid aluminium skimming;
- using compressed air to recover aluminium residues;
- separating collected metal chips from oils using drying.

Achieved environmental benefits

Minimisation of residue generation and reduction of emissions to air.

Environmental performance and operational data

No information provided.

Cross-media effects

No cross-media effects occur from these minimisation measures. Concerning the melting of clean scrap, the considerations raised in Section 3.2.1.3.4 should be taken into account.

Technical considerations relevant to applicability

Generally applicable. This technique applies to all new and existing installations. The applicability of the use of clean scrap has been fully discussed in Section 3.2.1.3.4.

Economics

This technique does not involve any investment, since it concerns operational measures.

Driving force for implementation

High disposal costs for residues.

Example plants

This technique is part of existing operational procedures in the majority of European foundries.

Reference literature

[36, Vereniging van Nederlandse Gemeenten 1998]

3.2.1.4.5.3 Mechanical pretreatment of slag / dross / filter dust / spent refractory linings to facilitate recycling

Description

Generated slag/dross/filter dust/spent refractory linings are pretreated on site, by using techniques such as crushing, segregation, granulation and magnetic separation. This may also take place off site.

Technical description

In order to allow an external re-use of solid residues, the material may need treatment. Table 3.27 gives the required processing for the various (non-sand) solid residues and possible limitations for their reuse.

For cupola furnace slag, the physical form, and therefore to some extent its options for reuse, depend on the type of de-slagging used. Dry slagging, i.e. pouring of the slag in pots for cooling and solidification, produces a crystalline non-porous mineral. Concerning technological aspects, this slag is comparable to blast furnace slag. Wet slagging generates a granular slag by cooling the slag with a water jet.

Table 3.27: Necessary treatment and possible limitations for external reuse of solid residues

Residue type	Treatment	Limitations
Air-cooled cupola slag	Crushing	- generation of glassy dust - handling requirements due to glassy nature
Water quenched cupola slag	None	- generation of glassy dust - handling requirements due to glassy nature
Induction melting slag	Crushing	- generation of glassy dust - handling requirements due to glassy nature - little data available on leachates
EAF slag	Crushing	- generation of glassy dust - handling requirements due to glassy nature - little data available on leachates
Desulphurisation slag	Extraction of metal and other coarse particles	- handling requirements, CaC ₂ needs careful handling to avoid injury - run-off - may be a special waste
Dusts and sludges	Sludge pressing, drying and granulation needed for most applications	- health and safety requirements for some dusts - problems with transport of dusty materials - high leaching potential due to nature of product and large surface area

Source: [70, The Castings Development Centre 1999]

Achieved environmental benefits

In external applications, the recycled material will serve as a secondary construction material and can substitute virgin materials. The recycling results in a reduction in the amount of material for disposal.

Environmental performance and operational data

A summary of external recycling applications for various solid wastes is given in Table 3.28.

Table 3.28: Summary of external recycling applications for solid foundry residues (status 1999)

SUMMARY OF RECYCLING APPLICATIONS	SAND						SLAGS					OTHER	
	Greensand	Alkaline phenolic	Phenolic urethane	Furan	Resin shell	Sodium silicate	Air-cooled cupola	Water quenched cupola	Induction	Electric arc furnace	Desulphurisation	Investment casting shell	Dusts and sludges
Construction type uses													
Asphalt	x	x	+	+	+	O	x						
Ballast							+		+				
Block making	+	x	+	+	x	+		x					
Brick manufacture	x	x	+	+	+		+	+					
Cement	x	x	+		x	x							
Coarse aggregate substitute							x		x	x		x	
Concrete		x	+	+	+								
Fine aggregate substitute	x	x	+	+	+	+							
Foamed concrete, etc.	x	x	+										
Insulating/mineral/glass wools	+	+	+	+	+	+	+	+					+
Lightweight aggregate production													+
Mortar production						+							
Road base construction		x	+		+	x	x		x	x		x	
Roofing felt				x									
Re-use in another foundry													
As new sand addition to greensand				x									
Soil type uses													
Artificial topsoils	x	+	+	x	+								+
Decorative ground cover							+	+					
Ground cover in riding stables								+					
Fertiliser filler													x
Landfill - capping	x	x	+										+
Landfill - daily cover	x	x	+	x	x	x							
Landfill - liner	+												+
Soil modifier/improver	+	+	+	+	+	+		+			+		+
Miscellaneous													
Abrasives/blasting media		x	+					x	+				
Absorbent media												+	
Blast furnace slag cement manufacture						+				+			
Chemical/industrial applications													x
Slaked lime replacement											+		+
Smelting fluxes		+	+		+	+							
Waste vitrification	+	+	+		+	+							

- x Proven re-use application, with successful projects running in the UK
 - + Re-use application that has been proven in theory but no re-use project is currently running in the UK
 - Unsuitable for recycling in untreated form
- Source:* [70, The Castings Development Centre 1999], [100, TWG 2002]

Cross-media effects

Pretreatment requires energy and may generate dust emissions.

Technical considerations relevant to applicability

Generally applicable.

The technique is applicable for new and existing installations, as long as there is a suitable local market for the residue.

Economics

The costs associated with recycling are mainly the processing and transport costs, but these can possibly be reduced by taking into account the income generated from selling the material. However, the latter in general may be low or close to zero, whereas typically mechanical treatment costs are in the range of EUR 8/tonne.

The further the materials have to be transported, the greater the increase in costs. In order to assess the economic viability of the re-use option, the applicable disposal costs should be taken into account. These differ between various regions and depend on the residue type.

Driving force for implementation

Legislation stimulating the recycling of mineral wastes, partly by setting high disposal fees to reduce the amount of residues for disposal.

Example plants

Multiple examples of sand and slag recycling have been reported throughout Europe, e.g. in Finland, the Netherlands, Belgium, Germany and the UK.

Reference literature

[70, The Castings Development Centre 1999], [100, TWG 2002]

3.2.1.4.5.4 Adjustment of the slag acidity/basicity

Description

Use of an appropriate flux (e.g. limestone for acidic and calcium fluoride for basic cupola operations) to render the slag fluid enough to separate from the iron.

Technical description

A flux is used to render the slag fluid enough to separate from the iron and to allow it to flow freely from the cupola. The most commonly used flux is limestone (calcium carbonate), which calcines in the cupola shaft to form lime, a basic oxide, which then combines with the other slag-forming constituents (mainly acidic in character) to provide a fluid slag.

The basicity of a slag is given by the following ratio: $(\text{CaO \%} + \text{MgO \%})/\text{SiO}_2 \%$.

Most cupolas operate with an acidic or slightly basic slag (basicity < 1.2). Basic cupolas (basicity up to 2) offer three advantages:

- higher carbon;
- lower sulphur;
- possibility of charging lower quality scrap.

But they present the following disadvantages:

- silicon losses are high;
- refractory costs are high, unless operating with a liningless cupola;
- fluxing material costs are higher;
- metal analysis is more difficult to control than acid cupola melting.

For acidic cupolas, dry filters can be used. The slag of basic cupolas has a higher melting point. So a flux based on CaF_2 is generally used to make it fluid. In this type of cupola, there are emissions of fluorine-containing components. The application of wet scrubbers reduces emissions of fluorine-containing compounds.

Achieved environmental benefits

Improved operational conditions.

Environmental performance and operational data

No information provided.

Cross-media effects

When wet dedusting is applied, this can lead to additional/higher water consumption and to water emissions.

Technical considerations relevant to applicability

Generally applicable. This technique applies to all new and existing cupola installations. If basic slag is used, a wet dedusting system is necessary.

Economics

No information provided.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

This technique is commonly applied in European foundries using cupola furnaces.

Reference literature

[20, ETSU 1993], [100, TWG 2002], [120, TWG 2003], [169, TWG 2021]

3.2.1.4.5.5 Collection and recycling of coke breeze

Description

Coke breeze generated during handling, transport and charging of coke is collected (e.g. by using collection systems below conveyor belts and/or charging points) and recycled in the process (injected into the cupola furnace or used for recarburisation).

Technical description

The handling, transport and charging of coke results in the production of coke breeze. Specific measures may be adopted for the collection and recycling of this material e.g. collection systems below conveyor belts or, at charging points.

The collected material may be recycled into the process by injection into the cupola or in its utilisation for recarburisation.

Achieved environmental benefits

Minimisation of the generation of residues.

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

Legal requirements.

Driving force for implementation

- High disposal fees for solid residues.
- Legal requirements.

Example plants

The technique is reported for several foundries in Europe.

Reference literature

No reference literature provided.

3.2.1.4.5.6 Recycling of filter dust in cupola furnaces using zinc-containing scraps

Description

Cupola filter dust is partially re-injected into the cupola furnace in order to increase the zinc content in the dust, up to a level that allows Zn recovery (> 18 %).

Technical description

Cupola filter dust can be re-injected into the cupola furnace. The aim of this technique is to achieve an accumulation of metals in the dust, mainly zinc, up to a level that allows reprocessing with Zn recovery (> 18 %). Zn recovery is performed using the Waelz process and reduces the net amount of dust sent out by the foundry.

Recirculation of the dust can be done through re-injection at the tuyères or by charging dust pellets through the charging door; in cold-blast cupola furnaces, coarser dust can be charged into the bottom of the charging pan. All these techniques are applied on an industrial scale. A mass balance analysis can be used to show that the zinc is sublimated and reappears in the recuperated dust. After a number of cycles the dust is rich enough in Zn to allow recovery. External recovery is technically possible above an 18 % Zn level.

There are two limits to recycling dust:

- The zinc essentially appears in the form of Zn_2SO_4 , a compound containing 64 % Zn. This therefore sets the maximum level of enrichment.
- The dust is also enriched in alkali, which causes flame extinction in the combustion chamber. This effect may be solved by injecting water vapour into the combustion air.

Injection at the tuyères can be based on several principles. There are fifteen (status May 2001) European foundries recycling dust by injection at the tuyères. Eleven use the positive pressure technique, and four use the venturi suction technique. The advantage of the venturi technique is that it consumes less injection air and so cools the melting zone less. With both techniques, the

dust becomes sticky after successive cycles. In the case of the venturi technique, the dust must therefore be mixed with petcoke to allow its transport in the pipes.

The recirculation of dust through agglomeration and charging is much less common than tuyère injection. This is because the process is much more difficult to automate. Furthermore, good control and knowledge of the pelletisation process is needed to give the pellets the necessary consistency. Ferrosilicon can be added to produce pellets with good consistency. In practical tests a mix of 2/3 FeSi with 1/3 of dust was needed to allow good operation. On the other hand the pellet technique can be used to treat large quantities. For cupolas with larger diameters, tuyère injection of the dust into the centre of the fire is difficult, this therefore favours the use of pellets.

Reintroduction of dust with a greater grain size (coming from the cyclone or from the heat exchangers) in the cold blast cupola is easier, and the process can be automated.

The properties of these techniques are compared in Table 3.29.

Table 3.29: Properties of injection techniques for recirculation of cupola furnace dust

Re-use of the fines collected in the purification of the cupola off-gas	Injection through nozzles	Introduction as pellets / bulk dust in the bottom of the charging pan	Observations
Influence of the waste			
Limitation in the introduced amount of fines	7 – 8 kg/tonne metal		Problem of extinction of flame
Reduction in the generated amount of fines	40 %	50 %	Approx. ⁽¹⁾
Increase in the content of zinc in the fines	30 %	20 %	Approx. ⁽¹⁾
Increase in slag production	?	?	
Influence on the operation of the cupolas			
Amount of coke necessary to counteract the temperature loss	0.5 – 0.6 %	0.2 – 0.3 %	Approx. ⁽¹⁾
Variation in the analysis of off-gases	No	No	n.a
Influence in melted metal			
Increase in the metal content (Zn, Pb) in the iron	Limited	No	(in the order of thousandths)
Influence in the losses to fire	10 – 30 %	No	Approx. ⁽¹⁾⁽²⁾
Effectiveness to add other products (C, FeSi) with the same method	Yes	No	n.a
Costs			
Reduction in the disposal cost of the fines	60 %	50 %	Approx. ⁽¹⁾
Operations			
Possibility of automating the process	Yes	Yes	n.a
Additional Problem	No	Yes	Crash-resistance of the pellets
Implementation of technology			
Existing Facilities	Yes	Yes	Preferably cupolas of large size
New facilities	Yes	Yes	
⁽¹⁾ Approximation, real value depending on the initial zinc oxide content the fines, of the degree of necessary enrichment for its re-use, and on the characteristics of the cupola.			
⁽²⁾ Function of the amount of steel in the load of the cupola.			
n.a: not applicable.			
Source: [37, FEAF 1999] (IT submission in [237, TWG 2023])			

Achieved environmental benefits

The main benefit of the technique is a decrease in the net amount of dust sent out by the foundry, for disposal or recovery. The foundry typically sends out a smaller amount of dust, but with a higher load of metals. This allows the recovery of Zn from the cupola dusts. The technique results in an enrichment of the Zn in the cupola dust, while for Pb a larger share ends up with the iron. If the Zn is effectively recuperated from the dust, the technique decreases the heavy metal load of the final dust for disposal, as well as its amount. On the other hand, the amount of slag produced increases.

Environmental performance and operational data

Recovery is technically possible above an 18 % Zn level. Cupolas with a Zn-rich charge have Zn levels in the dust > 20 %, without recirculation. A minimal content of 40 % zinc is needed for cost neutral recovery (see also Economics below).

It is not possible to re-inject the full dust production of a furnace. Injection of more than 8 kg/tonne metal results in an extinguishing of the flame.

An analysis of the input and output flows of French cupolas resulted in the mass balance shown in Figure 3.33 and Figure 3.34. The contribution of each flow to the Zn in/output is given together with the zinc level (as mass and %). The percentages given are average values over the indicated measuring period.

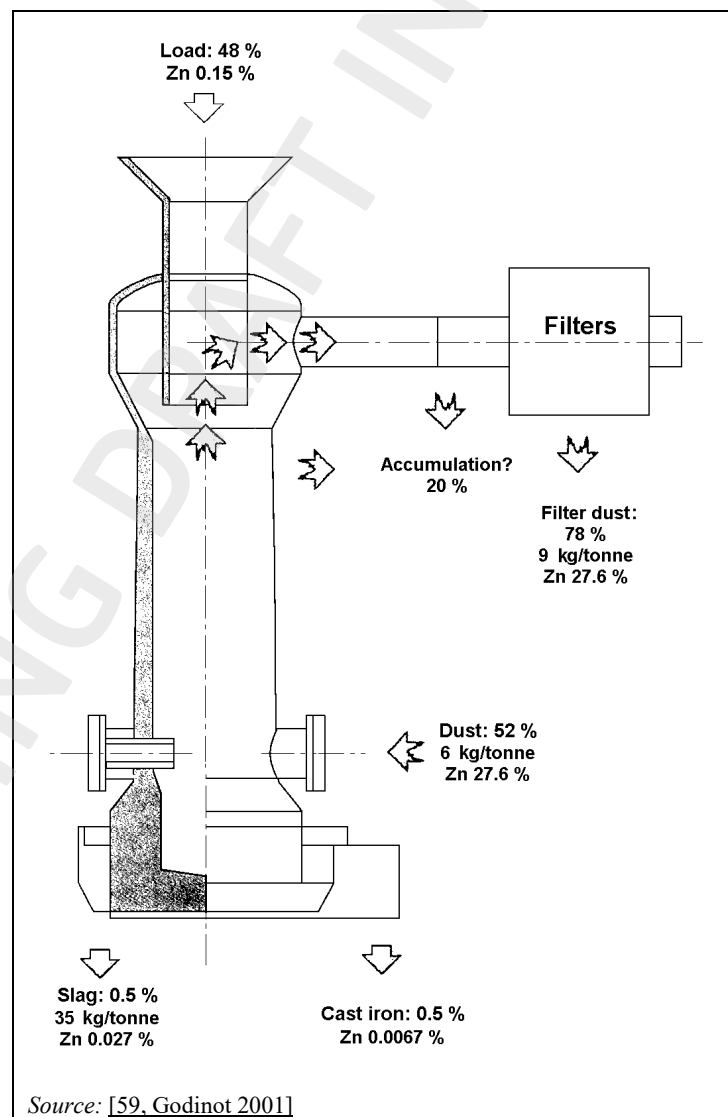


Figure 3.33: Zinc distribution for tuyère injection, upon injection during 20 days

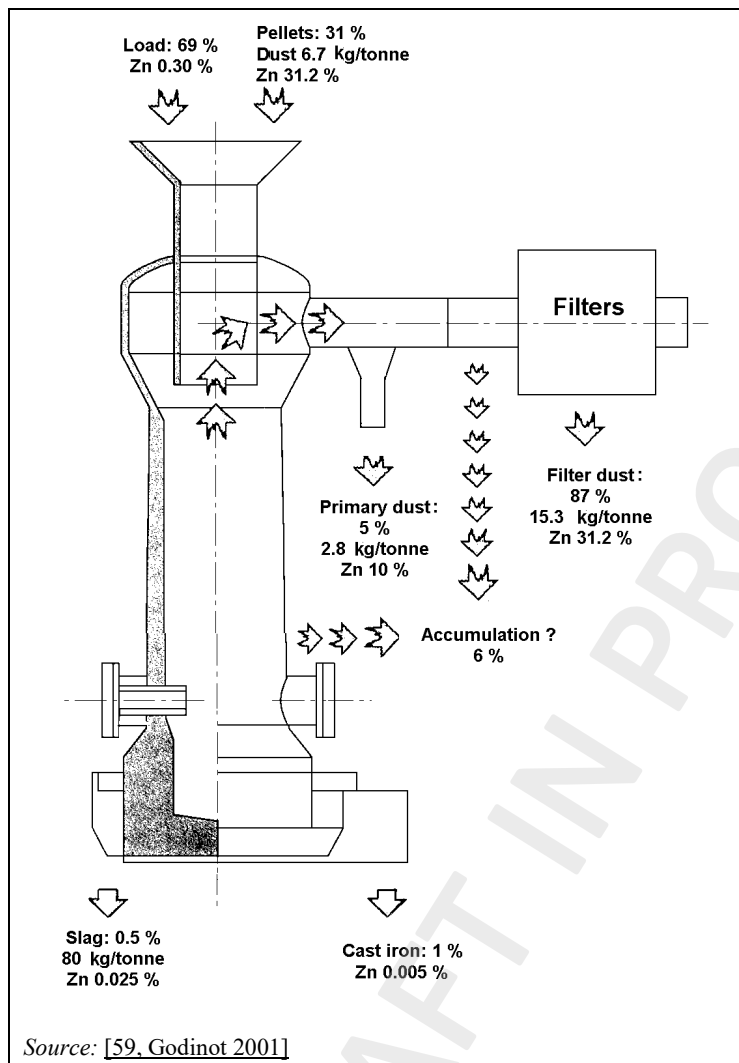


Figure 3.34: Zinc distribution for recirculation through the charge, upon charging during 11 days

The analysis of the input and output flows do not allow a full closure of the zinc balance. This indicates that a considerable part of the zinc (20 % for tuyère injection, 10 % for pellet charging) remains and accumulates in the system. Upon recirculation, the dust gets sticky and deposits in the combustion chamber, heat-exchanger and filters. The recirculation will therefore require increased cleaning efforts and will result in a material for disposal at this cleaning stage.

Mixed results (both positive and negative) have been reported by several foundries in Europe.

The recirculation of cupola dust (yearly iron production: 30 000 tonnes) in a Dutch iron foundry reduced the net amount of dust by 156 t on a yearly basis, without any significant effect on the environmental and construction qualities of the slag.

However, a Belgium foundry used to recycle the filter dust in the cupola furnace before 2022. Experience showed that it could not be continued due to several important disadvantages and significant negative impacts, such as:

- increased risk of clogging of the fabric filter sleeves when too much filter dust was recycled, leading to increased dust emissions;
- increased concentration of heavy metals after remelting, leading to quality issues;
- increase of coke consumption by 5 % to 10 %.

For these reasons, this technique is not employed anymore at this plant and it was recommended by the plant operator that it should not be considered BAT [225, COM 2022].

In an Italian foundry, the technique of dust reintroduction in the cold blast cupola is normally in use, as 2% of the weight of the charge, without any problem in the functioning of the furnace. It has significant advantages in terms of reducing the total amount of dust to be sent for disposal and in terms of material efficiency for the use of unburned organic substances present and the metals that are incorporated into the liquid metal produced (IT submission in [237, TWG 2023]).

Cross-media effects

The technique consumes energy, i.e. coke, to melt the product. An increase in coke use of 0.15 kg to 0.25 kg cokes/kg dust at a thermal efficiency of 40 % of the furnace is reported.

In addition, the injection of cold dust in the hot melting zone will lower the flame temperature, which accordingly will have to be restored by an injection of oxygen. The total amount of slag produced will also increase.

The loading of sticky dust to several of the internal parts of the system will cause medium-term loss of efficiency and possibly operational problems. These have not been quantified.

Technical considerations relevant to applicability

Generally applicable.

Economics

Recovery is technically possible above an 18 % Zn level. Operators report profitability of the recirculation and Zn recovery occurring for a Zn level > 40 %.

From the practical data from two foundries in France, additional operational costs were calculated. Tuyère injection showed an additional operational cost of EUR 0.35/tonne cast iron; pellet injection EUR 0.90/tonne cast iron (2001 data). This calculation does not take into account any extra costs for slag disposal or maintenance works.

In the case of Venturi injection, the following data apply. In a German reference plant over a 5-year period an average of 7.5 kg zinc dust/tonne melted iron could be delivered to the processing industry. Disposal costs were thereby reduced by EUR 1.97/tonne liquid iron. Furthermore, 20 % of the coke could be replaced by petcoke. This allowed a reduction in the fuel cost of 15 %, which corresponded to a cost reduction of EUR 2.56/tonne liquid iron (2001 data). This calculation does not take into account any extra costs for slag disposal or maintenance works.

In the case of an Italian foundry, the reintroduction of the dusts in the furnace has allowed a saving of EUR 3.40/tonne liquid iron in the cost of disposal (2021 data) (IT submission in [237, TWG 2023]).

Driving force for implementation

- High disposal costs for furnace dusts.
- Legal requirements.
- Local conditions.

Example plants

- Venturi (NPT): Pont-a-Mousson (FR), Brebach (DE).
- Positive Pressure (VELCO): John Deere, Mannheim (DE).
- Bulk dust in the bottom of the charging pan: Montini (IT).

Reference literature

[37, FEAF 1999], [38, Vito 2001], [47, EU Thematic Network Foundry Wastes 2001], [59, Godinot 2001], [80, Ruffin, A. and Godinot, P. 1998], [96, Fischer 2000], [100, TWG 2002], [225, COM 2022], (IT submission in [237, TWG 2023])

3.2.1.4.5.7 Recycling of filter dust in the EAF

Description

Collected dry filter dust, usually after pretreatment (e.g. by pelletising or briquetting), is recycled in the furnace to enable the recovery of the metallic content of the dust. The inorganic content is transferred to the slag.

Technical description

Dry collected furnace dust can, under certain circumstances, be recycled in the furnace. The dust will preferably be pretreated, e.g. by pelletising or briquetting, as this will reduce the amount of dust that is just blown through the furnace. The idea is to recover the metallic part of the dust and to melt the inorganic part to slag. In general, the dust is added at the beginning of each melting cycle.

As discussed for cupola furnaces, and for the EAF, in some cases where significant quantities of Zn-containing scrap are used, recycling can lead to a Zn enrichment of the furnace dust up to a level where it can be used in the zinc industry (off-site) for the recovery of Zn if economically viable (up to 30 – 40 %).

Achieved environmental benefits

The main benefit of the technique is a decrease in the net amount of dust sent out by the foundry, for disposal or recovery. The produced dust contains a higher load of metals.

Environmental performance and operational data

Operational data from EAF steelmaking show a plant which recycles 75 % EAF dust from an original yield of 20 – 22 kg/t, and so only has to take care of about 50 % of the dust, with an average zinc content of 35 %.

Cross-media effects

Dust recycling possibly reduces furnace efficiency and rises the consumption of electrical energy (approximately 20 – 30 kWh/tonne). The technique results in an increased production of slag.

Technical considerations relevant to applicability

Generally applicable.

The technique is mainly used in case of dusts with a high metallic load. The actual use though depends on many factors, which may be dissimilar for different plants.

Economics

The technique does not involve any additional investment.

Driving force for implementation

- High disposal costs for furnace dusts.
- Legal requirements.
- Local conditions.

Example plants

This technique is applied in several European foundries.

Reference literature

[14, CAEF 1997], [109, COM 2013]

3.2.1.5 Diffuse emissions to air

Diffuse emissions occur when emissions from specific process sources are not collected. Besides the process-related emission sources, potential sources of diffuse emissions to air include:

- storage areas (e.g. bays, stockpiles, heaps);
- the loading and unloading of transport containers;
- transferences of material from one vessel to another (e.g. furnace, ladle, silos);
- the mixing and curing of chemical binders (inorganic and organic chemical emissions);
- mould coatings (solvents);
- conveyor systems for moving material around;
- pipework and ductwork systems (e.g. pumps, valves, flanges, catchpots, drains, inspection hatches, etc.);
- poor building containment and extraction;
- bypass of abatement equipment (to air or water);
- an accidental loss of containment from a plant or equipment failure, including leakages, e.g. from the sand reclamation plant;
- spills.

In order to minimise diffuse dust emissions, the following techniques may be employed:

- the covering of skips and vessels;
- the avoidance of outdoor or uncovered stockpiles;
- where outdoor stockpiles are unavoidable, using sprays, binders, stockpile management techniques, windbreaks, etc.;
- cleaning wheels and roads (i.e. avoiding the transfer of pollution to water and wind);
- using closed conveyors, pneumatic conveying (although note the higher energy needs), and minimising drops;
- vacuum cleaning of the moulding and casting shop in sand moulding foundries, with the exception of areas where the sand has a technical or safety-related function, e.g. the pouring area, and with the exception of hand-moulding jobbing foundries;
- keeping outside doors shut, e.g. using an automatic shutter system or flaps;
- carrying out good housekeeping, i.e. ensuring that regular inspections are carried out by responsible and delegated staff as a practice of good housekeeping and keeping up-to-date records;
- in-process or primary measures for avoiding or reducing emissions (e.g. minimisation of binder and resin consumption).

[62, UK Environment Agency 2002], [64, UK Environment Agency 2002], [1, COM 2017]

3.2.1.5.1 Covering the delivery equipment (containers) and the cargo space of transport vehicles

Description

The cargo space of transport vehicles and delivery equipment (containers) is covered (e.g. with tarpaulins).

Achieved environmental benefits

Reduction of uncontrolled diffuse emissions to air.

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable. The technique is applicable to all new and existing installations.

Economics

The technique does not involve any additional investment or operational cost.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

Widely used.

Reference literature

[169, TWG 2021]

3.2.1.5.2 Cleaning roads and transport vehicle wheels

Description

Roads as well as the wheels of transport vehicles are regularly cleaned, e.g. by using mobile vacuum systems, water lagoons.

Achieved environmental benefits

Avoiding the transfer of pollutants to water and air.

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable.

Economics

The technique does not involve any significant additional investment or operational cost.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

Widely used.

Reference literature

[62, UK Environment Agency 2002], [64, UK Environment Agency 2002], [1, COM 2017], [169, TWG 2021]

3.2.1.5.3 Use of closed conveyors

Description

Materials are transferred using conveyor systems, e.g. closed conveyors, pneumatic conveying. Material drops are minimised.

Technical description

Material is transferred using closed conveyors, pneumatic conveying (although it may be associated with higher energy needs). Special attention is paid to minimising material drops as much as possible.

Achieved environmental benefits

Reduction of uncontrolled diffuse emissions to air.

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable.

Economics

Pneumatic conveying requires additional energy.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

Widely used.

Reference literature

[62, UK Environment Agency 2002], [64, UK Environment Agency 2002], [1, COM 2017], [169, TWG 2021]

3.2.1.5.4 Vacuum cleaning of moulding and casting process areas**Description**

The moulding and casting process areas in sand moulding foundries are regularly vacuum cleaned.

Technical description

Vacuum cleaning of the moulding and casting shop in sand moulding foundries, with the exception of areas where the sand has a technical or safety-related function, e.g. the pouring area, and with the exception of hand-moulding jobbing foundries.

Achieved environmental benefits

Reduction of uncontrolled diffuse emissions to air.

Cross-media effects

None.

Technical considerations relevant to applicability

May not be applicable in areas where the sand has a technical or safety-related function.

Economics

The technique does not involve any significant additional investment or operational cost.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

Widely used.

Reference literature

[62, UK Environment Agency 2002], [64, UK Environment Agency 2002], [1, COM 2017], [169, TWG 2021]

3.2.1.5.5 Substitution of alcohol-based coatings with water-based coatings**Description**

Substitution of alcohol-based coatings of moulds and cores with aqueous coatings. Aqueous coatings are dried in ambient air or using drying ovens. See Section 3.2.1.9.12.

3.2.1.5.6 Control of emissions from quenching baths**Description**

This includes the following:

- Minimising the generation of emissions from quenching baths by using water-based polymer solutions (e.g. containing polyvinylpyrrolidone or polyalkylene glycol).
- Collecting emissions from quenching baths (especially from oil quenching baths) as close as possible to the emission source, using roof ventilation, extraction domes or edge extractors. Extracted off-gases may be treated, e.g. by using an ESP (see Section 3.2.1.10.5).
- Use of tempered water as quenching media.

Technical description

To establish certain metallurgical properties, steel castings are subjected to heat treatments. It may be necessary for the parts to be rapidly cooled. Quenching can be done with different cooling agents and are chosen mainly by the differences in cooling rates and can be divided in the following main groups:

- Oils;
- Water based polymer solutions;
- Water/salt solutions (brine);
- Pure water.

Oil cooling is slower than water cooling and the different methods are used depending on the desired microstructures. The sensitivity for cracking the products due to cooling rate is also a factor that should be taken into consideration. (SE input in [223, SF TWG 2023])

Emission capture and reduction essentially involves the capture of fume at the quenching baths, especially at the oil quenching baths. Roof ventilation, extraction domes and edge extractors are used. Here similar difficulties arise as with shake-out grids. The baths must be frequently loaded by a crane, so the extraction hoods need to be installed high above the hall floor.

The usually applied extraction techniques for different types of baths are characterised in Table 3.30.

Table 3.30: Usually applied fume collection techniques for quenching baths

	Roof ventilation	Dome-shaped roof	Dome, rigid	Dome, adjustable	Edge extraction
Water	x				
Emulsion	x	x	x	x	x
Hardening oil	x	x	x	x	x
NB: x : applicable Source: [14, CAEF 1997]					

Edge extractors are only effective up to a certain size and lose their effectiveness almost completely at the time of the highest emissions, i.e. when a hot workpiece is submerged in the bath. In spite of this, edge extraction is the most sensible capture measure, utilising big baths combined with a blast veil and a roof dome.

Abatement systems are not widely applied at this point in general, but if any abatement is performed, electrostatic filters are mostly used.

Achieved environmental benefits

In case of oil-based quenching of castings, extraction of exhaust gases results in reduction of diffuse emissions of oil-mists.

A new system has also been developed where quenching baths are filled with a polymer solution. The polymer solution consists of an aqueous polyvinyl concentrate with anti-rust, anti-foam additives and preservatives. It contains no hazardous ingredients and is non-flammable.

By changing the concentration of the polymer solution, different cooling curves can be realised. This is particularly inspired by similar oil-cooling curves, where the disadvantages of quenching in oil emulsions such as oil fumes, odour nuisance and fire hazards can be avoided.

By using a polymer solution with a concentration between 12 % and 15 %, similar hardness and delay results can be achieved compared to an intense high-quenching oil.

Usually aqueous solution at concentrations between 5 % and 15 % are used. Polymer basic materials are usually products based on polyvinylpyrrolidone (PVP), polyalkylene glycol (PAG). [133, DE UBA 2014]

Advantages of using polymer solution compared to the use of oil-water emulsion for quenching are:

- favourable emission characteristics;
- lower odour nuisance;
- not combustible.

The emissions from water use in the quenching bath is mainly steam and do not need any extraction, compared to oil bath.

The water quality needed is normally low and water can easily be recycled. Excess water does not need special handling since it is not considered hazardous waste like waste water from quench bath with oil. Water is also an enabler for easy heat recovery (SE input in [223, SF TWG 2023]).

Environmental performance and operational data

In terms of emissions, the use of polymer solutions offers significant advantages over the use of quenching oil. Thermal stress of the quenching oil at a temperature range between 120 °C and 300 °C results in increasing oil vapour rates. Higher temperatures may lead to formation of cracked gases. In case of incomplete combustion, flue gases may result containing carbon monoxide, hydrocarbons, oil vapour, aldehydes, carbon black, partly also aromatic or polycyclic hydrocarbon compounds.

By using polymer solution vapour is minimised and no dip flame are produced so that no fumes are released.

The following table summarises operational data for quenching with polymer solutions.

Table 3.31: Operational data quenching

Pool size	Ca. 30m ³
Content	30 000 litres
Rec. concentration	10 – 30 %

Application temperature	20 – max. 50 °C
Source: [133, DE UBA 2014]	

Cross-media effects

Extraction of exhaust gases consumes energy.

In the case of polymer-based quenching, due to the extreme thermal stress of the polymer components during the quenching process, formation of thermal degradation products, such as short-chain hydrocarbon compounds or carbon dioxide, can be expected. Anyhow, the total amount of emitted organic substances is lower compared to the use of oil. No measuring and analytical data are available. [133, DE UBA 2014]

Technical considerations relevant to applicability

Generally applicable.

The following factors may influence the applicability of polymer-based quenching:

- Check whether the required cooling curves can be realised. Certain cooling curves may not be possible.
- Technically, existing oil quenching baths (pools, tanks for oil emulsion) can be usually converted for application of polymer solution without problems. However, the quenching baths of polymer solution may require more space. [133, DE UBA 2014]

Economics

Application of the polymer-based quenching technique does not require additional installations. Significant changes in the operating, maintenance and disposal costs are not to be expected either. [133, DE UBA 2014]

Driving force for implementation

- Regulations on emissions and occupational health and safety.
- Legal requirements.

For polymer-based quenching, the following were reported:

- Favourable emission behaviour with respect to organic substances in comparison to an oil bath;
- Simple control of the concentration which is responsible for the quenching effect;
- Occupational safety: no risk of fire.

Example plants

Extraction of emissions from quenching is applied in several foundries around Europe. Polymer-based quenching: Stahlwerke Bochum GmbH 44791 Bochum, Germany. Quenching steel with pure water: Sandvik SRP AB in Svedala, Sweden.

Reference literature

[14, CAEF 1997], [133, DE UBA 2014], [223, SF TWG 2023]

3.2.1.5.7 Control of emission from transfer operations in metal melting**Description**

This includes the following:

- i. Extraction as close as possible to the source of diffuse emissions (e.g. dust, fumes) from transfer processes such as furnace charging/tapping using hoods, for example. The

extracted off-gases are treated using, for example, fabric filters, wet scrubbing (see abatement techniques in Section 3.2.1.9).

- ii. Minimisation of diffuse emissions from liquid metal transfer through launders using covers for example.

Technical description

Dust from material transfers, e.g. to the furnace, is collected or furnaces are enclosed. The emissions are collected and extracted and the collected emissions are treated where dusty material transfers take place (e.g. furnace opening, charging and tapping points, transfer of liquid metals, covered launders). Potential difficulties in applying this technique in cases of big ladles (e.g. with a capacity of more than 2 000 kg) or in bottom pouring ladles has been reported [237, TWG 2023].

Achieved environmental benefits

Reduction of uncontrolled diffuse emissions to air.

Environmental performance and operational data

No information provided.

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable.

Economics

Costs will depend on technical factors.

Driving force for implementation

- Regulations on emissions and occupational health and safety.
- Legal requirements.
- Local considerations.

Example plants

[210, TWG 2022]

Reference literature

[210, TWG 2022], [237, TWG 2023]

3.2.1.6 Channelled emissions to air

3.2.1.6.1 Limiting the number of emission points

Description

The combined treatment of waste gases with similar characteristics ensures more effective and efficient treatment compared to the separate treatment of individual waste gas streams. The combination of waste gases is carried out considering plant safety (e.g. avoiding concentrations close to the lower/upper explosive limit), technical (e.g. compatibility of the individual waste gas streams, concentration of the substances concerned), environmental (e.g. maximising recovery of materials or pollutant abatement) and economic factors (e.g. distance between different production units). Care is taken that the combination of waste gases does not lead to the dilution of emissions.

Technical description

In order to obtain maximum advantage from thermal buoyancy, hot emissions may be combined into the minimum practicable number of chimneys. A multiplicity of discharge points may thus

be avoided. This is particularly important when new plants are being designed or when changes are being made to existing processes.

Foundries are generally equipped with more than one furnace, and several moulding, core-making and casting lines may be used in the same plant. 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

Gathering multiple off-gas streams into one stack allows control of the emissions and increases the total volume (and load) going to treatment and thus reduces the total emission level.

Energy savings and improved abatement efficiency of emissions to air are other benefits.

Environmental performance and operational data

In a number of foundries, several emission points are often combined, e.g.:

- emissions from the same type of furnaces may be combined into one (e.g. melting furnaces / heat treatment furnaces);
- emissions from parallel moulding / core-making lines;
- emissions from casting, cooling and shake-out operations.

Cross-media effects

None expected.

Technical considerations relevant to applicability

Generally applicable.

Economics

Costs will depend on technical (e.g. compatibility of the individual waste gas streams) and economic factors (e.g. distance between different emission points).

Driving force for implementation

Reduction of monitoring and abatement costs due to a lower number of emission points.

Example plants

Widely used in foundries.

Reference literature

[62, UK Environment Agency 2002]

3.2.1.7 Emissions to air from thermal processes

3.2.1.7.1 Selection of an appropriate furnace type

Description

Selection of the appropriate furnace type(s) based on the level of emissions and technical criteria, e.g. type of process such as continuous or batch production, furnace capacity, type of castings, availability of raw materials, flexibility depending on raw materials' cleanliness and alloy change. The energy efficiency of the furnace is also considered (see Section 3.2.1.3.1).

Technical description

Given the fact that various melting techniques show overlapping fields of application, a basic technique is the selection of the melting technology. In this selection, the decisive criteria include technical/operational and environmental criteria that are summarised below:

- metal type (alloying concept);
- continuous or batch production;
- size of the series (long or short series production/product portfolio);
- metal throughput or capacity;
- flexibility towards input material type and cleanliness;
- flexibility towards alloy change;
- type of product made;
- overall production volume;
- emissions and other environmental considerations;
- availability of raw materials;
- availability of fuels/electricity.

The application of the different melting techniques is very dependent on the criteria indicated above. In addition, considerations based on the energy efficiency of the various furnaces and potential melt losses associated are also key factors to consider. This is discussed separately in Section 3.2.1.3.1.

For cast iron production, the following generalities can be made:

- *Metal type*: Electrical furnace are better suited for production of nodular or alloyed cast iron.
- *Continuous production*: Cupola is better suited for continuous production of cast iron.
- *Batch production*: Electrical or rotary furnace are better placed for batch production of cast iron.
- *Flexibility towards input material type and cleanliness*: Cupola allows better flexibility towards input materials (e.g. use of scrap of lower quality).
- *Flexibility towards alloy change*: Induction and rotary furnace offer better flexibility in terms of alloy change.
- *Environmental considerations*:
 - cupola is better placed only if well de-dusted;
 - induction furnaces have a lower CO, SO₂, NO_x, dioxin emissions and slag formation rate than cupola furnaces; indirect emissions from electricity production need to be considered.
- *Availability of raw materials*: When cheap scrap is available, the cupola is better placed.

It is noted that the generalities mentioned above may be subject to reconsideration following recent trends in decarbonisation of the thermal processes in general and the ‘green’ transformation of the sector.

When selecting an appropriate furnace type, all these criteria must be considered together. Table 3.32 gives a summary of the criteria to consider when choosing between cupola, induction or rotary furnaces in the case of cast iron production.

The use of cupola furnaces for production of lamellar cast iron or nodular iron has been shown to be more cost-effective only for total throughputs above 10t/h and 20t/h, respectively. Accordingly, induction or rotary furnaces, which provide a better environmental performance overall than cupola furnaces, are often a preferred choice in small foundries.

Table 3.32: Choice of the melting equipment for cast iron melting

CRITERION		ONLY GREY CAST IRON					GREY + NODULAR	ONLY NODULAR CAST IRON			ONLY MALLEABLE CAST IRON
Type of product made		Counter weights	Sewer castings, pipes, urban furniture	Enameled castings, heating appliances	Mechanical parts		Mechanical parts	Sewer castings, pipes, urban furniture	Mechanical parts		Mechanical parts
Size of series		Medium to large	All	Medium to large	Batch to small	Medium to large	All	All	Batch to small	Medium to large	Medium to large
Cupola	Cold blast	++	++ (<10 – 15 t/h)	++ (<10 – 15 t/h)		++ (<10 – 15 t/h)			(+)		
	Hot blast	+	++ (>10 – 15 t/h)	++ (>10 – 15 t/h)	0	++ (>10 – 15 t/h)		++ (>10 – 15 t/h)	0	+ (>10 – 15 t/h)	
Induction			+	+	++	++	++	+	++	++	++
Rotary furnace		(+) batch			++	+	++	(+) batch or small series	++		++
NB: ++: technically more adapted; +: technically adapted (+): adapted in some cases 0: not adapted Source: [100, TWG 2002]											

Achieved environmental benefits

Replacement of a cupola by an induction or rotary furnace results in a reduction in the direct emissions of CO and SO₂ and a reduced amount of slag. Induction furnaces show a reduced emission of NO_x and a lower risk of dioxin formation. The indirect emissions generated by the use of induction furnaces, depend on the local electricity generation infrastructure.

Environmental performance and operational data

No information provided.

Cross-media effects

Replacement of a cupola by an induction furnace generates a strong increase in electricity consumption.

Technical considerations relevant to applicability

Only applicable to new plants and major plant upgrades.

The replacement of a cold blast cupola by an induction or rotary furnace is applicable under the criteria stated above and upon major refurbishment of the installation.

For new installations, the criteria of Table 3.32 apply besides local and site-specific considerations. If cupola and induction or rotary furnaces are indicated as most adapted, the induction and rotary types may be preferred on the basis of their environmental benefits.

Economics

In Table 3.33 a summary is given of cost data collected by an example Spanish foundry that wanted to replace an existing cupola by a rotary or electric furnace. No emission collection or filtration equipment costs are included. Data are from 1997 – 1998. The comparison involves the following three systems:

- cold blast cupola: 3.5 tonnes/h capacity;
- oxy-fuel rotary furnace: 3 tonnes capacity;
- 2 medium frequency induction furnaces: 2 + 1 tonne capacity.

The cost calculation was performed for melting costs for a melting production of 1 tonne/h, working 8 hours/day. For the induction furnace a distinction is made between peak-time electricity costs and off-peak-time. Since electricity is the major component of the costs, this distinction makes a big difference to the final cost. Operation of the induction furnace during off-peak time (night-time) results in costs comparable to rotary furnace costs. The data show that the investment has a 5 – 9-year payback period.

Table 3.33: Example plant cost data for replacement of an existing cupola with a rotary or induction furnace

Costs in EUR/tonne of molten metal	Cupola	Rotary	Induction	
Energy	30.7	29.8	40.8 27.2	(peak) (valley)
Refractory	3.6	1.3	1.4	
Man power	52.9	22.7	22.7	
Raw materials	205	205	205	
Total cost	292	259	270	
Yearly costs in EUR				
Cost for melting 1320 tonne/year	385000	341000	356000 338000	(peak) (valley)
Savings	none	44000	29000 47000	(peak) (valley)

Costs in EUR/tonne of molten metal	Cupola	Rotary	Induction	
Investment	none	250000	260000	
Building		Not needed	Needed	
NB: Data from 1997 – 1998, Spain				
Source: [100, TWG 2002]				

Driving force for implementation

- Reduction of direct emissions from cast iron melting.
- Legal requirements.

Example plants

Conversion from coke-fired cupola to induction furnaces:

- Römheld & Moelle Eisengießerei GmbH (DE),
- Kovis (SI).

Reference literature

[100, TWG 2002], [38, Vito 2001], [120, TWG 2003]

3.2.1.7.2 Use of clean scrap

More information on the technique

See Section 3.2.1.3.4.

3.2.1.7.3 Techniques for maximising the thermal efficiency of furnaces

More information on the technique

See Section 3.2.1.3.2.

3.2.1.7.4 Use of a fuel or a combination of fuels with low NO_x formation potential

Description

Fuels with a low NO_x formation potential include natural gas and liquefied petroleum gas.

Technical description

In order to reduce or control NO_x emissions, a fuel or a combination of fuels with low NO_x formation potential can be used. This technique generally involves the use of fuel gas (e.g. natural gas) instead of liquid fuels. Fuel gas usually has a low content of nitrogen compounds and complete combustion is achieved more easily than with liquid fuels.

Achieved environmental benefits

Reduced NO_x emissions.

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

Legal requirements.

Example plants

Many plants use natural gas as fuel gas. Some plants also reported the use of LPG.

Reference literature

[169, TWG 2021]

3.2.1.7.5 Use of a fuel or a combination of fuels with low sulphur content**Description**

Fuels with low sulphur content include natural gas and liquefied petroleum gas.

Technical description

In order to reduce or control SO₂ emissions, a fuel or a combination of fuels with low sulphur content can be used. This technique generally involves the use of fuel gas (e.g. natural gas) instead of liquid fuels. Fuel gas usually has a low content of sulphur compounds (e.g. H₂S, mercaptans) and complete combustion is achieved more easily than with liquid fuels.

Achieved environmental benefits

Reduced SO₂ emissions.

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

Legal requirements.

Example plants

Many plants use natural gas as fuel gas. Some plants also reported the use of LPG.

Reference literature

[169, TWG 2021]

3.2.1.7.6 Low-NO_x burners**Description**

The technique (including ultra-low-NO_x burners) is based on the principle 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

Low-NO_x burner 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. This is generally achieved by air staging, fuel staging and/or internal flue-gas recirculation. [168, COM 2022]

A common mode of operation of low-NO_x burners is the creation of a fuel-rich zone within the flame. This favours the conversion of fixed nitrogen, chemically bound fuel-nitrogen, to N₂. It also has the effect of reducing the peak flame temperature. Both fuel and thermal NO_x mechanisms are retarded and the formation of NO_x is reduced. There are two main types of low-NO_x burners which both involve the use of staged combustion to achieve the desired effect. These are air-staged and fuel-staged burners.

Achieved environmental benefits

- Reduced NO_x emissions.
- Increased energy efficiency.

Environmental performance and operational data

Two foundries in the SF data collection reported the use of low-NO_x burners:

Plant AT015

NO_x emissions from an annealing furnace equipped with low-NO_x burners (emission point N.6) ranged from 30 mg/Nm³ to 120 mg/Nm³ using natural gas and the corresponding CO emissions ranged from 34 mg/Nm³ to 70 mg/Nm³.

Plant DE065

NO_x emissions from a heat treatment furnace (roller hearth furnace) equipped with low-NO_x burners (emission point N.3) ranged from 18 mg/Nm³ to 66 mg/Nm³ using natural gas and the corresponding CO emissions ranged from 0.8 mg/Nm³ to 18 mg/Nm³.

Cross-media effects

None.

Technical considerations relevant to applicability

Applicability to existing plants may be restricted by furnace design and/or operational constraints.

Economics

No information provided.

Driving force for implementation

Legal requirements.

Example plants

[AT015], [DE065]

Reference literature

[168, COM 2022], [169, TWG 2021]

3.2.1.7.7 Oxy-fuel combustion

More information on the technique

See Section 3.2.1.3.7.

3.2.1.8 Emissions to air from heat treatment

3.2.1.8.1 Selection of an appropriate furnace type

Description

Selection of the appropriate furnace type(s) based on the level of emissions and technical criteria, e.g. type of process such as continuous or batch production, furnace capacity, type of castings, availability of raw materials, flexibility depending on raw materials' cleanliness and alloy change. The energy efficiency of the furnace is also considered.

Technical description

Various types of furnaces are used in heat treatment (e.g. bogie hearth furnaces, top hat furnaces, hub open-hearth furnaces, tunnel furnaces or shaft furnaces for pipes, etc.) (comment CAEF-331 in [210, TWG 2022]). Based on the information from the data collection, the following furnace types for the heat treatment process were reported: resistance, induction furnace (electric coreless), bogie hearth, radiant roof, solution annealing and ageing.

Example plants

The plants' reported emissions from heat treatment processes are shown in the presentation of emission data in Section 2.3.2.2.

Reference literature

[169, TWG 2021], [210, TWG 2022]

3.2.1.8.2 Techniques for maximising the thermal efficiency of furnaces

More information on the technique

See Section 3.2.1.7.3.

Example plants

The plants' reported emissions from heat treatment processes are shown in the presentation of emission data in Section 2.3.2.2.

Reference literature

[169, TWG 2021], [210, TWG 2022]

3.2.1.8.3 Use of a fuel or a combination of fuels with low NO_x formation potential

More information on the technique

See Section 3.2.1.7.4.

3.2.1.8.4 Low-NO_x burners

More information on the technique

See Section 3.2.1.7.6.

3.2.1.8.5 Off-gas extraction as close as possible to the emission source

Description

Off-gases from heat treatment furnaces (e.g. annealing, ageing, normalising, austempering) are extracted using hoods or cover extraction. The collected emissions may be treated using techniques such as fabric filters (see Section 3.2.1.12.7).

Achieved environmental benefits

Reduction of emissions.

Environmental performance and operational data

See Section 3.2.3.1.3.

Cross-media effects

Off-gas extraction increases the energy consumption.

Technical considerations relevant to applicability

Generally applicable.

Economics

No information provided.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

Widely used.

The plants' reported emissions from heat treatment processes are shown in the presentation of emission data in Section 2.3.2.2.

Reference literature

[169, TWG 2021], [210, TWG 2022]

3.2.1.9 Emissions to air from core-making and moulding using lost moulds

3.2.1.9.1 Use of best practices for green sand moulding

Description

This includes techniques such as:

- precise addition of the required quantity of key components (e.g. clay, water, coal dust or other additives) to restore the chemical properties of the returned green sand;
- when needed, addition of new silica sand (e.g. up to 10 %) to the returned green sand and disposal of an equivalent amount of spent sand;
- regular testing (e.g. daily) of the green sand properties (e.g. moisture, green strength, compactability, permeability, loss on ignition, volatile content).

Technical description

After pouring iron and steel into green sand moulds, the heat evaporates some water from the sand and burns some of the additives (e.g. coal dust) and a proportion of the clay destroying its bonding properties. It is essential to restore the sand properties by removing burnt clay, coal dust and ash and adding in new clay, coal dust (or dextrin) and water. The following additions are usually carried out at the sand reconditioning mill:

- 0.3 – 0.5 % of new clay;
- 0.3 – 0.5 % of coal dust (or 0.2 % dextrin);
- 1.5 – 2.5 % of water.

Another priority is that new sand must be added on a continuous basis to the returned sand in the ratio of about 10 % of the weight of metal poured, or 2 – 3 % of the sand mixed. Often foundries consider that the sand returned via cores is sufficient, but experience showed that this can create

extensive problems. Indeed, care must be taken because certain core binder residues (particularly from phenolic-isocyanate binders) can degrade the green sand properties.

Good green sand control is essential and depends on careful monitoring of the sand system. The normal additions of clay, coal dust or other additives at each cycle represent only about 10 % of the total active clay or coal present in the system. It is important to bear in mind that changing the total clay or coal dust content quickly is not possible since any change takes about 20 cycles to work its way fully into the system. For example; an addition of 0.3 % clay is usually sufficient to maintain the total clay level at 3.0 %. If the clay addition is increased to 0.4 %, the total clay content after one cycle will only rise to about 3.1 % and it will take 20 cycles (about 1 week) for the clay level to rise to around 4.0 %.

Regular testing of the green sand quality is very important. It is recommended that a minimum of five samples are taken per shift and analysed for key parameters such as: moisture, green strength, compactability and permeability. In addition, the loss on ignition (LOI) and the volatile content should be monitored on a daily basis. It is also good practise to keep a record of the following:

- weight of clay, coal dust and new sand added each day;
- number of moulds made;
- weight of iron poured;
- weight of used sand removed from the system each day.

Achieved environmental benefits

Reduced emissions during pouring.

Environmental performance and operational data

Typical green sand properties for an iron foundries are summarised in the following table.

Table 3.34: Typical green sand properties in iron foundries depending on the type of moulding

Type of moulding	Jolt or squeeze moulding machines	Automatic moulding machines (e.g. DISA)
Water content (%)	3 – 4	2.5 – 3.2
Green strength (kPa / psi)	70 – 100 kPa / 10 – 15 psi	150 – 200 kPa / 22 – 30 psi
Compactability (%)	45 – 52	38 – 40
Permeability	80 – 110	80 – 100
Live clay (%)	5.0 – 5.5	6.0 – 10.0
Volatiles (%)	2.5	2.0
LOI (%)	7.0 – 7.5	6.0

Source: [73, Brown, J. R. 2000]

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable.

Economics

No information provided.

Driving force for implementation

- Material efficiency - minimisation of the number of casting defects.
- Environmental requirements.

Reference literature

[73, Brown, J. R. 2000]

3.2.1.9.2 Preparation of clay-bonded sand by vacuum mixing and cooling

More information of the technique

See Section 3.2.1.4.4.3.

3.2.1.9.3 Substitution of coal dust

Description

Coal dust is replaced by clays (e.g. bentonite) containing additives such as graphite, coke flour and zeolites, resulting in significantly lower diffuse emissions during the casting process.

Technical description

The addition of coal dust in green sand has been shown to greatly improve the stripping of the iron castings after pouring as well as the surface finish of castings. This is due to the formation of lustrous carbon during the heating of the coal dust by the liquid iron which improves the casting surface finish. However, coal dust typically has a volatile content ranging from 33 % to 36 %, generating significant emissions during casting.

To minimise emissions while maintaining the surface finish of castings, coal dust replacement may be used. They generally consist of blends of natural clays (e.g. bentonites) to which additives which may contain essential volatiles are added (e.g. graphite, coke flour, zeolites). Presently, one of the best substitutes is graphite in combination with an adequate dispersing agent.

Achieved environmental benefits

Reduction of VOCs and odour emissions. The reduction ratio depends on the core sand inflow. The positive effect regarding emissions depends on the following factors: [133, DE UBA 2014]

- reduced or no use of lustrous carbon formers (coal);
- enhanced adsorption of emerging casting gases that result mainly from core binders;
- filtration measurements of operating moulding sands from core-intensive green sand systems. Comparing coal-free products with traditional moulding sand additives shows that the reduction of condensates and dust formation during casting can be over 50 %.

Resulting environmental benefits are: [133, DE UBA 2014]

- cleaner workplace: less smoke; carbon monoxide concentrations at the workplace are reduced by approximately 50 %;
- benzene emissions are reduced by approximately 40 %;
- blends have a higher percentage of bentonite than traditional blends with coal; consumption is related to bentonite, so less blend (not bentonite) is used, resulting in less truck loads needed (5-10 %);
- increased possibilities of moulding sand reuse, due to lower content of pollutants and condensates;
- smaller air extraction and filter installations and less cleaning/maintenance.

Environmental performance and operational data

In general, inorganic coal replacements do not emit VOCs during heating/casting. Due to this, they cannot generate lustrous carbon (graphite film from pyrolysis) and carbon residues. Coal replacements are in general graphite, specially treated graphite, coke flour, porous minerals and swelling minerals. Each producer can have a different composition depending on their own research and experience. Products are customised and can be blended with traditional coal-containing products.

Bentonite binders should be of high quality and have a high clay/montmorillonite content to reduce accumulation of accompanying non-clay minerals.

Bentonite preference:

- 85 % montmorillonite,
- durability 50 % after heating the clay for 2 hours at 550 °C,
- compression strength according to VDG P69, above 8 N/cm² and
- wet tensile strength above 0.25 N/cm.

Product classification: not dangerous and no auto-ignition, if not blended with coal. [133, DE UBA 2014]

The use of a mixture containing bentonite, microcrystalline graphite and zeolite instead of coal dust for iron casting was tested by the University of Science and Technology of Krakow, showing that emissions of VOCs and BTEX were reduced by 50 %. [190, Holtzer et al. 2020]

Cross-media effects

None.

Technical considerations relevant to applicability

- Applicability may be restricted by operational constraints (e.g. less efficient shake-out or occurrence of casting defects).
- The technique is applicable as a pure inorganic binder system or as a blend in combination with classical products (coal). It is added to the moulding sand like a traditional moulding sand binder or blends.
- Applicability considerations may arise because of poorer behaviour during shake-out (separation casting and mould) and occurrence of specific casting defects.

Economics

Coal-free blends have higher raw material costs. This can be partly compensated by reduced consumption and by the lower operation cost for air extraction, such as for a smaller installation, less cleaning and maintenance. Less contaminants in the moulding sand waste make it easier to reuse it in other applications and industrial sectors. Savings in transport costs can be achieved due to coal replacement by minerals of which less is needed.

Driving force for implementation

- Legal requirements regarding reducing emissions and regarding occupational health reasons.
- Local requirements.
- Operational requirements:
 - normal moulding sand practice;
 - less/no penetration defects, grey iron casting;
 - waste sand is cleaner.

Example plants

- Iron foundry Componenta in Heerlen/NL.
- The use of a mixture containing bentonite, microcrystalline graphite and zeolite instead of coal dust for iron casting is implemented in a few foundries in the EU. [190, Holtzer et al. 2020]

Reference literature

[73, Brown, J. R. 2000], [133, DE UBA 2014], [190, Holtzer et al. 2020], [210, TWG 2022]

3.2.1.9.4 Use of cereal binders

Description

Cereal binders (e.g. starch, dextrans) are added to increase the toughness of the sand and prevent fracture of the compacted sand during mould drying.

Technical description

Cereal binders (e.g. starch and dextrans) are used mainly in steel casting production, but occasionally in iron casting for specific applications. Cereals tend to increase green strength, dry strength and sand toughness, but sometimes can also reduce flowability.

Dextrans promote better flowability and plasticity. They help with moisture retention and are particularly useful in providing harder and less friable mould surfaces and edges when drying out.

Starches are very good anti-scabbing agents and typically the higher the amount of starch, the greater the resistance to expansion scabbing. Starch is more effective in preventing expansion scabbing than a dextrin and should be employed when making larger green sand moulds.

Achieved environmental benefits

- Increased material efficiency.
- Reduced emissions during pouring.

Environmental performance and operational data

The proportion of cereal binders to new green sand typically ranges from 0.5 % to 0.75 %. Cereal binders lose their properties at temperatures above 225 °C. It is recommended to add between 0.1 % and 0.25 % of cereal binders at each recycle depending on the amount of cereal burn-out.

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable.

Economics

No information provided.

Driving force for implementation

Minimisation of the number of casting defects.

Example plants

No information provided.

Reference literature

[73, Brown, J. R. 2000]

3.2.1.9.5 Minimisation of binder and resin consumption

More information on the technique

See Section 3.2.1.4.3.3.

3.2.1.9.6 Use of best practices for cold-setting processes

More information on the technique

See Section 3.2.1.4.3.5.

3.2.1.9.7 Use of best practices for gas-hardening processes

More information on the technique

See Section 3.2.1.4.3.7.

3.2.1.9.8 Use of non-aromatic solvents for cold-box core production

Description

Non-aromatic solvents are used that are based either on protein or animal fat (e.g. fatty acid methyl esters of vegetable oil) or on silicate esters in order to reduce emissions of VOCs (e.g. benzene, toluene).

Technical description

Classical cold-box systems use organic solvents. These cause releases of noxious and odorous VOCs during core production and storage. Furthermore VOC emissions (benzene, toluene, xylene) occur during pouring, cooling and shake-out. Alternative solvents for cold-box core production are based on protein or animal fat (e.g. vegetable-oil methyl esters) or on silicate esters. These solvents are not noxious to workers health, nor inflammable and therefore transport and storage are easier.

The low volatility of the vegetable-oil methyl esters enhances the storage capabilities in humid atmospheres and their persistence when applying water-based coatings.

The resulting cores have a higher strength, lower sticking of the sand and good shake-out properties.

Achieved environmental benefits

There is no vaporisation due to the high boiling point (about 300 °C) and thus there is no solvent odour emission during storage.

VOC emissions are reduced during core manufacturing and storage, and (more importantly) during pouring, cooling and shake-out.

Environmental performance and operational data

Table 3.35 shows operational emission values for benzene, toluene, xylene and phenol, as measured in one aluminium green sand foundry. Measurements were performed both at the shake-out grate and in the exhaust-air stack. Data are given for the traditional cold-box system and for one using vegetable-oil based solvents. A clear reduction in BTX and C emissions is observed (25-50 % of stack emissions).

Table 3.35: Emission data for cold-box core systems in an aluminium foundry, measured at the shake-out grate and in the exhaust-air stack

Compound	At shake-out			At exhaust-gas stack		
	Aromatic based (mg/m ³)	Vegetable-based (mg/m ³)	Difference (%)	Aromatic based (mg/m ³)	Vegetable-based (mg/m ³)	Difference (%)
Benzene	0.08	0.05	- 44	0.1	0.07	- 30
Toluene	0.12	0.05	- 58	0.08	0.06	- 25
Xylene	0.09	0.04	- 56	0.09	0.05	- 41
Phenol	14.8	14.6	- 2	7.2	6.57	- 9
Total C	61.0	29.5	- 52	37.0	18.5	- 50

Source: [88, Hüttenes-Albertus 2002]

Results of emission measurements in a German iron foundry are given in Table 3.36. For this table, the measured emission of each compound is expressed relative to the emission of the same compound for the aromatic-based system. For example: the emission of toluene at the second cooling is only 58 % of the toluene emission for the aromatic system. The table shows a clear reduction of VOC emissions in the second cooling and shake-out phase.

Table 3.36: Emissions (%) of selected compounds from vegetable-based cold-box core systems

	Benzene	Toluene	Xylene	Phenol
Pouring and cooling 1	83	100	100	100
Cooling 2	78.5	58	46	74
Shake-out	78	78	78	12

Emission data expressed as %, relative to emission of the aromatic based system (set at 100 % for each measurement)
Source: [114, Hobelsberger et al. 1997]

The total mass flow reduction of the specified compounds was:

- benzene: - 21 %;
- toluene: - 26 %;
- xylene: - 30 %;
- phenol: - 62 %.

A survey measurement of the total carbon emission over the full foundry process is given in Figure 3.35. The data show that the vegetable-based solvents partially result in a shift of emissions from the core-making area to the finishing area. Nevertheless, an overall reduction of 17 % carbon emission reduction is reached.

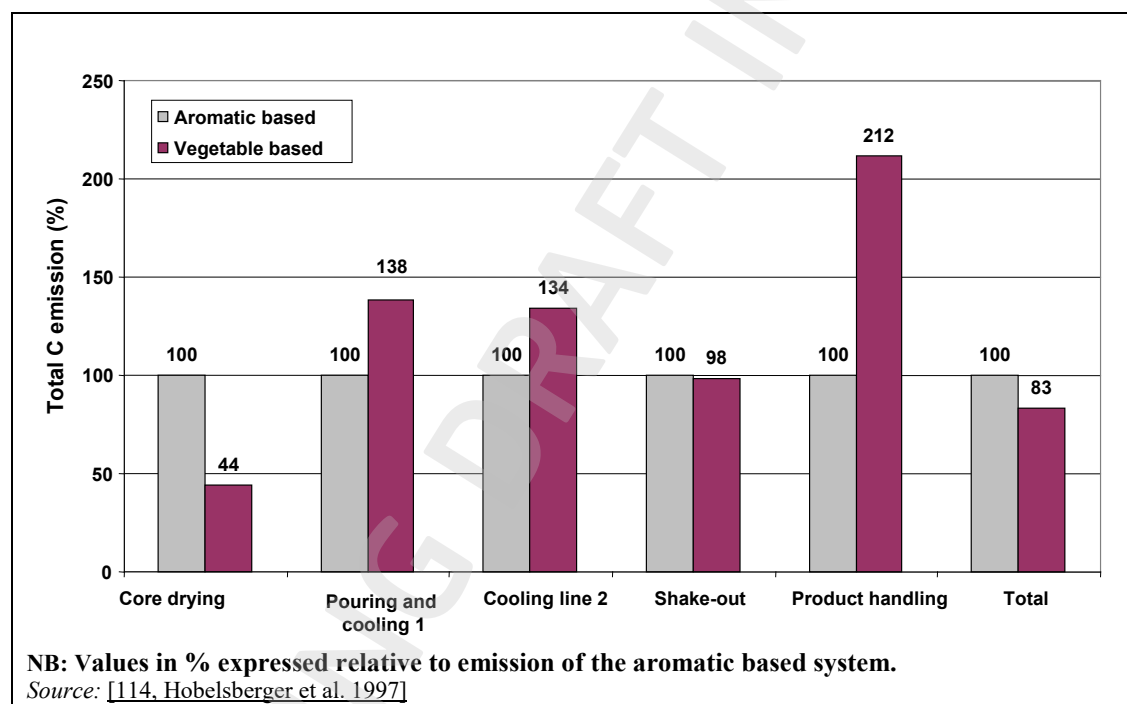


Figure 3.35: Total carbon emissions from various process steps, using aromatic- and vegetable-based solvents

Cross-media effects

Vegetable-based solvents cause increased fume production during pouring and (in the case of die-casting) upon opening of the die. This is due to the low evaporation and consequently high residual solvent content upon pouring. This effect does not occur with silicate ester solvents.

Protein and animal fat based solvents produce a distinctive odour, and have been reported to cause odour problems inside the foundry.

Technical considerations relevant to applicability

Generally applicable.

Economics

Data from the Italian foundry association indicate that non-aromatic solvents have a cost that is double that of the aromatic equivalent, e.g. EUR 0.82/kg against EUR 0.36 – 0.48/kg.

Operational data from a large series ferrous foundry showed that binder prices for aromatic cold box were around EUR 2/kg (2001) and went up with some 30 %, upon changing to the non-aromatic system. After one year (2003), the price lowered again however, to a level 10 % above the price of the traditional system.

Driving force for implementation

- Reduction of VOC and odour emissions.
- Legal requirements.

Example plants

Widely used.

Reference literature

[49, Inasmet and CTIF 2002], [88, Hüttenes-Albertus 2002], [100, TWG 2002], [114, Hobelsberger et al. 1997], [120, TWG 2003]

3.2.1.9.9 Use of best practices for hot-curing processes**Description**

Several hot-curing processes may be used and a series of measures are in place to optimise each process including for the following:

Hot-box process:

- Curing is carried out within the optimum temperature range (e.g. 220 °C to 300 °C).
- Cores are usually pre-coated using water-based coatings to prevent burns at the core surface which may result in brittleness during pouring.
- Core blowers and the area around them are well ventilated and exhausted to capture efficiently the formaldehyde liberated during curing.

Warm-box process:

- Curing is carried out at a lower optimum temperature range than the hot-box process (e.g. 150 °C to 190 °C), resulting in lower emissions and energy consumption than the hot-box process.

Shell (Croning):

- Pre-coated sands with a phenol-formaldehyde resin are binded using hexamethylenetetramine that decompose at 160 °C releasing formaldehyde, necessary for cross-linking the resin, and ammonia.
- The curing and/or core blowers area is well ventilated and exhausted to capture efficiently the ammonia and formaldehyde liberated during curing.

Technical description**Hot-box process**

The hot-box core-making method employs a starting sand mixture comprised of resin binders and a liquid catalyst. A wide range of resins can be used: urea-formaldehyde, urea formaldehyde-furfuryl alcohol, urea-formaldehyde-phenol. The catalysts are aqueous solutions of ammonium chloride or ammonium nitrate (acid salts), with urea additions to reduce the free formaldehyde. Cores are usually pre-coated using water-based coatings to prevent burns at the core surface. The mixture is blown into the interior of the core box and polymerisation takes place by applying heat.

The heat generates an acid vapour from the catalyst which triggers the hardening reaction. Heat is conducted from the outer regions of the sand core to the interior regions and, although the curing action starts at temperature as low as 50 °C, it is necessary to reach temperatures within the range of 220 °C to 300 °C for complete polymerisation of the sand core within a short period of time (e.g. 5 to 10 seconds in the case of thin cores, the curing time may vary depending on the size and shape of the cores). It is essential to capture emissions from core blowers and ensure that the work area is well ventilated and exhausted.

Warm-box process

The warm-box process is very similar to the hot-box process; it only differs in the type of resins used that are curing at a lower temperature and in the type of catalyst used. In the warm-box process, the binder is based on furfuryl alcohol (with a typical composition containing around 70 % mass furfuryl alcohol or a low polymer of furfuryl alcohol). Curing takes place at a lower optimum temperature range than the hot-box process (e.g. 150 °C to 190 °C), resulting in lower emissions of formaldehyde and ammonia and lower energy consumption than the hot-box process. The catalysts are copper salts derived from aromatic sulphonic acids; in water or alcohol solution, they are nitrogen-free. The resins are formulated to a low nitrogen content (less than 2.5 wt-%).

Shell (Croning)

This process is the only one among all moulding and core-making processes that uses pre-coated sand, directly available from suppliers and ready for use. Sand is pre-coated with a solid phenolic novolak resin and a catalyst to form a dry, free-flowing material. The coated sand is blown into a heated core box or deposited onto a heated pattern, causing the resin to melt and harden. In this process, the catalyst is in the form of hexamethylenetetramine (as a hardener) that decomposes at 160 °C, releasing formaldehyde, necessary for cross-linking the resin, and ammonia. When core boxes are used, they should be made of cast iron and heated to 250 °C. The minimum curing time is 90 s, but 2 minutes is usually employed. It is essential that the core blowers area is well ventilated and exhausted to efficiently capture the ammonia and formaldehyde liberated during curing.

Achieved environmental benefits

- Reduction of formaldehyde, ammonia and VOC emissions.
- Increased energy efficiency in the case of the warm-box process.

Environmental performance and operational data

Hot-box resins contain 4 % to 10 % free formaldehyde and 6 % to 13 % nitrogen (the catalyst containing about 15 % to 25 % nitrogen). The formaldehyde odour is irritating and is most apparent at the core-making station. Nitrogen is also present and emitted in the form of ammonia.

The emissions will generally contain formaldehyde in a concentration range of 0.1 ppm to 0.75 ppm. By capturing these emissions, the odour level in the ambient air around the process station is substantially reduced after opening of the core box.

The warm-box process leads to substantial energy savings of about 15 – 25 % compared to the hot-box process.

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable.

Economics

The cost of the resins used in the warm-box process are substantially higher than the resins used in the hot-box process.

Driving force for implementation

Legal requirements.

Example plants

Hot-box process: [AT006, Line 2], [ES094, Line 1], [IT132, Line 3], [PL137, Line 1]

Warm-box process: [DE076, Line 2]

Shell (Croning): [AT006, Line 1], [DE039, Line 1], [FR119, Line 3], [PL138, Line 1]

Reference literature

[73, Brown, J. R. 2000], [191, Holtzer et al. 2015]

3.2.1.9.10 Use of aliphatic organic binders**Description**

Use of organic binders based on aliphatic polyalcohols, instead of aromatic binders.

Technical description

The use of organic binders is necessary in numerous applications for process and casting quality reasons and is state of the art in many foundries. Nevertheless, they cause harmful emissions in all application steps (especially when using aromatic compounds), e.g. during the preparation of moulds, moulding and after casting (cooling and demoulding). These emissions are highly problematic both from an occupational hygiene perspective and for environmental reasons; indeed emissions can also contain high contents of phenol and BTEX, for example.

Organic binders for the formation of moulds in a foundry are currently nearly completely based on resins derived from phenol or furfuryl alcohol, both used in combination with formaldehyde. These are designated as aromatic organic binders. As an intrinsic property, these materials decompose during the casting, resulting in highly detrimental emissions containing high levels of aromatic compounds, e.g. phenol or BTEX. The monomeric components phenol and furfuryl alcohol are toxic. Also, the formaldehyde used is toxic, especially in its monomeric form. The solvents, mainly also aromatic solvents, used for the resin and the hardener are highly volatile and evaporate during use. During casting, the polymeric structures based on furfuryl alcohol or phenol decompose, which results in a release of the toxic monomers or derivatives of these compounds. Often higher aromatic compounds are formed from the recombination of fragments. The abatement of these emissions requires high investments and running costs. Since any input of aromatic substances in the process leads to increased aromatic emissions, the problem cannot be solved as long as aromatic substances are employed. Only the extent of emissions during the formation of the moulds might be slightly influenced by reducing the content of free monomers in the starting materials of these resins.

Alternatively, it is possible to use a resin that is based only on aliphatic polyalcohols in order to avoid the use of harmful aromatic monomers. This resin has proven to deliver a high technical performance in the preparation of casting moulds while significantly reducing the level of emissions during casting. It is designated as an aliphatic organic resin.

The new binder is also a two-component system consisting of resin and hardener. The final product formed is a polyurethane, similar to the final product obtained with the phenolic resin and hardener system but the resin is now based on a fully aliphatic structure. The aliphatic organic resin contains only aliphatic compounds, mainly polyalcohols. None of the compounds used are toxic or dangerous and do not require labelling for hazardous material.

Environmental performance and operational data

The basic difference between the phenolic organic binder and the new aliphatic organic binder is shown in Figure 3.36.

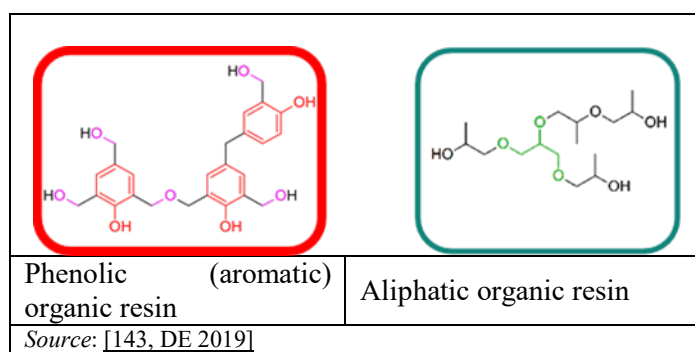


Figure 3.36: Structural elements of phenolic (aromatic) organic resin compared to aliphatic organic resin

Using the aliphatic organic resin, there is no need to use volatile aromatic solvents, significantly reducing the risk of exposure during preparation of the mould. The hardener can be changed in the composition as a result. While an isocyanate is still used as an active ingredient, the corresponding solvents can be adapted to solvents less prone to cause emissions and pollution. In terms of preparation and technical performance, the resin and hardener are mixed together with the moulding material. Using quartz sand with different grain sizes as moulding material, a strong bending flexural strength can be observed.

A comparison of the flexural bending strength of all three binders (furan, phenol and the alternative aliphatic organic binder) is shown in Figure 3.37. The results show a favourable bending strength using similar binder amounts for the new binding system.

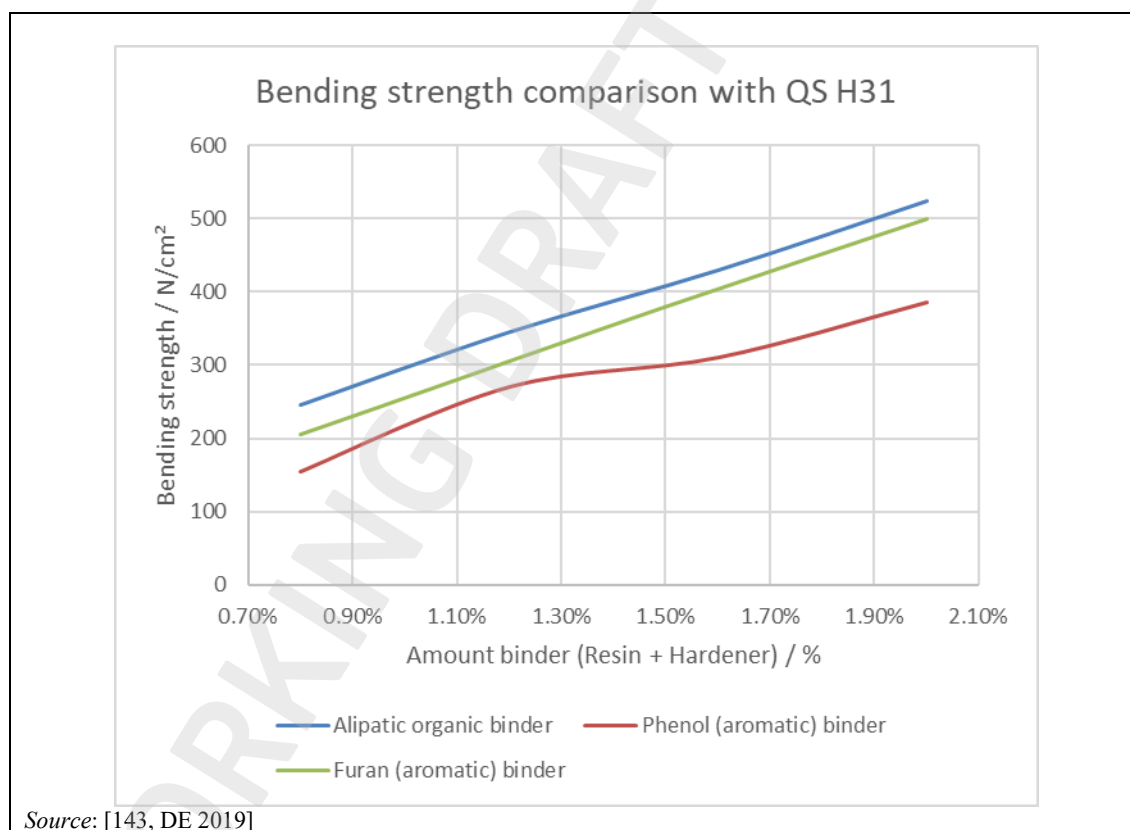


Figure 3.37: Bending strength comparison of the aliphatic organic binder, phenol (aromatic) binder and furan (aromatic) binder with quartz sand

With different types of moulding materials, a high bending strength has also been demonstrated as shown with chromite in Figure 3.38. This high strength provides the option of using reduced

amounts of binder in the formation of the mould, which results in significant environmental benefits.

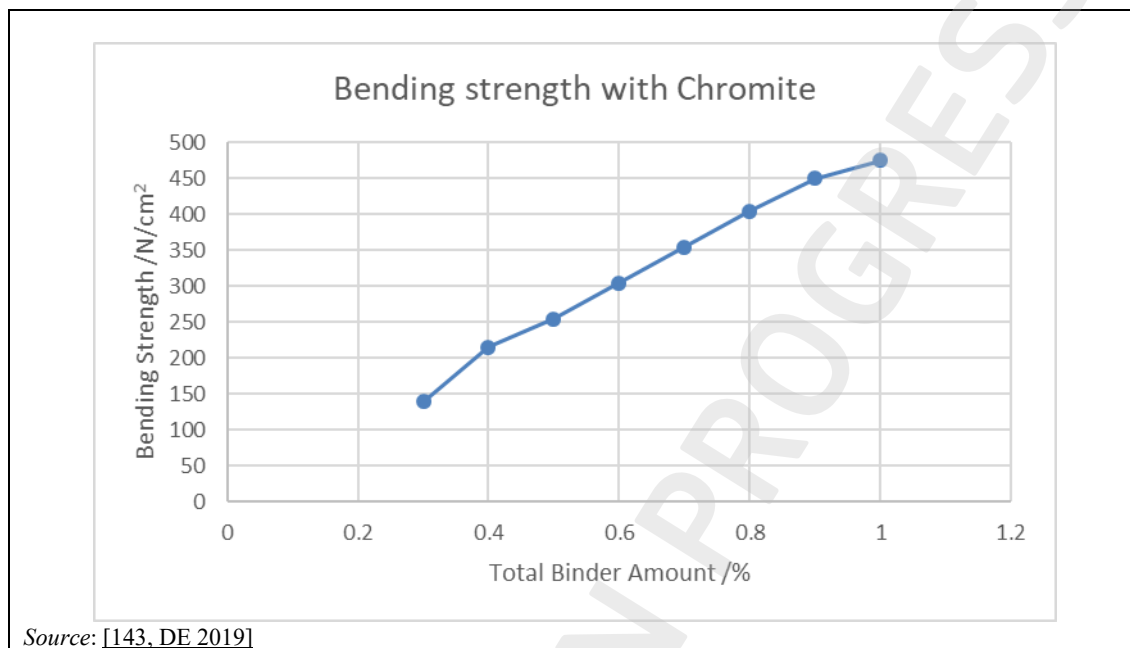


Figure 3.38: Bending strength of the aliphatic organic binder with chromite

The handling time for formation can be adjusted to the needs depending of the amount of catalyst used in the reaction. The catalyst used is usually a tertiary amine in small amounts (0 – 0.3 % catalyst based on the total amount of binder). The amine can be mixed into the resin during production of the binder or added afterwards in the overall mixture. The binding material is compatible with bentonite moulds, which are used in combination.

The reclamation of moulding materials based on the new aliphatic organic binder results in similar values to a phenolic (aromatic) binder.

The amount of gas developed when heated is similar to a phenolic (aromatic) binder. The gas permeability is also similar to the permeability of the phenol (aromatic) binder.

The tendency for casting errors was investigated by a standard test. The results for testing of veining properties is shown in Figure 3.39. A tendency to be less prone for casting errors is directly visible. Even a phenolic (aromatic) binder used in combination with additives does not allow a similar result. These observations have been confirmed at several foundries using different metals. The binder can actually be used for a wide range of metal applications ranging from aluminium and magnesium to iron casting and steel. Furthermore, the quality of the casting surfaces have been highly satisfactory.

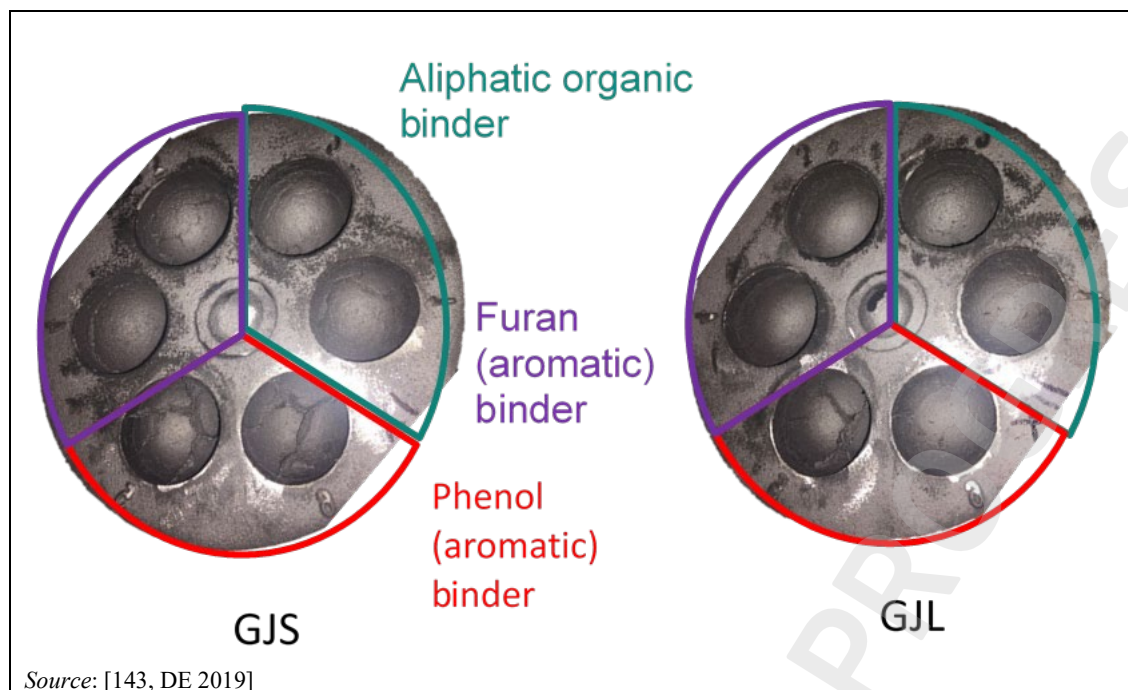


Figure 3.39: Iron casting – Veining comparison

Achieved environmental benefits

Due to the avoidance of hazardous and toxic monomers combined with the use of less volatile and hazardous solvents/additives, emissions during casting and the quantity of hazardous substances in the remaining moulding material during reclamation or deposition are greatly reduced.

This has been investigated in pyrolysis experiments and in measurements in a foundry at all steps along the process chain (mould formation - casting- remaining moulding material).

The pyrolysis measurements were based on GC-MS techniques. The basic set-up is shown in Figure 3.40.

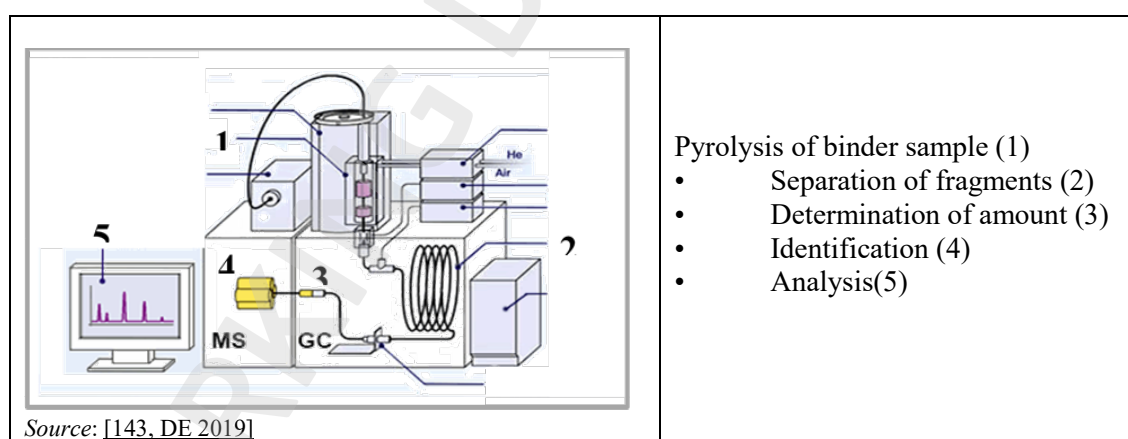


Figure 3.40: GC-MS set-up for pyrolysis

The results of the pyrolysis measurements are shown in Figure 3.41, showing a reduction of aromatic compounds in the composition of the aliphatic organic binder resulting in a significantly reduced amount of hazardous emissions especially of aromatic components (BTEX).

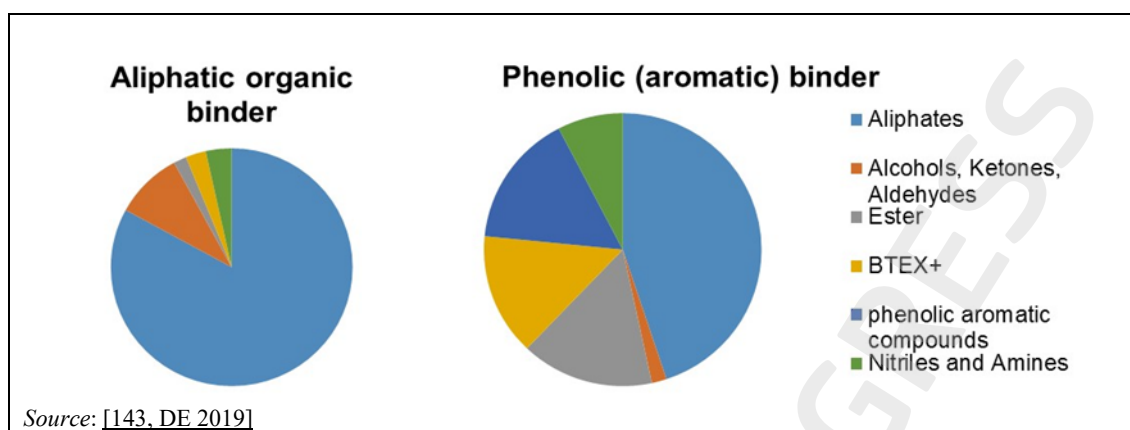


Figure 3.41: Distribution of type of compounds detected after pyrolysis

Measurements of the phenol index in the core material in a foundry were also performed during formation of the mould and during casting. Samples of the remaining moulding materials were taken for analysis. In Figure 3.42 a summary of the results is shown.

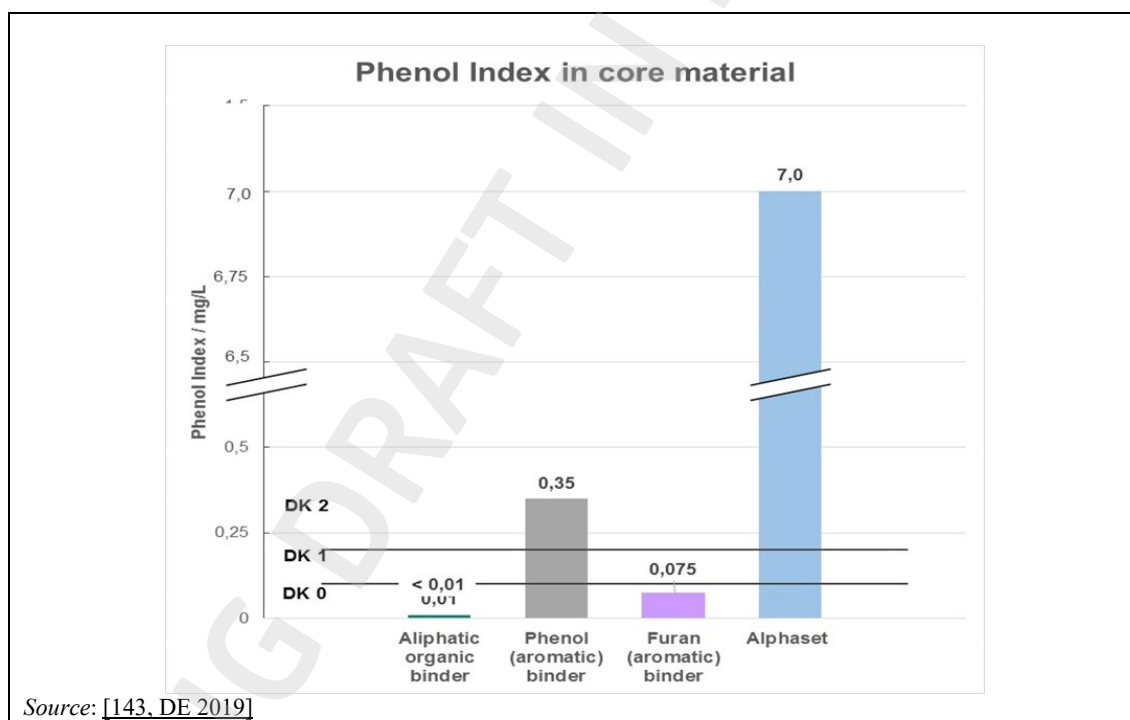


Figure 3.42: Phenol index in core material

Table 3.37 shows the results of emission measurements (moulding and casting), realised at a foundry utilising aliphatic organic binders, for a number of chemical compounds including diisocyanates, ammonia, benzene, formaldehyde, isopropylalcohol, triethylenediamine. This analysis shows that low emissions of hazardous substances can be achieved, mainly diisocyanates, phenol, formaldehyde and aromatic compounds.

Table 3.37: Selected compounds in analysis during mould formation and casting

Parameter		Moulding (mg/m ³)	Casting (mg/m ³)
2,4-toluene diisocyanate (2,4-TDI)		<0.001	-
2,6-toluene diisocyanate (2,6 TDI)		<0.001	-

Parameter		Moulding (mg/m ³)	Casting (mg/m ³)
Hexamethylene diisocyanate (HDI)		<0.001	-
Methylene diphenyl diisocyanate (MDI)		<0.001	-
Aromatic compounds (C7-C8)		0.043	0.064
Aromatic compounds (C9-C10)		0.019	-
Ammonia		-	<0.19
Benzene		0.040	<0.012
Formaldehyde		0.026	-
Isopropylalcohol		0.0017	0.3
CO		-	7.8
NO		-	0.18
NO ₂		-	0.35
Triethylenediamine		<0.001	-
<i>Source: [143, DE 2019]</i>			

Cross-media effects

None.

Technical considerations relevant to applicability

Only applicable to cold-setting processes.

Economics

In terms of process, this technique is similar to the work with the aromatic binders. Therefore, no additional cost for infrastructure adaptations are necessary.

The direct cost of the new binders are slightly higher than that of the aromatic binders.

However, potential savings may arise from the following:

- The reduction of volatile solvents during moulding, leading to savings in protective measures and reduced health risks for the workers. A direct effect is also seen in the air ventilation system, resulting in a reduced volume needed.
- The observed improvement in the casting quality constitutes a significant benefit for the foundry. This results in time savings for grinding and polishing, which are very labour-intensive. It also reduces the overall number of casting defects.

Driving force for implementation

Legal requirements.

Example plants

This technique is mainly in use in foundries situated in Germany, but it has also been tested in Austria and Switzerland. The total number of companies using this technique is around 15 (at the end of 2019).

Reference literature

[143, DE 2019]

3.2.1.9.11 Use of inorganic binders in aluminium die-casting

Description

Inorganic binders such as sodium silicates (water glass) hardened using, for example, CO₂, organic esters are used in aluminium die-casting.

Technical description

Inorganic binder systems are used in aluminium die-casting foundries. They combine a liquid component (a modified sodium silicate solution) with additives known as promoters, which contain high concentrations of minerals. The system is cured by use of heated tools. Flushing the system with hot air removes moisture and helps to optimise curing times and storage times of the cores.

Achieved environmental benefits

- Prevention of amine emissions in core-making.
- Reduction of 98 % of the organic carbon emissions and odour emissions after pouring, compared to organic cold-box binders.
- Reduction of energy consumption and related CO₂ and air pollutant emissions: 20 % of die-casting compared with die-casting using urethane cold box cores or hot-box cores. Specific energy consumption per tonne of mixed sands:
 - 0.089 kWh per tonne mixed sand (quartz sand, 2.95 % inorganic binder & promoter);
 - 1.723 kWh per tonne mixed sand (quartz sand, 1.2 % urethane cold box binder, part 1 and 2).
- Reduction of noise (less tool cleaning).

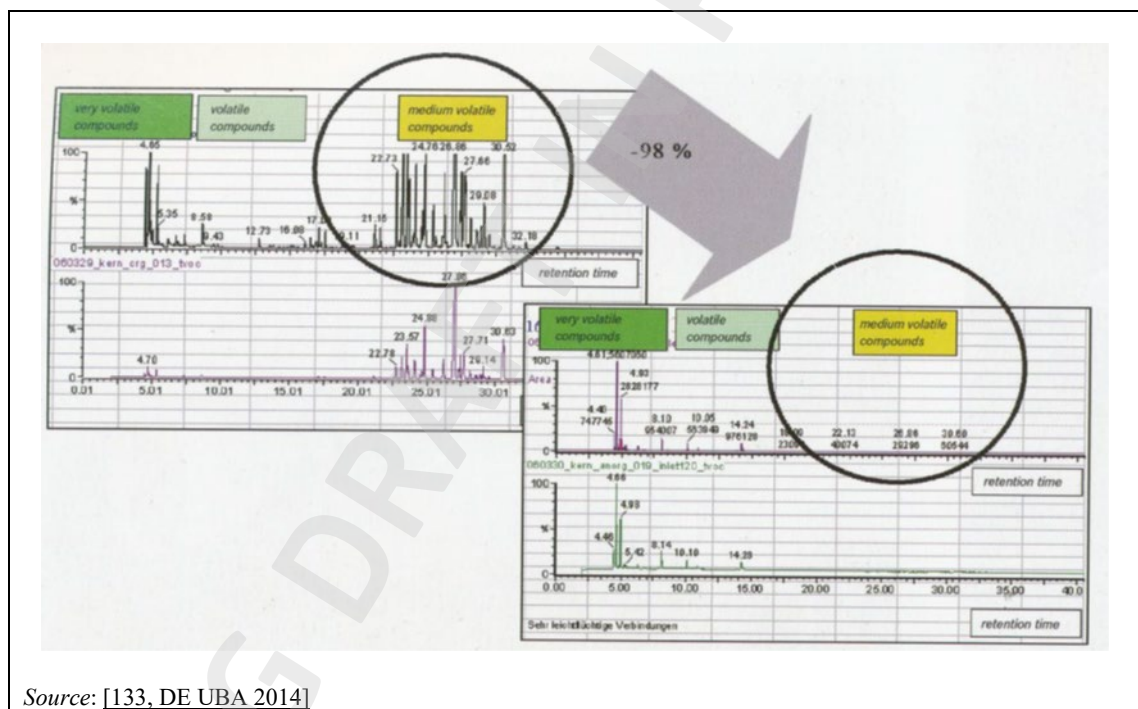


Figure 3.43: Reduction of organic emissions using inorganic binders in aluminium die-casting

Environmental performance and operational data

Aluminium serial production of automotive castings:

- 5 000 to 150 000 castings per year.
- BMW foundry in Landshut, Germany (in 2010):
 1. foundry processes using sand cores: gravity die casting, low pressure die-casting;
 2. 45 000 t aluminium and magnesium castings (only high pressure die casting): cylinder heads, motor blocks.
- Adapted core shooting machine, gassing equipment and sand reclamation plant.
- Core box temperature: 180 °C.
- Curing air temperature: 150 °C.
- Gravity die-casting, low-pressure die-casting.

Cross-media effects

Energy consumption for curing of inorganic binders with heat (drying process). Note: For the urethane cold-box process, curing is carried out without heat by using the catalyst amine.

Thermal sand regeneration (600 °C to 700 °C) is performed with a reclamation efficiency of 90 % to 95 %.

Technical considerations relevant to applicability

The technique is applicable in foundries with aluminium gravity die-casting and low-pressure die-casting and serial production, with short-term core storage in the case of hot and wet climates.

The conversion of an existing foundry line needs many process stages (see Economics). It also needs heated core boxes made of metal; many SME foundries use core boxes made of wood or plastics.

In the die-casting process there is only one kind of sand, which is a precondition, using inorganic binders in serial production. In iron or steel foundries, for example, there is a self-curing no-bake sand system or there are green sands with cores. In both processes, there is no alternative to organic binders.

Economics

Conversion of an existing foundry or production line

When using inorganic binders, all stages of an aluminium foundry process have to be adapted: die design, core box design, sand mixer, heated core box, core shooting machine, gassing (hot air) equipment, core handling and storage (climate-dependent), thermal sand reclamation.

Building of a new foundry or production line:

Investment and running costs: there is an advantage compared to a foundry or a production line with the urethane cold-box process.

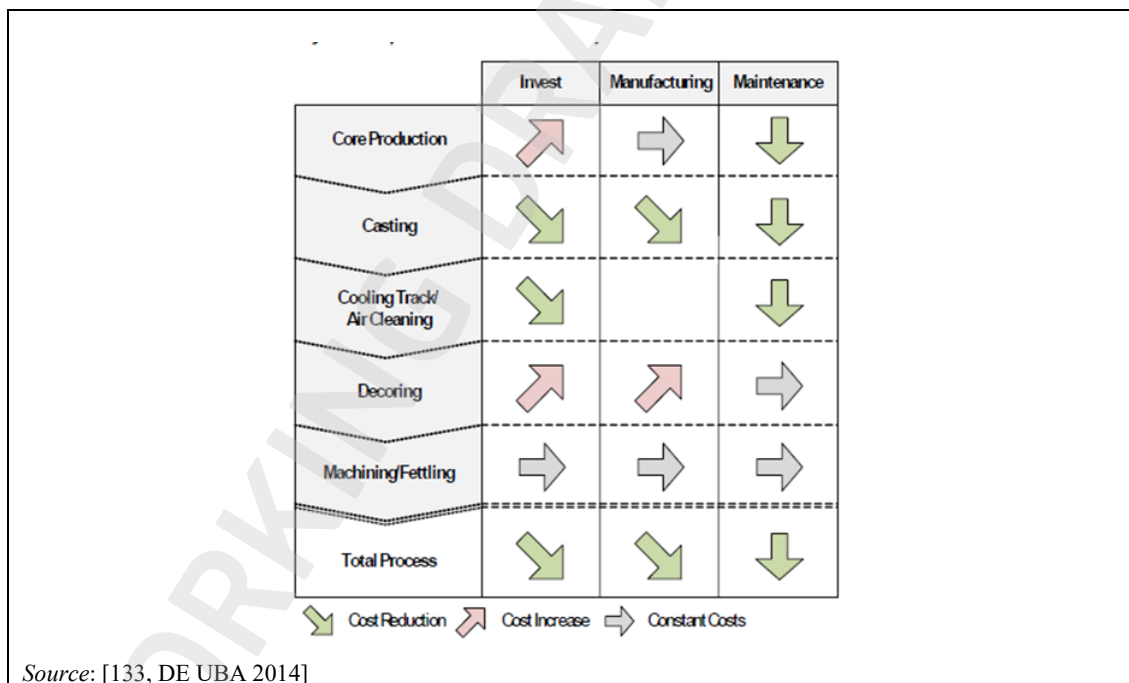


Figure 3.44: Depiction of economic aspects

- Productivity increase +10 %.
- Tool maintenance -50 %.
- Tool cleaning -75 %.

- Manufacturing cycle time (casting) -10 %.
- Thermal post-combustion of the exhaust air -100 %.

Driving force for implementation

Sustainability within production:

- Reduction of emissions, exposure and fire risk.
- Improvement of aluminium casting quality: lower temperature of the die (< 200 °C) therefore smaller dendrite arm spacing in Al castings and higher strength.
- Higher productivity and less maintenance (-50 %) compared to a foundry process with urethane cold-box cores.

Example plants

- BMW AG, Landshut, Leichtmetallgießerei.

Users of other kinds of inorganic binders with heat hardening: VW Nutzfahrzeuge Gießerei, Hannover and Posnan, DC Foundry.

Reference literature

[133, DE UBA 2014]

3.2.1.9.12 Substitution of alcohol-based coatings with water-based coatings

Description

Substitution of alcohol-based coatings of moulds and cores with aqueous coatings. Aqueous coatings are dried in ambient air or using drying ovens.

Technical description

Coatings are applied to the surface of moulds and cores to create a refractory barrier at the mould-metal interface and to ensure a good surface appearance. Coatings serve to reduce veining, erosion and metal penetration defects and also help to reduce finishing operations. The carrier liquid forms a suspension with the base material. In this way, the coating material can be processed. Such carrier liquids are generally water or alcohol. Alcohol-based coatings are mainly based on isopropyl alcohol (IPA - isopropanol). The coating is dried by evaporation or by a burning-off of the solvent. This produces VOC emissions. Water-based coatings have been developed as an alternative.

Before the cores and mould parts are assembled together to prepare the final mould, cores and mould parts must be completely dry. The drying process depends on the size and geometry of the parts to be dried. Large parts or parts with varying formats, which have been typically made from furan or phenolic resin-bonded moulding materials (cold resin process), must be dried for several hours or days in the hall. For smaller parts with unvarying shapes, a drying oven can be used.

If drying is supported by using heat, energy consumption and energy efficiency might be an issue. A newly developed drying oven, already used in foundries, shows increased energy efficiency. In this drying oven, the airflow is optimised in a way that the air jet can be guided directly to the coated mould surface. With this airflow, the air temperature can be set below 90 °C.

The advantages of water-based coatings are:

- safety (no fire risk);
- workers' health (less exposure to organic compound vapours);
- reduced costs of reagents (water vs. alcohol);
- mostly better surface finish of castings.

The difficulties for implementation are:

- the need for greater (process) time and space; also, cores need a longer drying time, which results in the need for a drying line, passing through a drying furnace;
- changing the process requires a case-by-case optimisation period;
- growth of bacteria, which cause short shelf-life of coatings (1 – 2 weeks) and causes odour emissions;
- cost of re-approval by specific customers in aerospace and defence related applications.

Water-based coatings can be dried in ambient air, or by using a drying furnace, a microwave or an infra-red furnace. They generally need a longer drying time compared to alcohol-based coatings. The drying does not generate noxious emissions, but may cause odour emissions. Drying is done using a drying line, which transports the cores from the core-making to the mould assembly, thus allowing for the necessary drying time. The line may also pass through a drying furnace. Microwave and infra-red drying is applied for small, medium and large series.

The different rheological properties of water-based coatings compared to solvent-based coatings has necessitated the development of new application techniques. These allow a constant coating quality.

Achieved environmental benefits

The main advantage of using aqueous coatings and drying in the ambient air is the reduced diffuse solvent emissions. No additional energy is needed for drying in ambient air.

If use of aqueous coating is combined with the use of newly developed (energy-efficient) drying ovens, energy consumption and related CO₂ emissions are reduced compared to the use of traditional drying ovens.

Environmental performance and operational data

Changing from IPA-based to water-based coatings is becoming more widespread in various foundries nowadays. Automotive foundries have changed the majority of their production to water-based, leaving solvent-based coatings being used only for specific applications (see applicability).

Operational data were obtained from a Dutch foundry. When drying in ambient air, the air velocity is the main factor (rather than temperature or humidity). In order to allow sufficient air velocity over the drying trajectory, additional fans and ventilators were installed in the foundry. In order to reach a good and constant quality, the fines content of the (regenerated) core-making sand was reduced. Water-based coatings can cause a swelling of the fine residual (bentonite and coal dust) particles, which then causes core defects.

Operational data obtained from a foundry in France, operating a dryer with a capacity of 540 cold-box cores, which is heated with a natural gas burner. Two ventilators are used to evacuate the fumes and to mix the fresh air. The design temperature of the hot air is 165 °C. A heat balance was set-up on the basis of measurements using 0.4 kg cores with a humidity of 5.5 %. The balance, as given in Figure 3.45, applies for a throughput of 390 cores, which is equivalent to 72 % of full capacity.

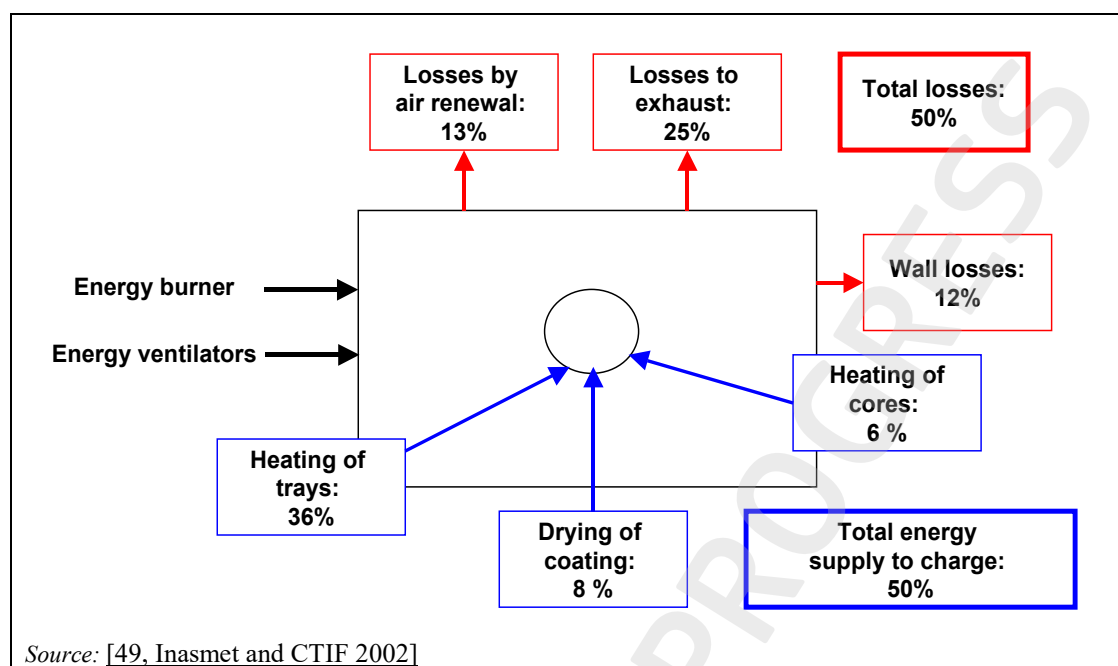


Figure 3.45: Thermal balance of a dryer for core drying, working at 72 % capacity

The balance shows that 50 % of the energy is lost, with indeed effectively less than 10 % being used for core drying. The balance gives a consumption of 8.5 kWh per kg of water evaporated, which corresponds to 465 kWh per tonne of cores at a throughput of 156 kg/h. When the dryer works at a lower capacity rate, the losses increase further. Similar measurements in another foundry confirmed the high (> 50 %) losses and low (< 10 %) effective energy use. Energy efficiency can be increased using microwave drying. This is discussed in Section 3.2.1.3.10.

Newly developed energy-efficient drying ovens make the use of water-based coatings less energy-demanding compared to previously used ovens. The following table describes operational data of newly developed drying ovens and compares them to the previous technique.

Table 3.38: Operational data for new developed drying oven

	Previously used drying ovens	Newly developed drying ovens
Thermal processing power [kW]	400	225
Electrical power input [kW]	30	55
Drying time [h], castings with 10 tonnes	3.5	1.9
Drying time [h], castings with 5 tonnes	2.7	1.4
Drying time [h], castings with 3.5 tonnes	2.8	1.4
Mean specific energy consumption [kWh/t]	303	79

Source: [133, DE UBA 2014]

Cross-media effects

None, if drying takes place in ambient air. Higher energy consumption and related CO₂ emissions arise when conventional drying ovens are used compared to alcohol-based coatings. Energy consumption can be reduced by using drying ovens with improved energy efficiency (see Environmental performance and operational data above).

Aqueous coatings contain a variety of (organic) chemicals to enhance their properties. This may affect the emission profile upon shake-out.

Drying the aqueous coating results in an increased volatilisation of binder solvents. This may cause increased odour emissions, due to the evaporation of BTX-containing core solvents.

Water-based coatings require a higher use of energy due to transport (during air drying) and drying in a furnace.

Drying in ambient air may result in a reduction of the air temperature in the foundry. In a Dutch foundry, an overall reduction of the ambient temperature of 2 °C was experienced. This results in a higher consumption of fuel for heating during wintertime.

Technical considerations relevant to applicability

Applicability may be restricted in the case of large or complex casting shapes because of difficulties for circulation of the drying air.

Not applicable to water-glass-bonded sands, the magnesium casting process, vacuum moulding or the production of manganese steel castings with MgO coating.

The implementation of water-based coatings is applicable for new and existing large-scale, large series foundries. For new and existing small-scale foundries, the implementation may be hindered by technical or economic factors.

Water-based solvents can be used in most situations. However, alcohol-based coatings cannot be replaced in some specific applications and will still need to be used:

- for large or complicated moulds/cores, where drying problems may occur due to difficulties for the drying air to penetrate;
- for water glass bonded sands;
- in Mg casting: water creates $Mg(OH)_2$ and thus causes technical problems;
- in the production of manganese steel with MgO-coating.

The use of aqueous coating and the mould/core drying time require consideration of certain aspects of the production process:

- size of the cores or moulds and their increasing drying time with greater size;
- processing times;
- space in the foundry for the storage of forms/cores.

In the planning of a new foundry, these three variables should be taken into account.

In particular, in existing foundries, area and space requirements can be limits, which are not possible to overcome.

Economics

The investment cost depends on several factors, such as the available space for a drying line in the foundry, the choice of the drying technique, and the need to adapt the sand mix.

The complete replacement of alcohol-based coatings by water-based coatings in a Dutch iron foundry, using ambient air drying involved a total investment of EUR 71 000. This included the installation of ventilators and optimisation of the sand quality. A reduction of the IPA-emission of 161 tonne/yr corresponded to EUR 62.5/tonne IPA emission reduction.

The operational costs involve increased controls of the coating and cores (viscosity, layer thickness, water content, product quality) and amount to EUR 9 000/yr. Drying 1 tonne of coating consumes 2 100 kWh of energy.

On the benefits side of the economics balance is the reduction in expenses for the purchasing of solvent. For bigger foundries, examples exist where investment in a water-based system was paid back in 2 years, on the basis of the reduced purchasing costs of the IPA only.

The operational cost of drying is EUR 0.01/kg (2002 data, non-ferrous foundry in France).

The drying of mouldings coated with water-based coatings requires more space and increased production time.

The table below compares economic aspects of the application of a newly developed efficient drying oven with the previously applied drying technique.

Table 3.39: Expenditure in drying ovens

	Previously used drying ovens	Newly developed drying ovens
Investment (10-year amortisation) [EUR]	420 000	500 000
Maintenance costs per year [EUR]	4 200	5 000
Casting capacity per year [t]	4 000	7 000
Energy costs per ton of casting [EUR]	16.00	4.80
Total cost per ton of casting [EUR]	27.55	12.66
NB: 2013 data. Source: [133, DE UBA 2014]		

In total, savings of up to 54 % can be achieved when applying the new drying technique.

There are no energy costs for drying in ambient air. Costs for space requirements are variable.

Driving force for implementation

- Avoidance of solvent-based emissions in the work areas of the core shop and the moulding shop.
- Improved safety (no fire risk).

Example plants

- PSA Sept-Fons (FR).
- Fonderie Bréa, Montluçon (FR).
- De Globe b.v., Weert (NL).

Air-drying:

- Stahlwerke Bochum GmbH, DE.
- Heger Ferrit GmbH, DE.
- C. Grossmann Stahlguss GmbH, DE.

Drying in oven:

- AVA GmbH, Magdeburg.

Reference literature

[43, infoMil 1999], [49, Inasmet and CTIF 2002], [53, Beauvais et al. 2001], [133, DE UBA 2014]

3.2.1.9.13 Selection of a low-emission cold-setting binder system

Description

A cold-setting binder system generating low emissions of formaldehyde, phenols, furfuryl alcohol, isocyanates, etc. is selected. This includes the use of:

- no-bake furan resins with low furfuryl alcohol content (e.g. less than 40 wt-%) for production of iron castings for example;

- no-bake phenol/furan systems with a low-sulphur acid catalyst for production of steel castings for example;
- aliphatic organic binders based for example on aliphatic polyalcohols (instead of aromatic organic binders) for production of iron, steel, aluminium or magnesium castings, etc.;
- inorganic geopolymers based on polysialates (for production of grey iron, aluminium and steel castings, etc.);
- ester silicate (for production of medium and large steel castings, etc.);
- alkyd oil (e.g. for single castings or small batch production in steel foundries);
- resol-ester (e.g. for lighter alloys in small or medium production);
- Cement (for production of very large castings for example).

Technical description

Cold setting binders generating low emissions can be selected. This includes the use of the following binder systems:

- *No-bake furan resins with low furfuryl alcohol content (e.g. less than 40 wt-%):* No-bake furan resins are based on the polycondensation of furfuryl alcohol using an acid catalyst and are modified using formaldehyde, urea or phenol. Since the entry into force of the Regulation (EC) No 1272/2008, the furan resins containing furfuryl alcohol above 25 % are classified as toxic. See Section 3.2.1.4.3.5 for further information.
- *No-bake phenol/furan systems with a low-sulphur acid catalyst:* See Section 3.2.1.4.3.5 for further information.
- *Inorganic geopolymers based on polysialates:* The use of geopolymeric inorganic binders has been developed in the Czech Republic. It is based on polymers containing polysialates which contains chains of tetrahedrons of SiO_4 and AlO_4 . At the start, the binder has a low degree of polymerisation but during the hardening reaction, which may be triggered by heat or by the use of hardeners, a higher degree of polymerisation is reached. During this process, no odours are generated and the geopolymers emit extremely low quantities of VOCs in comparison to other more conventional moulding or core-making techniques. Furthermore, it is possible to reclaim the sand mixture when using this type of binder. The inorganic geopolymer binders may be used in cold-setting processes, gas curing systems using CO_2 (see Section 3.2.1.9.14) and in hot-curing processes (See Section 3.2.1.9.15).
- *Ester silicate:* In the ester silicate process, sand is mixed sodium silicates (typically within 2.5 % to 3.5% are used depending on the sand grade). A liquid organic ester hardener (e.g. glycerol diacetate, glycerol triacetate) is added (10 – 12 % based on the weight of silicate). Often, breakdown agents are also added. The curing process takes usually between 20 to 120 minutes.
- *Alkyd oil:* There are no emissions during the production of cores and moulds when using cold-setting. Odour emissions are only observed when heat is used for curing alkyd oil binders.
- *Resol-ester:* The resol-ester resin contains unreacted phenol and formaldehyde, but their emissions are extremely low and environmentally insignificant.
- *Cement:* The use of cement as a binder is not widespread but has been used for the production of heavy steel castings as well as other alloys. In this case, silica sand containing about 11 % Portland cement and 6 % water can be used in a boxless block moulding system using mounted patterns in temporary wood frames. There are no environmental issues associated with this technique.

Achieved environmental benefits

Reduced emissions of VOCs.

Environmental performance and operational data

- *No-bake furan resins with low furfuryl alcohol content (e.g. less than 40 wt-%):* Amongst all the plants in the data collection that reported using resins with a FA content < 40wt-%, most foundries were iron foundries producing grey or spheroidal graphite iron castings (i.e. BE023, DE070, ES088, FR119, IT 134) but one brass foundry also reported the use of this technique. See Section 3.2.1.4.3.5 for further information.

- *No-bake phenol/furan systems with a low-sulphur acid catalyst*: Applying a sulphur-reduced bake system, the odour emissions in a steel foundry (See Figure 3.46) can be reduced by 65 % when using new sand moulds and new sand cores. See also Section 3.2.1.4.3.5 for further information.
- *Inorganic geopolymers based on polysialates*: In the cold-setting process, the required addition rate of the geopolymer binder to achieve the required strength and properties of the moulds and cores ranges typically from 1.4 % to 2.0 % with new sand and from 1.8 % to 2.0 % for sand mixtures containing between 75 % and 100 % reclaimed sand. After 24 hours, the flexural strength achieved with the geopolymer-based binder (ranging from 1.3 MPa to 1.9 MPa) is very similar to those obtained with conventional methods such as the alkaline phenolic ester process or the furan no-bake process. The BTEX emissions reported when using the inorganic geopolymer binders are 36 mg/kg, compared to 666 mg/kg when using a furan-based resin containing less than 25 % furfuryl alcohol, 249 mg/kg when using a no-bake binder system based on an alkaline phenolic resin and 252 mg/kg when using green sand. No PAH emissions were reported when using the inorganic geopolymer binders, compared to 12 mg/kg when using a furan-based resin containing less than 25 % furfuryl alcohol, 5 mg/kg when using a no-bake binder system based on an alkaline phenolic resin and 2 mg/kg when using green sand.
The used sand mixtures with the geopolymer binder exhibit significantly easier reclaimability in comparison to organic binder systems. A better collapsibility of the used sand mixtures with geopolymer binder after pouring has been reported by foundries producing both aluminium and non-ferrous castings. The reported utilisation of the reclaimed sand is 75 % for the facing sand mixture and 100 % for the backing sand mixture.
- *Ester silicate*: The system has been widely applied in the manufacture of steel castings with very little odours and fumes emitted during casting.

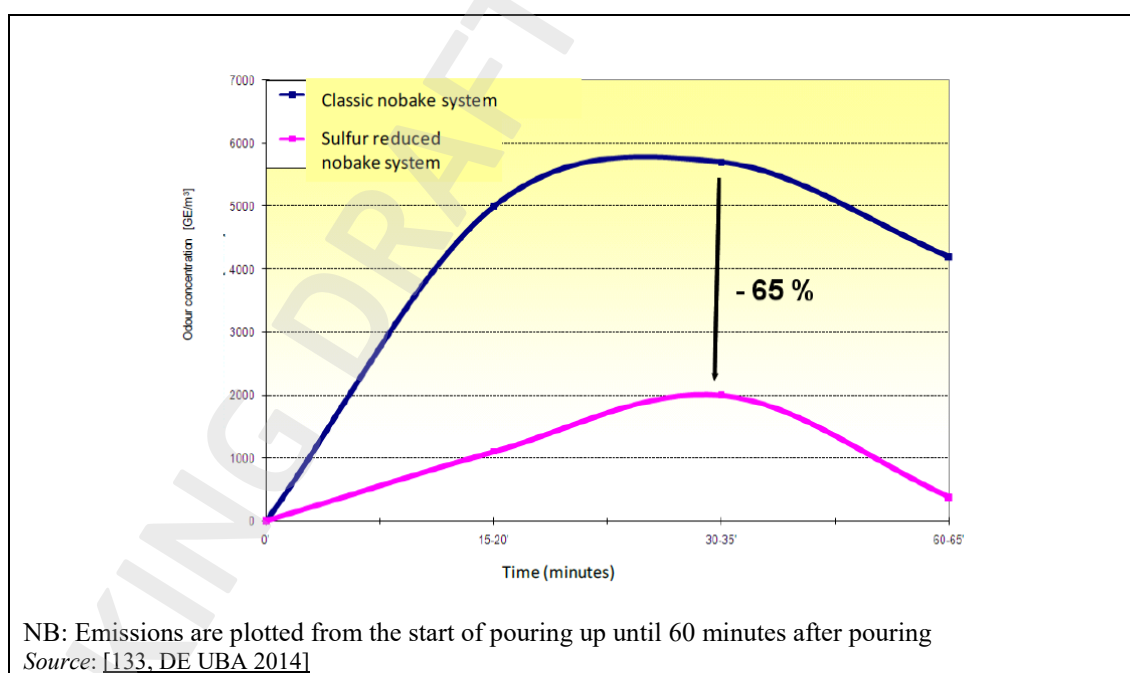


Figure 3.46: New binder to reduce emissions of sulphur compounds (odours and pollutants) in a steel foundry

Cross-media effects

None.

Technical considerations relevant to applicability

Applicability may be restricted due to product specifications.

Economics

- The use of emission-reducing binders requires no investment.
- The costs of the innovative binders are typically higher than that of the conventional binders.

Driving force for implementation

- Legal requirements.
- Reduction of VOC and odour emissions.

Example plants

Inorganic geopolymers are used in:

- a grey iron foundry in the Czech Republic (since 2004), in replacement of a no-bake binder system based on an alkaline phenolic resin;
- an aluminium foundry in the Czech Republic (since 2014);
- a large steel foundry in the US producing die blocks and gear segment castings up to 50 tonnes.
- a steel foundry in the Middle East producing castings up to 7 tonnes.

Reference literature

[133, DE UBA 2014], [200, Zennaro et al. 2019], [201, Vykoukal, M. et al. 2019], [202, Merta, V. et al. 2021]

3.2.1.9.14 Selection of a low-emission gas curing binder system

Description

A gas curing binder system generating low emissions of amines, benzene, formaldehyde, phenols, isocyanates, etc. is selected. This includes the use of:

- inorganic binders, e.g. sodium silicate (water glass) or inorganic geopolymers based on polysialates cured with CO₂;
- aliphatic organic binders based for example on aliphatic polyalcohols (instead of aromatic organic binders);
- phenolic urethane binders with very low free phenol and formaldehyde content;
- phenolic urethane binders with reduced amounts of solvents.

Technical description

- *Inorganic binders - sodium silicate (water glass) catalysed with CO₂*: Inorganic sodium silicate binders can be hardened using CO₂ (or organic esters). When using a high ratio of sodium silicate (e.g. 3.0 % to 3.5 % addition rate), the gassing times and the consumption of CO₂ are reduced and improved post-casting breakdown is observed. However, reduced core strength and poor core storage properties may arise. When using a lower ratio of sodium silicates (e.g. 2.0 % to 2.2 %), better core storage is achieved but the gassing times are extended and the breakdown properties are not as good. Often, the second option is preferred.
- *Inorganic binders - geopolymers based on polysialates cured with CO₂*: Inorganic geopolymers can be used in the production cores, or even moulds, and cured using CO₂. During the curing process, a polymerisation of the inorganic geopolymer takes place. Some additives (accelerators in a liquid or solid form) may be added to the sand to achieve faster the required strength and minimise the consumption of CO₂.

Typically, the inorganic geopolymer binder is added to quartz sand at levels ranging from 2.3 % to 3.0 %; the accelerators are added at levels ranging from 0.5 % to 0.8 %, based on the weight of sand.

- *Aliphatic organic binders based for example on aliphatic polyalcohols (instead of aromatic organic binders)*: See Section 3.2.1.9.10 for further information.
- *Phenolic urethane binders with very low free phenol and formaldehyde content*: A new binder system for use in the cold-box process has been developed in which the free phenol

content of the resin has been drastically reduced with the aim of minimising emissions during casting. The binder based on ultra-low free phenol is composed of two parts. The solvents used in the first part to solubilise the phenolic resin do not contain any hazardous materials that would need to be mentioned (compulsory labelling) due to their workplace exposure limits. The solvents used in the second part used to dilute the isocyanate resin still require labelling. The free phenol content of this binder is below 1 % and, in addition, the free formaldehyde content is below 0.1 %. [203, Vacelet et al. 2018]

- *Phenolic urethane binders with reduced amounts of solvents:* Another binder system has been developed for the cold-box process (both for iron and aluminium casting) where no solvents are actually used in the second part for dilution of the isocyanate resin, instead selected additives are employed.

Achieved environmental benefits

Reduced emissions of VOCs.

Environmental performance and operational data

Inorganic binders – e.g. based on sodium silicate or hydrated sodium silicate: The manufacture of cylinder heads from a cast aluminium alloy shows that the change of the binder system in the cold-box process from an organic system to a silicate system resulted in an odour emissions reduction of approximately 60 %. Additionally, when the process was further changed to an inorganic method based on hydrated sodium silicate, an almost complete elimination of the odour emissions was achieved (-99 %). This is illustrated in Figure 3.47 and Figure 3.48. The new binder systems also reduced significantly BTX emissions from the aluminium foundry.

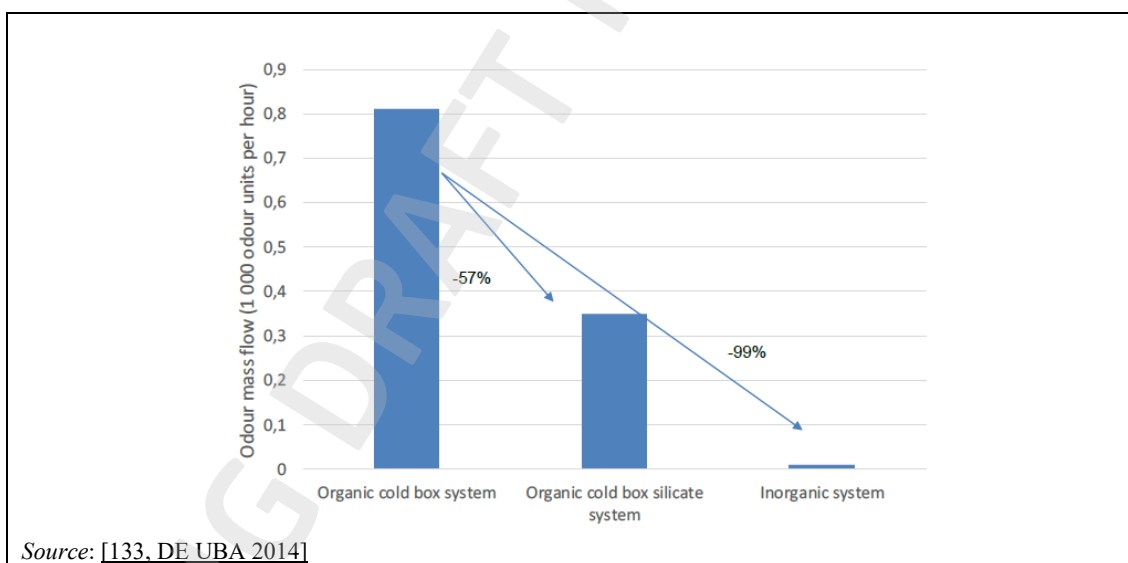


Figure 3.47: New inorganic binder systems used in an aluminium foundry – Effects on odour emissions compared to conventional organic cold-box systems

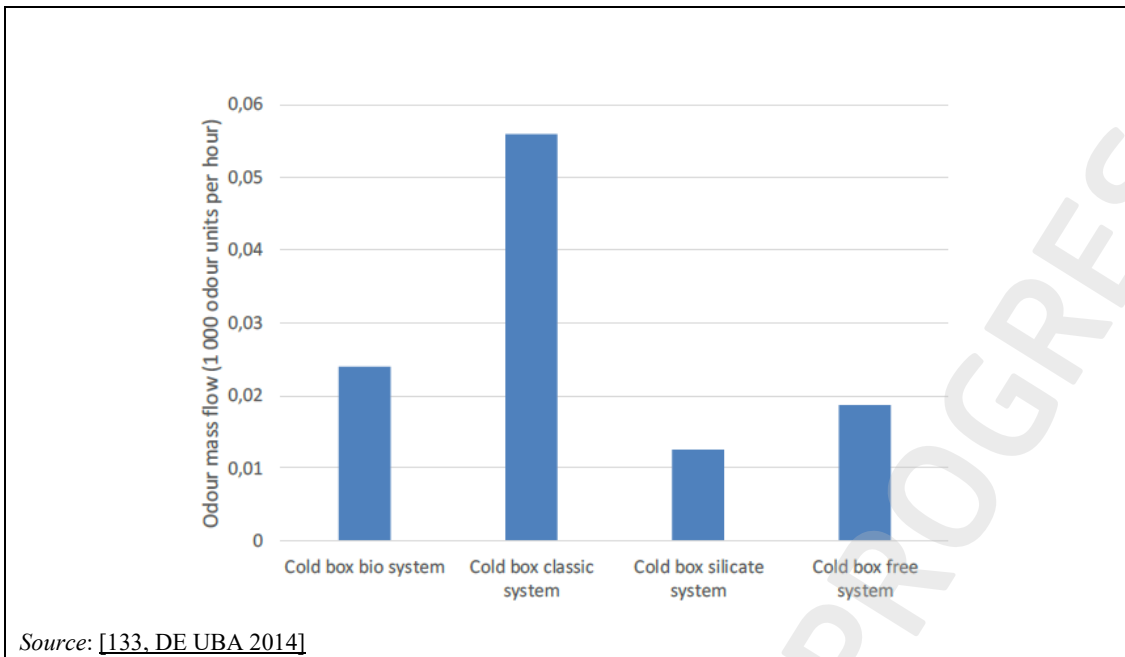


Figure 3.48: New inorganic binder systems used in an aluminium foundry – Effects on odour emissions compared to conventional organic cold-box systems

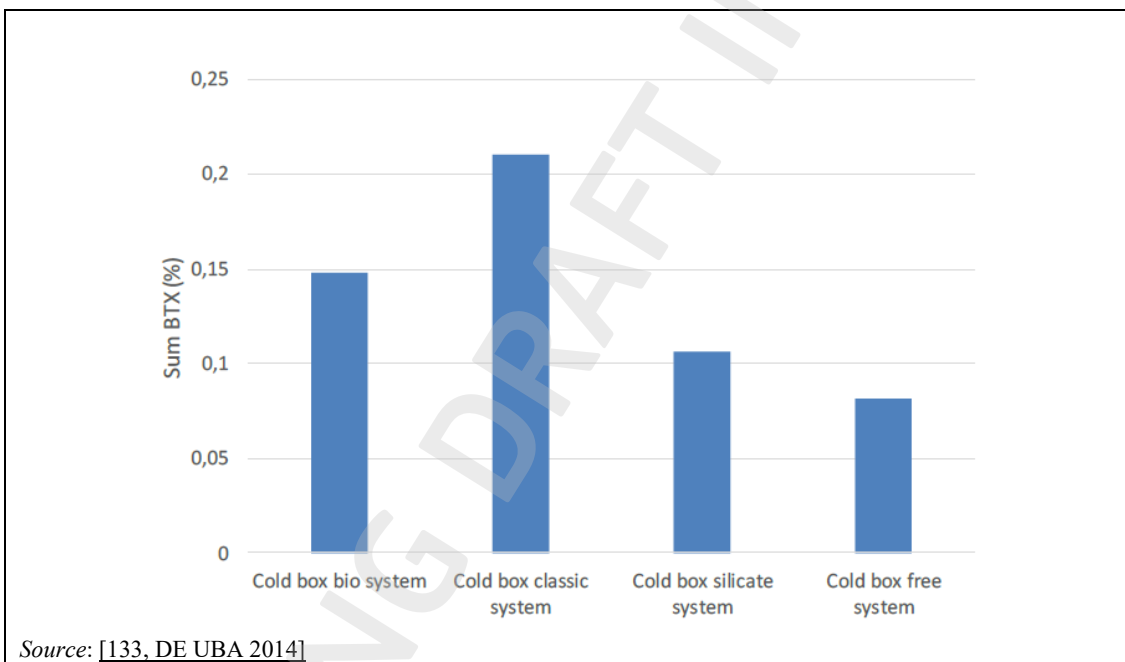


Figure 3.49: New inorganic binder systems used in an aluminium foundry – Effects on odour emissions compared to conventional organic cold-box systems

When using a silicate system in combination with an inorganic additive instead of using a classic silicate system with an organic additive (a wood flour additive), the odour emissions from the production of gear houses in an iron foundry were reduced by 46 %. (See Figure 3.50.)

When replacing the hexamethylenetetramine-hardened shell moulding sand with resol-hardened sand, test results showed a reduction of odour emissions of 77 % (see Figure 3.50), similarly achieved at the Harzguss Zorge and at Halberg Guss in Brebach (crankshaft masks) reference plants.

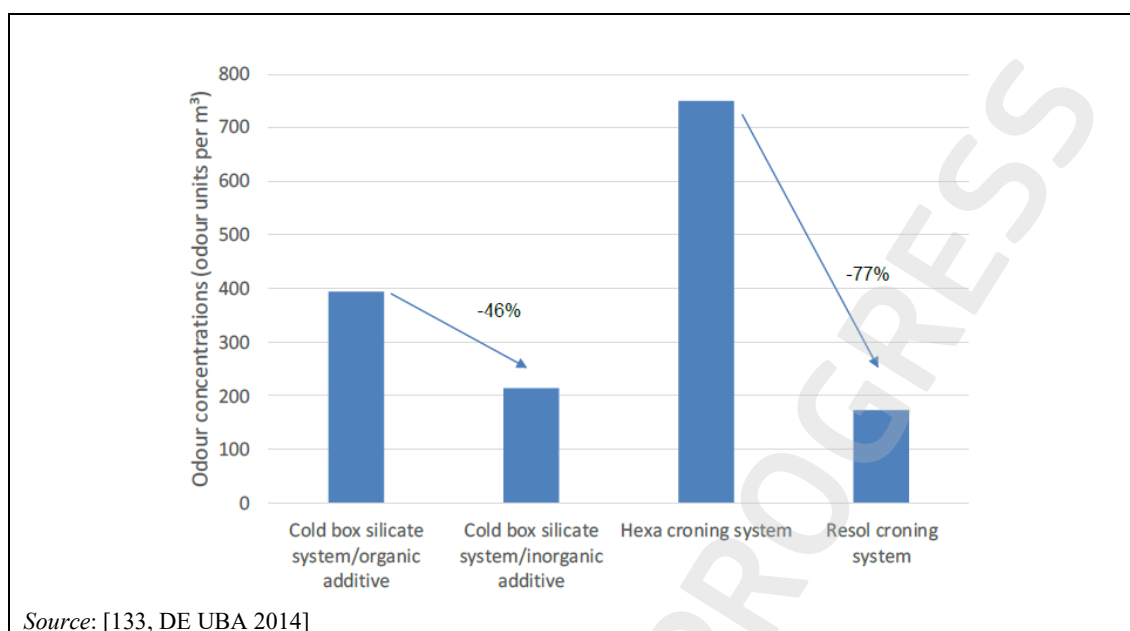


Figure 3.50: New binder system for odour and BTX reduction in an iron foundry – Part A

- *Phenolic urethane binders with very low free phenol and formaldehyde content:* The use of ultra-low phenolic urethane binders in the cold-box process, particularly in iron and steel casting, leads to reduced emissions throughout the the production process from the core production to casting. A long-term analysis showed a 22 % reduction in the binder consumption compared to a conventional cold-box binder system and reduced benzene emissions by 66 %. [203, Vacelet et al. 2018]
- *Phenolic urethane binders with reduced amounts of solvents:* Using this binder technology, the consumption of solvents is reduced by a third compared to a conventional cold-box system. This leads to reduced emissions of VOCs. Furthermore, it has been reported that the amine consumption is also reduced. [204, Vacelet et al. 2013]

Cross-media effects

None.

Technical considerations relevant to applicability

Applicability may be restricted due to product specifications.

Economics

- The use of emission-reducing binders requires no investment.
- The costs of the innovative binders are typically higher than that of the conventional binders.

Driving force for implementation

- Legal requirements.
- Reduction of VOC and odour emissions.
- Reduced consumption of binders.

Example plants

VW-Gießerei AG Nutzfahrzeuge, Hannover

Eisenwerk Brühl GmbH , Brühl

Harzguss Zorge GmbH, Zorge

Edelstahlwerke Schmees GmbH, Pirna

Phenolic urethane binders with a very low free phenol content: Düker GmbH, Laufach, Germany, a foundry producing valve bodies and pressure pipe for drinking water and gas supply and plant DE061 in the SF BREF data collection.

Reference literature

[133, DE UBA 2014], [203, Vacelet et al. 2018], [204, Vacelet et al. 2013]

3.2.1.9.15 Selection of a low-emission hot-curing binder system

Description

A hot-curing binder system generating low emissions of formaldehyde, phenols, furfuryl alcohol, benzene, isocyanates, etc. is selected.

This includes the use of:

- inorganic binders such as geopolymers based on polysialates;
- inorganic binders cured using a warm-box process without phenol, formaldehyde and isocyanates (for preparing aluminium castings with complex shapes for example);
- aliphatic polyurethane warm box binders: these binders can be used as an alternative to the cold box process without the need of amines for gas-curing (See Section 3.2.1.9.22).

Technical description

- *Low-emission hot-curing binder systems*: Conventional hot-box systems are typically furan- or phenol-based. They all contain urea and their free formaldehyde content may vary from 2 % to 10 %. In addition, the nitrogen content of the resins is typically between 6 % and 13 %, originating from the catalysts used (e.g. aqueous solutions of ammonium chloride or ammonium nitrate). For the hot-box process, binders with lower free formaldehyde content are commercially available; however, they may present lower reactivity. Alternatively, in the warm-box process, binder systems with a free formaldehyde content lower than 2.5 % are available. More recent binders with a free formaldehyde content of less than 0.1 % have also been reported. [205, P. R. Carey, Technical Paper 2021]
- *Inorganic binders cured with heat*:
 - Inorganic geopolymers based on polysialates can be used in the serial or mass production of cores cured with heat in non-ferrous metal applications. The sand mixture is introduced into a heated core box and the curing process is facilitated by blowing hot air within the range of 100 °C to 200 °C. Typically, the inorganic geopolymer binder is added to the sand at levels ranging from 1.4 % to 2.0 %; an accelerator is also added at levels ranging from 0.3 % to 0.9 %, based on the weight of the sand. [201, Vykoukal, M. et al. 2019]
 - Inorganic binders which may be cured using a warm-box process have also been reported. They are typically used in the production of complex cores for aluminium castings in the automotive industry. They do not contain phenol or formaldehyde and therefore can significantly reduce VOC emissions. [206, V. Haanappel 2021]
 - aliphatic polyurethane warm box binders (See Section 3.2.1.9.22).

Achieved environmental benefits

Reduced emissions of VOCs.

Environmental performance and operational data

The production of cores using inorganic geopolymers does not generate fumes or odours during the pouring process, compared to cores produced using the cold-box technology, for example. In addition, the inorganic geopolymers enable the achievement of higher mechanical properties than resin-coated sands typically used in the Croning process (i.e. phenol-formaldehyde type – novolak), in particular higher transverse strengths (both hot and cold). Another important aspect to consider is the collapsibility of the cores. In the case of the inorganic geopolymer binder system, comparable or even better collapsibility of the cores has been reported in comparison to resin-coated sands used in the Croning process.

Cross-media effects

None reported.

Technical considerations relevant to applicability

Applicability may be restricted due to product specifications.

Economics

The cost of a warm-box system is significantly higher than the conventional hot-box system. Compared to a hot-box phenolic system, the price of the resins used in the warm box process are two to three times higher and the price of the catalysts used can be three to seven times higher. [205, P. R. Carey, Technical Paper 2021]

Driving force for implementation

- Legal requirements.
- Reduction of VOC and odour emissions.

Example plants

No information provided.

Reference literature

[205, P. R. Carey, Technical Paper 2021], [201, Vykoukal, M. et al. 2019], [206, V. Haanappel 2021]

3.2.1.9.16 Aliphatic polyurethane warm box binding system**Description**

Use of an aliphatic polyol resin and a MDI-containing (methylene diphenyl diisocyanate) hardener. The instantaneous hardening is achieved with a thermal impulse accomplished by a heated core tool and the purging of warm air to the core tool.

Technical description

Aliphatic polyurethane warm box binders (APWBB) consist of an aliphatic polyol resin and a MDI-containing (methylene diphenyl diisocyanate) hardener. These binders are used for rapid core production processes similar to classic cold box binders (CB binder). Since they do not include VOCs, aromatic solvents or phenolic resins, hazardous components like BTEX and phenolics are not released when using the binders for core production. The aromatic load of the emissions along the process chain in general is significantly reduced compared to conventional CB binders. The fast hardening of the mould material mixture is not achieved with toxic amine gas, as is the case with classic CB systems, but with a thermal impulse. This thermal impulse is accomplished by a heated core tool and the purging of warm air to the core tool, which leads to the instantaneous hardening of the moulding material at ~80 °C. By using a heated core tool, the process enables cores to be produced at a similar high frequency to the classic CB process, without the need for toxic gaseous amines. The core shooting machines previously used in the CB process can continue to be used after the core tool has been modified.

APWBB were developed to facilitate core production with short cycle times by avoiding the use of toxic gaseous amines. These binders further reduce the emission load of hazardous gases during casting like BTEX, phenolics and PAHs. Since all polyurethane hardener components contain MDI, a low amount of aromatic emissions is also detected during casting while using APWBB. A crucial point in core production is the absence of amine gases such as DMEA, DMPA or DMIPA facilitating rapid curing of the molding sand in the CB process. Instead of this gassing, APWBB systems are usually hardened by heating the core tool and using hot air to briefly heat up the moulding material to around 80 °C. Tool and air temperature are generally above 120 °C for that purpose. The moulding material hardens completely within 15-30 seconds. The binding strengths and cycle times achieved for a specific core largely correspond to the values known from the CB process (see Figure 3.52). In terms of reaction performance, APWBB are equivalent to phenolic CB binders.

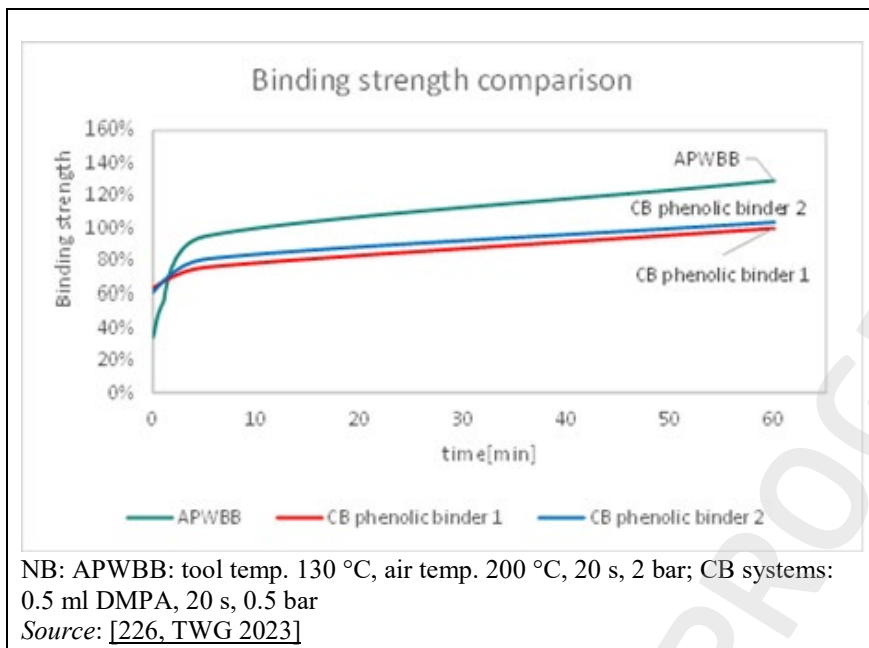


Figure 3.51: Comparison of time-dependent binding strength

Achieved environmental benefits

The technique eliminates the use of amine gas for core curing completely. The amine gases used in the CB process are toxic, highly flammable and possess a strong unpleasant odor. With APWBB, extensive ventilation to transfer amine gas from the core tool to an amine scrubber is not needed. It allows for the substitution of the CB binders which were established in core production around 50 years ago. In terms of their productivity, core shooting processes with short cycle times are viable for keeping foundries in Europe profitable. APWBB can be used in these processes.

The improved emission profiles of APWBB compared to CB binders were not only proven during casting but along the entire process chain. Emission tests using laboratory pyrolysis-GC/MS were performed, showing a reduction in hazardous emissions, especially for BTEX, phenolics and PAHs as presented in Figure 3.52 and Figure 3.53.

Reducing foundry emissions, e.g. BTEX, may result in further operational savings along the process chain.

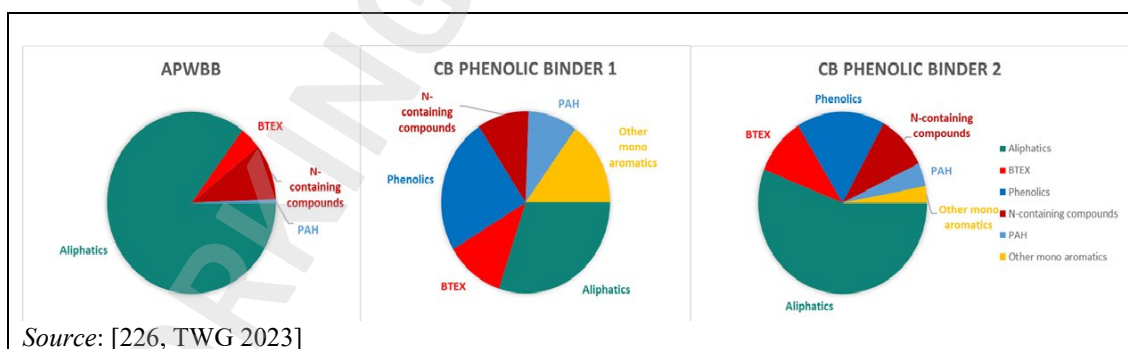


Figure 3.52: Comparison of binder emission profiles measured by pyrolysis-GC/MS at 900 °C

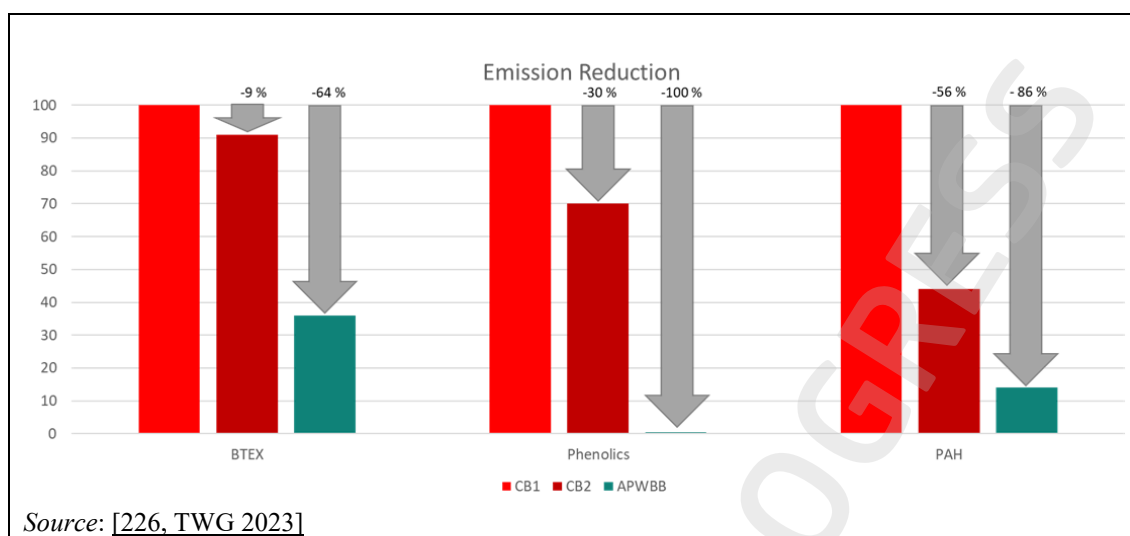


Figure 3.53: Emission reduction for BTEX, phenolics and polyaromatic hydrocarbons (PAHs) based on the previous figure

Environmental performance and operational data

APWBB are in the introduction phase in several foundries and will be implemented there within the year 2023.

Cross-media effects

The use of APWBB avoids the application of toxic substances. This also results in significantly improved emission profiles of the binder resins facilitating the complete elimination of toxic amine gases for mould curing. As a result, amine scrubbers, related filters and downstream air cleaning equipment are no longer required in the core-making process. This results in lower energy consumption compared to the CB process by avoiding the costly amine gas filtration step. The environmental impact of APWBB concerning emissions from moulding and casting as well as for the sand reclamation is reduced compared to CB binders.

Technical considerations relevant to applicability

Generally applicable.

APWBB can be used for common casting materials such as aluminium, iron or steel. The hardening process used is similar to the CB process in terms of equipment and achieves similar short cycle times for core production. Currently used core shooting machines remain operational. APWBB are particularly suitable for automated production of core assemblies. In contrast to the CB process, there is no amine gassing. It is replaced by the brief implementation of heat into the moulding material for instant hardening. For this purpose, metal tools must be provided, which are heated either with electric heating cartridges or a heating circuit containing a heat-transfer oil. In many foundries, heat circuits using waste heat of other foundry processes are already in place. These can easily be used for metal tool heating in the core shooting process with APWBB. Furthermore, the requested hot air used in the hardening process should deliver pressures above 2 bar and a temperature of 160 – 200 °C. That ensures rapid heat input into the moulding material and correspondingly short core hardening times.

Economics

In order to avoid investment, the APWBB process is designed to use the existing core shooting technical infrastructure. Only the moulding tool for the core requires heating adaptation, either electrical or by heated oil circuit. Existing tools for inorganic core shooting can be used without any modification. Tools for phenolic CB binders can either be modified or the change can be included in the normal exchange of the tools or their makeover. The detailed one-time investment costs depend on the specific tool situation in any given foundry.

The operation and maintenance costs require on one site the heating of the form. As the temperature range needed is far lower than with inorganic binders the heating can be easily provided by existing process (waste) heat in combination with the heated process oil circuit. Alternatively, electrical heating would be needed. Potential savings in operational costs would result directly due to significantly reduced VOCs and lack of amine gas emission during core shooting. Therefore, an amine scrubber, related filters and extensive downstream air cleaning equipment are no longer required or at least significantly reduced in the core-making process. Reduced emissions during casting, as well as from the reclamation of the used sand, provides further opportunities for operational savings.

Maintenance costs connected to the amine gas storage, gas formation and washing unit would be eliminated. Ventilation needs across the whole process would be reduced due to BTEX reduction and the disposal cost for waste sand could be reduced due to less toxic components.

Maintenance might be influenced by reduction of tool cleaning cycles due to the lack of impact of amine (corrosion, stickiness). The specific costs depend on the considered process situation in the foundry.

Due to the omission of amine gas as process material, there would be direct cost savings in the full amount of recurring costs for this material. Furthermore, the reduced safety risk of the overall process might reduce safety requirements.

There will be expenses for a transformation period. The main cost driver is the modification of core boxes with heating cycles. As this can mainly be done in parallel to general maintenance work, downtime for extra installation is not needed.

Driving force for implementation

The main driving factors will be the significant economic benefit of the new process and likewise the reduction of toxic emissions over the process flow as mentioned above.

Example plants

Implementation is done under a special agreement with industrial plants based in Germany.

Reference literature

[226, TWG 2023]

3.2.1.9.17 Extraction of off-gases generated from moulding and/or core-making

Description

Off-gases generated from moulding and/or core-making are extracted. The extraction system selected depends on the type of moulding/core-making process.

1. *Natural/green sand moulding*: Off-gases generated in the natural or green sand preparation areas (e.g. transport, sieving, mixing and cooling) and in the moulding areas, especially during pouring, are extracted. In the case of automatic moulding machines, appropriate extraction systems are used to collect emissions (e.g. roof extraction). In the case of hand moulding, extraction as close as possible to the emission source is achieved using mobile extraction hoods.
2. *Cold-setting, gas curing, hot-curing processes*: In the case of automatic moulding machines, extraction systems are used to collect emissions (e.g. fixed extraction hoods, canopy extraction). In the case of hand moulding, extraction as close as possible to the emission source is realised using mobile extraction hoods.

In the event that mobile hoods cannot be used due to the size of the mould and/or space restrictions, casting hall extraction is used [210, TWG 2022].

Core shooting machines are enclosed and off-gases are extracted. Extraction is also applied during checking, handling and storage of freshly made cores (e.g. by using hoods at the checking table, above the handling and temporary storage areas).

Technical description

Mould preparation

Only a few of the different green sand preparation stages cause significant dust generation, namely the vibrating screen, dedusting and cooling process stages. These stages are equipped with dust capture and treatment. The units are enclosed and connected to a centralised dedusting unit. The set-up of the dedusting system has to take account of the dew point of the exhaust air and the type of dust.

The exhaust air from the green sand preparation is saturated with water. Therefore, wet systems (often of the low pressure type) seem to be most suitable for exhaust capture. However, the wet system is widely being replaced by dry dust abatement. The latter has the advantage that part of the dust may be recirculated and that no waste water stream is generated. Additionally, the wet systems are prone to internal corrosion and the build-up of dust and oxidation products. The wet separation of exhausted air impurities can result in problems for the waste water cleaning. Dust contains bentonite which is difficult to dispose of due to its anti-sedimentable effects. [120, TWG 2003]

When applying fabric filters, condensation problems need to be prevented. Condensation may cause a deposition of dust, clogging and/or a tearing of the filter. The addition of cooling water to the sand needs to be done in a controlled way in order to minimise steam formation. The dew point of the airflow may be increased through heating with gas burners.

One benefit is that the collected dust is dry and so can be easily transported. After size separation, the coarse fraction and part of the fine fraction may be recirculated into the sand mixing.

Core-making

The type of binder and hardener used will determine the type of emissions that occur. The exhaust gas from core-making with chemical binders consists mainly of a mixture of organic solvents. Emissions of phenol, formaldehyde, or ammoniac etc. are much smaller and depend on the binder type. Mixing, core shooting and drying can be enclosed to varying degrees, depending on the emissions occurring. Various binder-specific techniques apply, and these are discussed in the subsequent sections. Volatile organic carbon emissions occur with all chemically bonded sand types, except for water glass sands. For self-setting and cold-setting binders, the emissions during mixing are low, given the low resin usage (1 – 2 % resin:sand ratio). The emissions during hardening, coating and drying can be considered for capture and treatment.

Upon regeneration of the chemically bonded sand, dust generation occurs in the shake-out drum. Sand cooling and dedusting is generally performed in a dry unit, since there are no problems with water condensation. It is not possible to recirculate the dust. [38, Vito 2001]

Achieved environmental benefits

Reduction of dust emissions to air.

Environmental performance and operational data

See data and relevant information in the sections below (on the abatement techniques) and in Section 2.3.

Cross-media effects

Extraction consumes energy.

Technical considerations relevant to applicability

Generally applicable.

Economics

No information provided.

Driving force for implementation

- Regulation of dust emissions.
- Legal requirements.
- Local requirements and local conditions.

Example plants

Widely used.

Reference literature

[38, Vito 2001], [120, TWG 2003], [169, TWG 2021], [210, TWG 2022]

3.2.1.9.18 Cyclone

Description

Equipment for the removal of dust from an off-gas stream based on imparting centrifugal forces, usually within a conical chamber. Cyclones are used as a pretreatment before further dust abatement or abatement of organic compounds. Cyclones can be applied alone or as multicyclone.

Technical description

Cyclones are used to remove dust, both as a recovery and as an abatement technique.

Achieved environmental benefits

- Possible material recovery.
- Reduced emissions to air.

Environmental performance and operational data

Cyclones can be used alone, but are often used in combination with other waste gas treatment techniques.

Reported data from five plants (7 EPs) using cyclones show a range for dust emissions from 0.4 mg/Nm³ to 14.3 mg/Nm³ with 5 out of 7 EPs with values lower than 1.5 mg/Nm³. [169, TWG 2021]

Cross-media effects

Disposal of the dust, if it is not used. Further information is provided in the CWW BREF [179, COM 2016].

Technical considerations relevant to applicability

Generally, there are no technical restrictions to the applicability of this technique. Further information is provided in the CWW BREF [179, COM 2016].

Economics

Cyclones are a low-cost technique. There is also the potential benefit of material recovery which depends on the dust concentration in the waste gas. Further information is provided in the CWW BREF [179, COM 2016].

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

DE029, DE039, DE064, ES082 and PT141.

Reference literature

[169, TWG 2021]

3.2.1.9.19 Fabric filter**More information on the technique**

See Section 3.2.1.12.7.

Environmental performance and operational data

Fabric filters are used alone or in combination with other off-gas treatment techniques.

Reported data from 62 plants (107 EPs) using fabric filters show a range for dust emissions from 0.01 mg/Nm³ to 27 mg/Nm³ with a median value of 1.27 mg/Nm³ and an average value of 2.88 mg/Nm³. [169, TWG 2021]

Example plants

Widely used.

Reference literature

[169, TWG 2021]

3.2.1.9.20 Wet scrubbing**More information on the technique**

See Section 3.2.1.13.4.

Environmental performance and operational data

Wet scrubbing is used alone or in combination with other waste gas treatment techniques.

Reported data from 10 plants (17 EPs) using wet scrubbing show a range for dust emissions from 0.1 mg/Nm³ to 27 mg/Nm³ with a median value of 0.9 mg/Nm³ and an average value of 2.8 mg/Nm³ [169, TWG 2021]

Example plants

BE028, DE039, DE043, DE062, DE064, ES082, FR114, IT132, IT155 and PT141.

Reference literature

[169, TWG 2021]

3.2.1.9.21 Adsorption

See Section 3.2.2.2.1.12.

Further information is provided in the CWW BREF [179, COM 2016].

Reference literature

[179, COM 2016]

3.2.1.9.22 Thermal oxidation**Description**

Abatement technique which oxidises combustible compounds in a waste gas stream by heating it with air or oxygen to above its auto-ignition point in a combustion chamber and maintaining it at

a high temperature long enough to complete its combustion to carbon dioxide and water. 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.

Technical description

Thermal oxidation is used as an abatement technique to reduce emissions of organic compounds (e.g. TVOC, benzene).

Further information is provided in the CWW BREF [179, COM 2016].

Achieved environmental benefits

- Reduced emissions to air.
- Possible energy recovery.

Environmental performance and operational data

Thermal oxidation is used alone or in combination with other waste gas treatment techniques (e.g. combined with pretreatment by condensation or adsorption or with post-treatment by absorption). Removal efficiencies for organic compounds typically range from 95 % to more than 99.99 %.

Reported data from one plant using thermal oxidation show a range for TVOC emissions from 1 mg/Nm³ to 2 mg/Nm³. [169, TWG 2021]

Optimisation of thermal oxidation can reduce the emissions of NO_x and CO. This is carried out by:

- optimising the design of the oxidiser:
 - residence time;
 - mixing of the flows (e.g. natural diffusion between turbulent streams, changes in flow direction);
 - combustion chamber;
- monitoring the combustion parameters:
 - oxygen content;
 - carbon monoxide concentration;
 - temperature;
- inspecting the burners regularly, and cleaning them when necessary.

When the oxidised VOCs contain sulphur and/or halogens, further emissions of sulphur dioxide and/or hydrogen halides might be expected. This might require an additional waste gas treatment after thermal oxidation (e.g. absorption).

Further information is provided in the CWW BREF [179, COM 2016].

Cross-media effects

- Generation of NO_x and CO and potentially of other pollutants (e.g. HCl, SO₂, PCDD/F).
- Consumption of fuel in the case of non-autothermal operation.

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.

Further information is provided in the CWW BREF [179, COM 2016].

Economics

Thermal oxidation is relatively expensive in comparison with some other techniques.

Cost information provided by the manufacturer Dürr in relation to the installation of a thermal oxidation unit as a function of the mass flow is as follows [210, TWG 2022]:

- 1 000Nm³/h: > 185.000 €;
- 5 000 Nm³/h: > 220.000 €;
- 10 000 Nm³/h: > 280.000 €;
- 20 000 Nm³/h: > 400.000 €;
- 180 000 Nm³/h: > 2.500.000 €.

The figure below also shows the relation between CO₂ emissions emitted and energy consumption (MWh/t) per tonne of TVOC abated depending on the TVOC concentration in the raw gases (mg/Nm³).

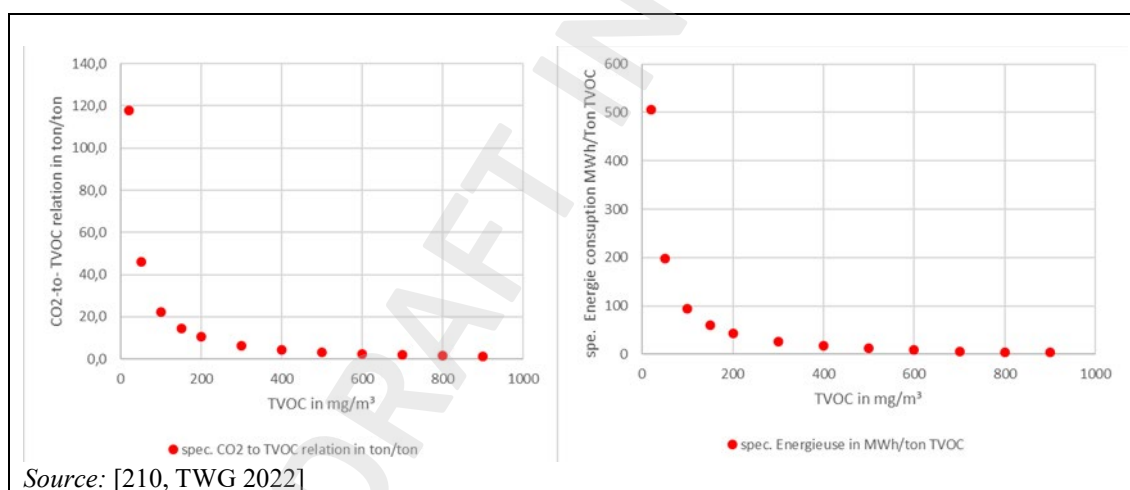


Figure 3.54: Relationship between CO₂ emissions, energy consumption per tonne of TVOC abated depending on the TVOC concentration in the raw gases

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

AT013. [169, TWG 2021]

Reference literature

[210, TWG 2022], [169, TWG 2021], [179, COM 2016]

3.2.1.10 Emissions to air from the casting, cooling and shake-out processes using lost moulds

3.2.1.10.1 Extraction of off-gases generated during the casting, cooling and shake-out processes

Description

Off-gases generated during the casting (especially emissions from pouring), cooling and shake-out processes are appropriately extracted.

For the casting and cooling processes, this includes:

- restricting the pouring process to a fixed area or position to facilitate the capture of emissions using ventilators and enclosure (e.g. in serial pouring);
- enclosure of pouring and cooling lines.

For the shake-out process, this includes:

- use of ventilator panels situated on both sides and at the rear of the shaker;
- use of enclosed units equipped with roof openings or removable covers (e.g. doghouse);
- installation of an extraction point situated underneath the shaker in the sand collection box.

Technical description

The emissions during pouring, cooling and shake-out are diverse and differ broadly in quality and quantity from one foundry to another. Basically, dust emissions are produced, as well as inorganic and organic gaseous compounds. These are mainly reaction products, caused by the high temperature and the reducing atmosphere upon pouring and cooling. The composition of pouring fumes is complex. They consist mainly of CO, CO₂, H₂, and methane as the main representatives of the organic decomposition products. Polycyclic aromatic hydrocarbons and benzene occur, depending on the composition of the mould- and core-system.

The capture and treatment of the off-gases of these process stages is generally possible for automated moulding and pouring installations. [13, Batz, R. 1986]

Relative emissions (as kg/t of molten metal) increase over the pouring-cooling-shake-out sequence. Exhaust capture efforts will need to take this variation into consideration.

Casting and cooling processes

The collection of emissions during pouring, cooling, and shake-out is as a rule more extensive as the plant becomes bigger.

The further the pouring process can be restricted to a fixed area or position, the smaller the amount of extracted air will be, and the easier it will be to capture emissions with ventilators and housings, and therefore air-treatment can be carried out more effectively.

In serial pouring, the emissions increase with increasing production capacity. Without extraction, the air at the pouring plant could at some point reach unacceptable concentration levels of noxious substances. To lessen the pollution in the work area, extractor ventilators or extractor surfaces are fitted as close to the moulds as possible, but without hindering the pouring process. The extractor elements are arranged in such a way that all emissions occurring during pouring, are moved away from the work area to the extracting equipment. The air-speed at the free extraction cross-section is kept between 0.5 m/s and 1 m/s.

Shake-out process

The technique used for the emission collection from shake-out depends on the degree of mechanisation, the emissions to be extracted and the size range of the castings, in particular the smallest and largest item cast on the same machine.

The system of collection and extraction of exhaust gases most commonly used is a ventilator panel on the side of the shaker. Usually, panels are installed on both sides of the shaker, regardless of the shaker size. If possible the rear of the shaker is enclosed in this way too. Frequently an extraction point is provided under the shaker in the sand-box, operating through a projecting pipe. This presents the risk of sand being extracted if the box is filled with sand up to the pipe. Moreover the pipe's inlet is often obstructed by sand lumps or adhering steam and dust.

The best way of achieving good emission levels with relatively small ventilation rates is when shake-out is performed in enclosed units. Roof openings, possibly with a moving screen, doors and entry/exit chutes make it possible to use a crane or other means of transport. In addition, the closed cabins reduce the noise level.

In automatic moulding plants, the casting-mould package is often pressed out of the moulding box by a hydraulic jack with a mounted pressing plate. Afterwards the casting is separated from the sand firstly on a jig-shaker and then to a rotating shake-out drum or tube or a sand cooler. Extraction drums or tube drums, which are now increasingly being used, are much more suited to the collection of emissions than the usual shakers, but they have the disadvantage of possible odour emissions.

The quantity of extracted air is not only determined by the workplace limit values required, but also by processing requirements. Large air volumes may be required for cooling and for protection of the filter bags. This needs to be balanced against the demands of any pollution abatement techniques, that usually need highly charged waste gases with small air volume streams in order to be effective.

Appropriate techniques for dedusting are cyclones combined with wet scrubbers or dry filters. Biofilters are also used and are discussed in Section 3.2.1.10.7.

For gravity die-casting and centrifugal casting, post combustion, chemical washing and adsorption to activated carbon are used in order to reduce organic emissions and odour.

Achieved environmental benefits**Casting and cooling processes**

Reduction of diffuse emissions of dust, CO, PAHs and other organic decomposition products. Extraction allows subsequent treatment of the collected exhaust gases.

For the example plant referred to in Environmental performance and operational data below, the following benefits were reported:

- in the case of subsequent dust abatement (with an assumed abatement efficiency of 95 – 99 % for the case of bag filter), the diffuse dust emissions are reduced by about 50 %;
- reduction of noise emissions by 3 – 9 dB(A), in the case of full enclosure;
- reduction in dust and CO concentration in the working area at percentages of about 50 % or more.

Shake-out process

Reduction of the emissions of VOCs and dust to air.

Environmental performance and operational data**Casting and cooling processes**

The following data refer to a foundry that produces over 3.5 million cast parts with a total tonnage of 33 000 tons per year. The production site is in Gutersloh, Germany.

An evacuation system is operated at the primary cooling area of the box-less moulding plant. The area of the secondary cooling section, which comprises the separation of sand and castings, the conveying in the cast cooler and the blasting of the castings, has been enclosed completely.

From the blasting unit, 15 000 m³ are extracted to filter No. 14, and from sand treatment, 59 000 m³ are extracted to filter No. 22. Most off-gas results from the cooling of the cast (85 000 m³ to filter No. 16). From cooling of sand and the polygon mesh 27 500 m³ and from the DISA cooler and the unpacking unit 38 000 m³ are extracted to filter No 34.

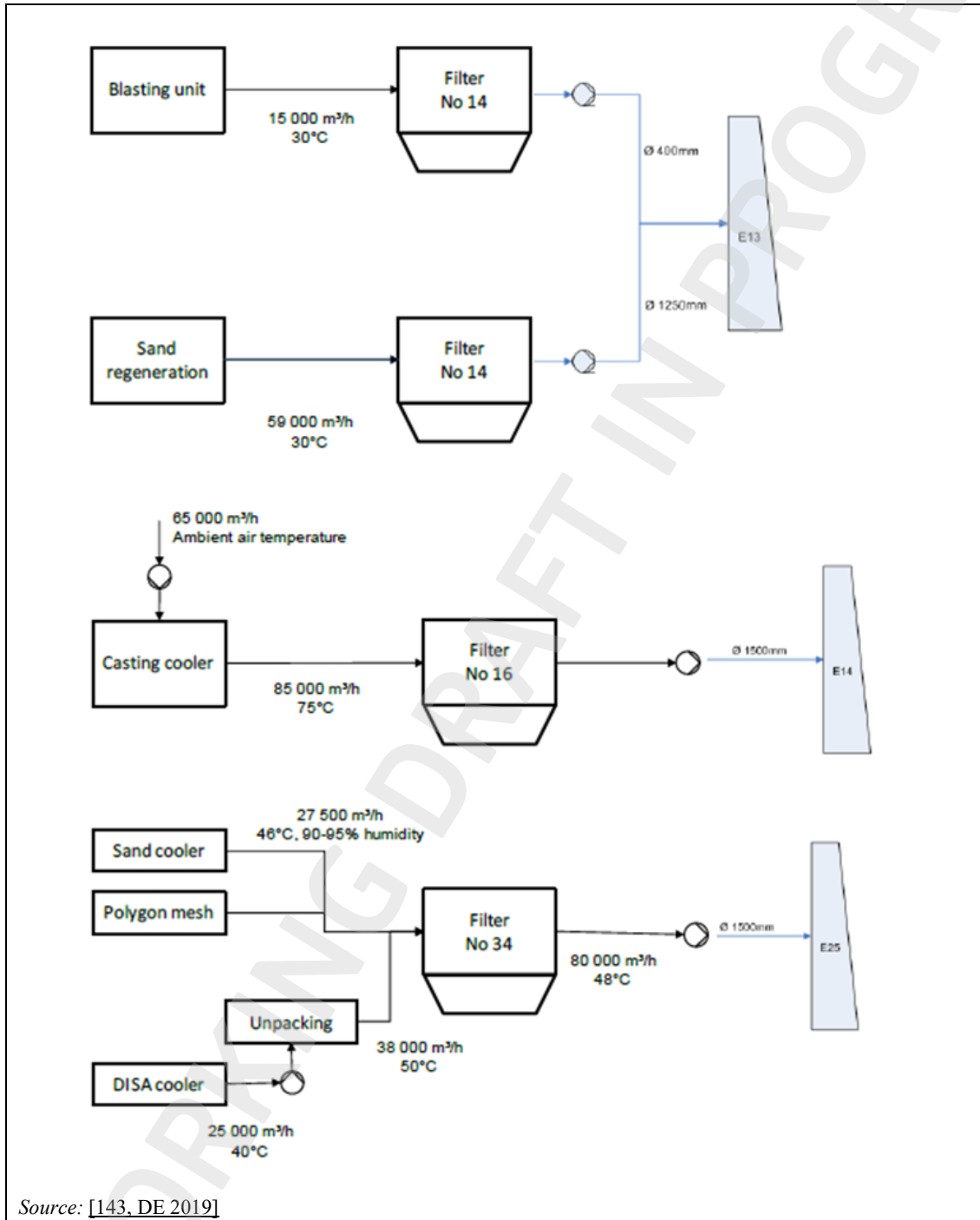


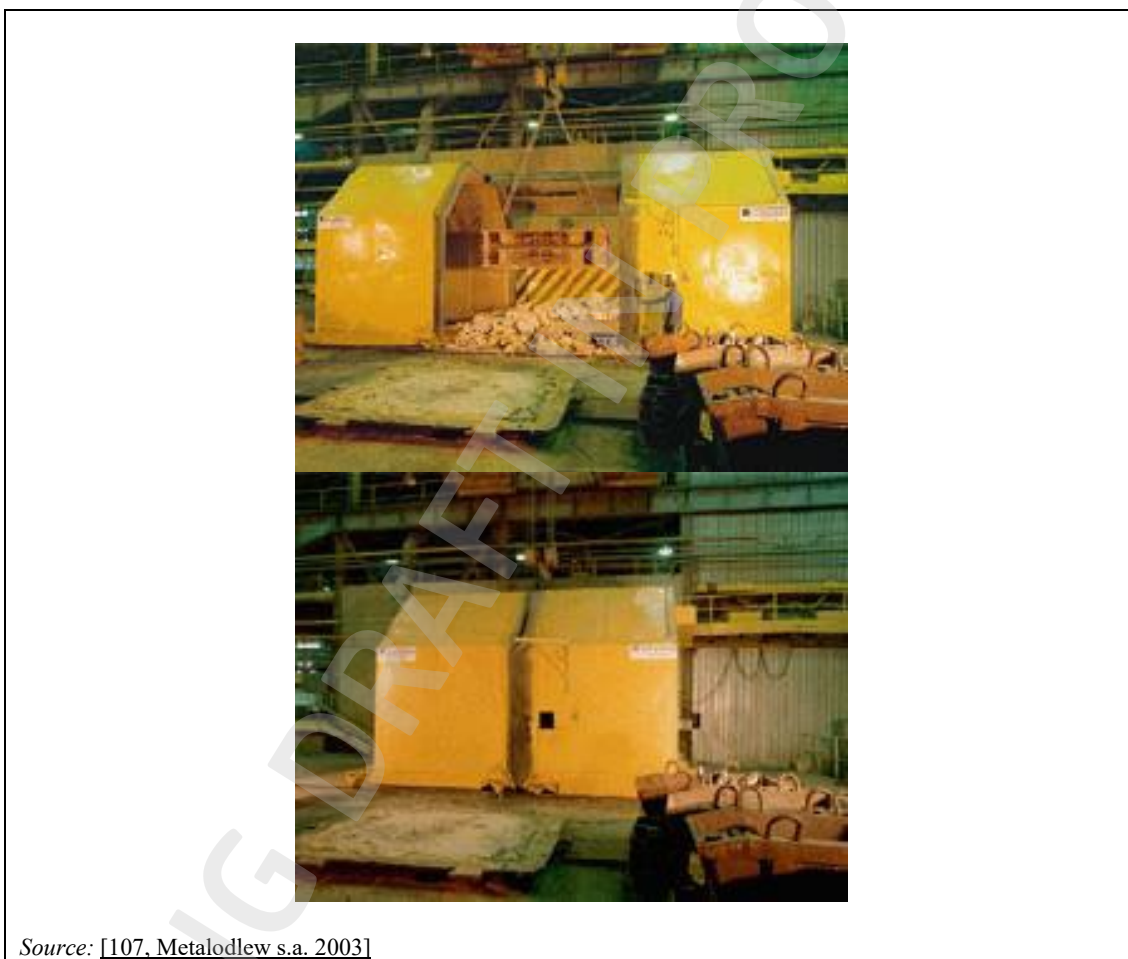
Figure 3.55: Exemplary process scheme and volume flows

Shake-out process

With free-standing extraction shakers up to 2 m in width, for every m² of shaker surface 7 000 Nm³/h to 9 000 Nm³/h of air is extracted in the case of a one-sided ventilation screen. With a two-sided screen, 5 000 Nm³/h per m² of shaker surface is installed.

If the extraction point is under the shaker in the sand-box, the amount of air extracted per m² of shaker surface is designed to be about 700 Nm³/h.

In a Polish example foundry for large-size cast steel castings, a removable doghouse type cover was constructed over the shake-out grate. The doghouse consists of two sideways moving doors, which are opened and closed hydraulically, as shown in Figure 3.56. The cover reduces dust and noise emissions into the foundry hall. The exhaust is cleaned using dry de-dusting. The noise level for shake-out was reduced from 100 dBA to below 85 dBA.



Source: [107, Metalodlew s.a. 2003]

Figure 3.56: Doghouse cover for a shake-out grate, for large batch castings

Cross-media effects

Extraction of exhaust air consumes electrical energy. In the case of dust abatement, the emitted dust which is collected by the abatement system must be disposed of as a waste.

Technical considerations relevant to applicability

Applicability to existing plants of enclosed units or removable covers in the case of shake-out operations may be restricted by a lack of space.

Economics

Casting and cooling processes

For the example plant mentioned above, the implemented technical measures of enclosure required an investment of approximately EUR 180 000 for the reduction of noise, dust and CO emission in the hall. Efforts for maintenance of the exhaust hoods could be reduced by changing the supply air. Information on the level of operating costs is not available.

Shake-out process

For the doghouse in the Polish example foundry, as mentioned above, the investment cost was EUR 220 000 (2003 data), including some additional equipment.

Driving force for implementation

- Reduction of diffuse emissions.
- Legal requirements.

Example plants

Casting and cooling processes

The technique is commonly applied in large-series foundries (e.g. Miele & Cie KG, Gütersloh, Germany).

Shake-out process

Metalodlew s.a., Krakow (PL)

Reference literature

[14, CAEF 1997], [6, Gerber et al. 1981], [107, Metalodlew s.a. 2003], [143, DE 2019]

3.2.1.10.2 Cyclone

More information on the technique

See Section 3.2.1.9.18

Environmental performance and operational data

Cyclones can be used alone, but are often used in combination with other waste gas treatment techniques.

Reported data from four plants (6 EPs) using cyclones show a range for dust emissions from 0.01 mg/Nm³ to 43 mg/Nm³ with 4 out of the 6 EPs with values lower than 2.7 mg/Nm³. [169, TWG 2021]

Example plants

BE022, BE023, DE039 and PL135.

Reference literature

[169, TWG 2021]

3.2.1.10.3 Fabric filter

More information on the technique

See Section 3.2.1.12.7.

Environmental performance and operational data

Fabric filters are used alone or in combination with other off-gas treatment techniques.

Reported data from 75 plants (140 EPs) using fabric filters show a range for dust emissions from 0.07 mg/Nm³ to 200 mg/Nm³ with a median value of 0.5 mg/Nm³ and an average value of 5.31 mg/Nm³. [169, TWG 2021]

Example plants

Widely used.

Reference literature

[169, TWG 2021]

3.2.1.10.4 Wet scrubbing**More information on the technique**

See Section 3.2.1.13.4.

Environmental performance and operational data

Wet scrubbing is used alone or in combination with other waste gas treatment techniques.

Reported data from five plants (7 EPs) using wet scrubbing show a range for dust emissions from 1.1 mg/Nm³ to 84 mg/Nm³ with 4 out of 6 EPs with emission levels below 17 mg/Nm³ [169, TWG 2021]

Example plants

CZ026, DE043, DE062 and FR115.

Reference literature

[169, TWG 2021]

3.2.1.10.5 Electrostatic precipitator**More information on the technique**

See Section 3.2.1.12.8.

Environmental performance and operational data

Reported data from four plants (14 EPs) using an ESP show a range for dust emissions from 0.14 mg/Nm³ to 7.1 mg/Nm³ with a median value of 3.35 mg/Nm³ and an average value of 3.52 mg/Nm³ [169, TWG 2021]

Example plants

AT005, CZ025, DE035 and ES087.

Reference literature

[169, TWG 2021]

3.2.1.10.6 Adsorption

See Section 3.2.2.2.1.12.

Further information is provided in the CWW BREF [179, COM 2016].

Reference literature

[179, COM 2016]

3.2.1.10.7 Biofilter**Description**

The off-gas stream is passed through a bed of organic material (such as peat, heather, compost, root, tree bark, softwood and different combinations) or some inert material (such as clay, activated carbon, and polyurethane), where it is biologically oxidised by naturally occurring microorganisms into carbon dioxide, water, inorganic salts and biomass. The biofilter is sensitive to dust, high temperatures or high variations in the off-gas composition. Supplementary nutrient feeding may be needed.

Technical description

Biofiltration is based on the ability of microbes living in a fibre-peat filter bed to oxygenate malodorous gases and convert them into odourless compounds. The gas to be purified is blown by a fan through a bed of humid filter material, exiting odourless from the upper side. The odorous compounds are adsorbed in the water phase and are decomposed by microorganisms living on the filter material. The good performance of the filter depends on the balance between the supply of nutrient (compounds for abatement/decomposition) and the number of microorganisms.

In foundries, biofilters are applied for the removal of odorous gases, which mainly consist of amines from the off-gas from cold-box core-making processes and for the removal of VOCs (e.g. benzene) from casting shop exhaust gases.

Critical parameters for good functioning of the biofilter are:

- *Permeability of the filter layer:* Gases need to flow through the bed in good contact with the filter bed material. An excess of fine material in the filter bed may cause clogging, pressure build-up and blowout of bed material.
- *Wetting of the filter medium:* A water dispersion system may be installed for continuous or intermittent wetting of the bed material.
- *Conditioning of the exhaust gas:* The exhaust gases need to be moistened before entering the filter. For optimum operation, a constant temperature (30 °C) has to be maintained. This may require preheating of the exhaust gas.
- *Adequate water treatment:* The biofilter produces residual water, containing phenol and cresol. This is treated in a waste water system before disposal or re-circulation. Re-circulation requires an additional salt removal step.

Introduction of the biofilter technique into a German foundry required a long optimisation period, until it was able to function satisfactory. It was found that the following characteristics appear to be important:

- Closure of the biofilter beds with a lid, in order to prevent CO- and condensation problems throughout the installation. The filtered air is evacuated through a centralised chimney.
- Close control of water quality (e.g. salt content), especially when applying a system not producing waste water.
- The addition of nutrient salts to the sprinkling water, to maintain bed activity.
- Control of the pH value of the bed material and the addition of lime to maintain a neutral pH value.

An updated biofiltering method (with additives) is applied in an example plant (Franz Kleinken GmbH, DE) which operates a bioscrubber micro cyclone system. Ambient air from the rooms first passes, in the cleaning installation, a spray chamber / water atomisation. The exhaust air (raw gas, a mixture of air and odour molecules) is treated with a water mist. The mist (fresh water with additives based on vegetable fatty acids) is produced by high-pressure nozzles. The active substance in the medium reacts with part of the odorous substances (sulphur compounds) and binds them.

At the same time, the water of the bioscrubber is sprayed into the air stream. The water, which is in a closed loop, contains natural enzymes and microorganisms as active compounds, which in the bioscrubber produce additional enzymes, and breaks down organic matter and biological odours.

The enzymes provide an improved transfer of the odour molecules into the water phase. A natural, herbal fragrance in the media is responsible for the change of plant-specific odour, without increasing the total odour load.

In a micro cyclone, drops and gaseous substances are separated from the gas stream. The separated liquid phase is collected and biodegradation of aromatic substances and media takes place. By added microorganisms, the organic ingredients are degraded mainly to CO₂ and water. In the demister unit, remaining drops are separated by the centrifugal deposition principle from the gas stream. They are then fed into the water circuit.

Further information on biofilters may also be found in the CWW BREF. [179, COM 2016]

Achieved environmental benefits

Reduction of odourous, amine and/or VOC emissions from the core shop and casting shop. The elimination of benzene and other VOCs takes place in biofilters but may not be regarded as reliable. The efficiency varies remarkably according to a wide spectrum of factors, such as weather conditions, age of substrates, etc. The use of biofilters alone is therefore not valid as a stand-alone technique for the reduction of VOCs. Their main purpose consists in the reduction of odour.

In the example plant mentioned above (Franz Kleinken GmbH, DE), direct odour measurements above a casting mould showed odour minimisation efficiency in a range between 60 % and 80 %. The odour quality is thereby altered so that the plant-specific odour of the foundry is no longer perceivable. A long-term olfactometric measurement before installation of the system and during the plant operation (> 6 months) confirmed the achieved environmental benefits.

Environmental performance and operational data

Pilot scale data for amine removal have been provided by Finland. A biofilter unit (diameter 0.8 m, height 1 m) was installed in a core-making off-gas line, after an acid scrubber. The equipment included a fan and a dewing unit, with which the dampness of the biofiltration unit was adjusted to an optimum level. The odour removal was measured using an olfactometer. Results for the odour and total hydrocarbon levels are given in Table 3.40. Variations in the input analysis are due to process variations. The results show that filtration results in a significant odour and hydrocarbon reduction.

Table 3.40: Operational data for the biofiltration of a cold-box core-making off-gas

Compound	Units	Before biofilter	After biofilter
Odour	OU/m ³	410 – 3000	150 – 310
Total hydrocarbons	mg C/m ³	20 – 35	5 – 10
OU = Odour units			
Source : [39, Salminen et al. 1999]			

Industrial scale data for VOC removal have been provided by Germany. A biofilter unit (specification: surface 300 m², height 1 m, in 5 rectangular beds, with a total throughput of 32 330 Nm³/h dry gas) was installed for the treatment of exhaust gases from pouring and cooling in a green sand cast-iron foundry, using croning and cold-box cores. The emission data are given in Table 3.41. Olfactometric measurements showed an average reduction of odour emissions by a factor of 94.5 %.

Table 3.41: Emission data for the biofiltration of exhaust from green sand pouring and a cooling line

Parameter	Units	Before biofilter	After biofilter	Reduction %
O ₂	%	20.74		
CO ₂	%	0.17		
NO _x	mg/m ³	3.65		
CO	mg/m ³	382	299	21.7
Benzene	mg/m ³	15.80	1.44	90.9
Toluene	mg/m ³	9.37	0.92	90.1
Ethylbenzene	mg/m ³	3.00	0.46	84.7
Xylene	mg/m ³	4.90	1.54	68.6
Formaldehyde	mg/m ³	0.37	0.01	68.6
Dust	mg/m ³	13.63	2.03	85.1
Ammonia	mg/m ³	8.97	0.16	98.2
Phenol	mg/m ³	4.67	<0.02	>99.6
Cresol	mg/m ³	3.73	<0.02	>99.5
PCDD/F	ng/m ³	0.0056	0.0041	26.8
Benzo(a)pyrene	mg/m ³	0.0001	0.00003	70.0
<i>Source: [9, Gapp, H. 1989]</i>				

In the iron foundry using the micro cyclone system for odour abatement, products are made from gray and ductile iron with a weight up to 30 t. The foundry is divided into a hand moulding for large cast and a hand moulding for small castings (up to 4 tons weight). Both moulding facilities are supplied by its own core shops. The melting process consists of 2 MF induction furnaces, with a capacity of 2 tonnes and 4 tonnes and in 2 cupola furnaces with a melting capacity of 6 t/h.

The extracted exhaust per reference foundry plant is 25 000 m³/h.

When operating a biofilter, one of the main problems is to prevent the filter material from drying out or becoming waterlogged in places, thereby enabling a uniform flow through the filter bed. Thus, biofilters reach the limits of their performance in the presence of the following exhaust air characteristics:

- strongly fluctuating exhaust air constituents in terms of type and concentration;
- discontinuous exhaust air flow;
- thermal and chemical instabilities caused by peak loads of temperature, dust, disinfectants, steam, etc. (Comment CAEF-315 [210, TWG 2022]).

Additionally, disadvantages are often the large space requirements of these systems, the cost-intensive fan energy for increasing the pressure and the permanent watering.

Cross-media effects

The biofilter produces a waste water flow. This may be recirculated internally after treatment, yielding a sludge cake for disposal.

Energy is consumed during the transfer of the off-gas to and through the filter, as well as for the surrounding equipment.

It has been reported that emissions of N₂O, a greenhouse gas, may be a problem.

Technical considerations relevant to applicability

In principal, bioscrubbers can be applied in new and existing plants. The required operating system depends on two conditions: the odour load and the hall suction. When the application of bioscrubbers is technically evaluated:

- the planned water flow and the amount of additives must be adapted to the odour load;
- uptime of the casting facility must be considered due to its consequence for energy consumption.

When no odours are generated (e.g. when no casting is done or during production downtime), it is possible to turn off the system manually. A time limit for downtime of the bioscrubber does not exist. The plant can operate continuously 24 hours a day.

It has to be considered that the microorganisms require relatively constant environmental conditions.

Economics

Investment costs for the biofilter unit in the example plant Halberg Guss (specification: surface 300 m², height 1 m, in 5 rectangular beds, with a total throughput of 32 330 Nm³/h dry gas), including a water treatment unit to allow operation without the production of waste water, have been estimated at EUR 3 247 000 (1998 data). This includes EUR 233 3000 for the filter and surrounding equipment and EUR 914 000 for the exhaust capture and ductwork. With a design load of 40 000 Nm³/h, operational costs are estimated at EUR 170 000/y (costs based on DEM for 1998).

These estimated operational costs are much higher than generally stated investment and operational costs for biofilter units. This is probably due to the large throughput and the extent of the surrounding equipment. In a 1998 paper the cost for an open-bed biofilter, treating 17 000 Nm³/h was estimated at USD 70 000 – 100 000 for investment and a yearly operating cost for water, labour and overheads of USD 15 000 – 25 000.

For the second example plant, Franz Kleinken GmbH (biofiltration with additives), the investment cost of air conditioning systems like indoor air extraction and indoor cleaning techniques are between EUR 150 000 and EUR 200 000. It should be considered in the evaluation of the economics whether the indoor air extraction and indoor cleaning techniques, which might be necessary anyway, must be redesigned to the needs of a bioscrubber system. The operating costs for the bioscrubber are between EUR 6 and EUR 10 per hour of operation (2013 data).

Driving force for implementation

- Reduction of nuisance effects (mainly odour) on neighbouring locations.
- Legal requirements.

Example plants

Halberg Guss, Saarbrücken-Brebach, DE.

Metallwerk Franz Kleinken GmbH, DE.

Reference literature

[9, Gapp, H. 1989], [39, Salminen et al. 1999], [100, TWG 2002], [106, Devlinny, J. S. 1998], [143, DE 2019], [179, COM 2016], [210, TWG 2022]

3.2.1.11 Emissions to air from Lost Foam casting

3.2.1.11.1 Extraction of off-gases generated from Lost Foam casting as close as possible to the emission source

Description

In the Lost Foam casting processes, off-gases from moulding and from the pyrolysis of the expanded polymer during pouring and shake-out are extracted using, for example, an enclosure or hood.

Further information and emission data for the Lost Foam casting process can be found in Sections 2.2.5.9.1 and 3.2.1.4.3.9.

More information on the ceramic shell casting process can be found in Section 3.2.1.4.3.10.

3.2.1.11.2 Catalytic oxidation

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.

Reference literature

[179, COM 2016]

3.2.1.11.2.1 Catalytic oxidation of off-gases in the Lost Foam casting process

Description

Off-gases from the Lost Foam casting process are captured (using vacuum) and treated using catalytic post-combustion.

Technical description

Exhaust gas capture using vacuum and a catalytic post-combustion system is used for treatment of waste gases in the Lost Foam process. A description of the Lost Foam process is given in Section 2.2.5.9.1.

In the catalytic thermal oxidiser (CTO), volatile organic pollutants are burnt. The catalyst reduces the amount of energy needed to crack the pollutants. The raw gas loaded with pollutants is led into the heat exchangers of the CTO by the process fan. Here the raw gas is preheated by the hot clean gas. When required, the blower heats the exhaust gas in the combustion chamber until the ignition temperature of the catalyser is reached. In the catalyser, the pollutants contained in the raw gas are converted mainly into CO₂ and H₂O. After the catalyser, the clean gas is led into the heat exchanger tubes. A compensation tank can be used to equalise concentrations of the gases.

Achieved environmental benefits

The benefit of the post-combustion is the reduction of emissions of organic pollutants (BTEX, TVOC).

Environmental performance and operational data

For the example plant (GussStahl Lienen GmbH & Co. KG, Lienen, Germany), the following operational data were reported:

- foundry processes: Lost Foam process and no-bake moulding;
- 1 300 t to 1 600 t (500 t Lost Foam castings) per year, steel castings, heat-resistant steel;
- weight per part: 1 kg to 1 t;
- turnover: EUR 15 million;
- employees: 75;
- two-shift operation.

The catalytic post-combustion system has the following characteristics:

- volume: 1 300 Nm³/h;
- the air cleaning system is operating roughly 15 min/day; the catalyst is preheated all day;

- after pouring there are emissions for some seconds; the ventilation system is operated for a minute.

Table 3.42: Operational post-combustion data

Compound	Emissions, without post combustion	Emissions, with post combustion
Benzene	596 mg/m ³ ; 320 g/h	0.04 mg/m ³ ; 0.047 g/h
Toluene	129 mg/m ³ ; 70 g/h	Not measured
Etylbenzene	23 mg/m ³ ; 13 g/h	Not measured
Xylene	43 mg/m ³ ; 23 g/h	Not measured
Styrene	863 mg/m ³ ; 466 g/h	Not measured
Methyl methacrylate	2 157 mg/m ³ ; 1 165 g/h	Not measured
Total organic carbon	Not measured	95 mg/m ³ , 0.111 kg/h
Parameters		
Air pressure	1 000 hPa	988 mbar
Gas flow	540 m ³ /h	1 167 m ³ /h
H ₂ O content	21 g/m	25.6 g/m ³
O ₂ content	-	18.9 Vol.-%
Gas temperature	24 °C	Not measured
Catalyst temperature	Not measured	394 to 626 °C
Clean gas temperature	Not measured	255 to 370 °C
Burner temperature	Not measured	420 to 437 °C
<i>Source: [133, DE UBA 2014]</i>		

Cross-media effects

Consumption of 400 m³ natural gas per month.

Technical considerations relevant to applicability

Post-combustion can be applied in new and existing plants. It is advantageous in the case of exhaust gas with relatively high organic content, e.g. after pouring in the lost foam process.

Economics

- Investment costs for catalytic post-combustion plant: EUR 250 000.
- Running costs (maintenance etc.) – post-combustion plant: EUR 5 000/year.

Driving force for implementation

Reduction of emissions and compliance with the German regulation TA Luft.

Example plants

GussStahl Lienen GmbH & Co. KG, Lienen, Germany.

Other users of lost foam process with post combustion: BMW AG, Landshut, Germany.

Plant FR115: Stellantis aluminium foundry, Charleville Mezieres, France.

Reference literature

[133, DE UBA 2014]

3.2.1.11.3 Fabric filter

More information on the technique

See Section 3.2.1.12.7.

Environmental performance and operational data

Fabric filters are used alone or in combination with other off-gas treatment techniques.

Reported data from one plant (4 EPs) using fabric filters show a range for dust emissions from 0.22 mg/Nm³ to 1.24 mg/Nm³. [169, TWG 2021]

Example plants

IT129.

Reference literature

[169, TWG 2021]

3.2.1.11.4 Adsorption

See Section 3.2.2.2.1.12.

Further information is provided in the CWW BREF [179, COM 2016].

Example plants

A study carried out by the Basque Government at two foundries in Spain using the Lost Foam process showed significant emissions of VOCs, in particular benzene, toluene and styrene. These emissions were occurring particularly during the moulding and casting processes as a result of the thermal decomposition of the expanded polystyrene. In both foundries, emissions were not extracted and purified properly prior to being released into the atmosphere. Accordingly, corrective measures were introduced in these two foundries with the installation of effective extraction and abatement systems including adsorption with activated carbon. [181, Basque Government 2019]

Reference literature

[179, COM 2016], [181, Basque Government 2019]

3.2.1.11.5 Thermal oxidation

See Section 3.2.1.9.21.

Reference literature

[179, COM 2016]

3.2.1.11.6 Wet scrubbing

See Section 3.2.1.13.4.

3.2.1.12 Emissions to air from the casting process in foundries using permanent moulds

3.2.1.12.1 General techniques for gravity and low-pressure die casting

Description

This includes techniques such as:

- selection of an appropriate lubricant to prevent castings surface defects;
- optimised lubricant preparation and application to avoid excessive use.

Technical description

The release agent (lubricants) to be used in die-casting plays a very important role to prevent the molten metal becoming welded to the die. It should also facilitate the release and later extraction of the casting from the die, without any change in the size or the structure of the casting.

In principle, the release agent must maintain its main characteristics after being in contact with the molten metal. The main principles that should be considered for the selection of the lubricating material are:

- to allow a trouble-free casting ejection from the die (e.g. in the shape and the surface appearance of the casting);
- to prevent the molten metal becoming welded to the die;
- to facilitate the flow of molten metal into the die and the filling up of all cavities;
- to leave the die clean (without any residue).

Equally important are the lubricant preparation (e.g. dilution with water) and the application method (e.g. spraying).

Achieved environmental benefits

- Optimised material efficiency.
- Reduction in the consumption of lubricants and water.
- Limitation of associated emissions to air and water.

Environmental performance and operational data

The use of lubricants has various environmental impacts, e.g. use of energy for the water and lubricant sprayer, generation of waste due to the low percentage of lubricant mixture that finally deposits on the die surface, VOC and hazardous pollutant emissions to air as a result of the decomposition of lubricants due to the heat of the die.

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable.

Economics

No information provided.

Driving force for implementation

- Savings in material and water consumption.
- Legal requirements.
- Local conditions.

Example plants

Widely used.

Reference literature

[184, Watkins et al. 2013]

3.2.1.12.2 General techniques for high-pressure die casting**Description**

This includes techniques such as:

- proper lubrication of the die and plungers using water-based emulsions of, for example, silicone oils, ester oils, synthetic waxes;
- minimisation of the release agent and water consumption by optimising the spraying process, e.g. use of micro-spraying for application of release agents (see also Section 3.2.1.4.3.2).

Technical description

Generally, release agents are a mixture of a lubricant and a carrier material. Formulations may also include additives to inhibit corrosion, to increase stability during storage, and to resist bacterial degradation. Lubricating materials are typically mineral oils and waxes in water emulsions. Silicone oils and synthetic waxes are finding increased use. Water-based lubricants are preferred to solvent-based ones to avoid VOC emissions.

Proper lubrication of the dies and plungers is essential for successful high-pressure die-casting. The proper die lubrication has positive effect on all of the following:

- the casting quality, density, and surface finish;
- the ease of cavity filling and of casting ejection.

Proper lubrication can also speed up the casting rate, reduce maintenance requirements, and reduce the build up of material on the die face.

Achieved environmental benefits

See Technical description above.

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

- Better product quality.
- Reduced VOC emissions.
- Legal requirements.

Example plants

Widely used.

Reference literature

[18, US EPA 1998], [42, IHOBE 1998], [175, COM 2021]

3.2.1.12.3 Optimisation of process parameters for centrifugal and continuous casting

Description

In centrifugal casting, important process parameters such as mould rotation, pouring temperature and mould preheating temperature are optimised (e.g. using flow simulation) to reduce the number of defects and minimise emissions.

In continuous casting, the casting rate and temperature are optimised and direct cooling with water is used for final solidification.

Technical description

In centrifugal casting, a set of important process parameters needs to be optimised in order to achieve the best possible product output (e.g. obtaining the minimum porosity). These parameters include:

- the material;
- the pouring temperature;
- the preheat temperature;
- the mould rotation.

The mould pouring temperature may be considered the most significant parameter that affects the quality of centrifugal casting components. Simulation software may also be used for the simulation of the density of casting and the visualisation of outputs of the cast products.

In continuous casting, the major challenge is to cast continuously without interruptions and without many kinds of defects. The solidification control is crucial for the surface and internal casting quality. Important control parameters in solidification include steel chemistry, casting speed, mould level, mould powder, mould oscillation, liquid steel temperature, and secondary cooling conditions, as well as parameters affecting the flow phenomena in the mould. Advanced control systems based on multiple sensor inputs are used to allow optimised operation with on-line quality prediction.

Achieved environmental benefits

Material and energy efficiency through the production of castings with less defects (internal scrap minimisation).

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

Better product quality with less defects.

Example plants

Widely used.

Reference literature

[185, Seetharaman 2014]

3.2.1.12.4 Separate spraying of release agent and water in high-pressure die-casting

See Section 3.2.1.4.3.1.

3.2.1.12.5 Use of water-free release agents in high-pressure die-casting**Description**

Water-free release agents (e.g. in a powdered form) are applied to the die using electrostatic deposition.

Technical description

A minimum amount of dry lubricant – about 0.3 – 0.5 grams for each kilogram of injected aluminium – is electrostatically applied to the mould at each production cycle (the consumptions were calculated at a mould temperature of 250 °C). When it comes into contact with the hot mould, the electrostatically distributed dry lubricant melts, expanding to the deepest points. In this way, it creates a highly efficient release film, without creating residual thickness and carbon formations, which are typical of water-based lubrication systems.

The major advantages of the dry lubrication system are as follows:

- Improved quality of the castings. Lack of water from the lubrication process, drastically reduces the formation of hydrogen, which causes porosity in the casting.
- No waste water generation.
- No oil mist generation.
- Drastically reduced suction.
- Reduced cycle times: lubricating with water-based products normally takes 10 – 15 % of the cycle time. Two thirds of the lubrication process are dedicated to the mould drying process, which is no longer necessary if water-free lubrication is used. The estimated overall time saving is of the order of 7 – 10 %.
- Longer-lasting moulds through the elimination of the thermal shocks and therefore the drastic reduction of dies expansion and thus the formation of cracks. In addition, the alloy remains smoother.

Achieved environmental benefits

- No waste water or oil mist generation.
- Reduced energy consumption because of reduced volume of sprayed lubricant and less need for blowing air to ensure that no water is left in the die cavity.

Environmental performance and operational data

See Technical description above.

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable.

Economics

No information provided.

Driving force for implementation

- Operational efficiency.
- No waste water or oil mist generation.

Example plants

No specific information on plants using water-free lubrication systems is available. Water-free lubrication systems are available in the market from various providers.

Reference literature

[186, Foundry (journal) 2021], [193, Neto et al. 2009]

3.2.1.12.6 Extraction of off-gases generated from the casting process as close as possible to the emission source

Description

Off-gases generated from the casting process in foundries using permanent moulds including high-pressure / low-pressure / gravity die casting, centrifugal and continuous casting are extracted using enclosures or extraction hoods and are sent to an abatement system.

Technical description

The use of mainly water-based release agents generates emissions to air (mainly in the form of mist) with low concentrations of decomposition products. These emissions are collected using enclosures or extraction hoods and sent to an abatement system.

Achieved environmental benefits

Reduction in the emission of release agent containing organic compounds. Prevention of diffuse emissions.

Environmental performance and operational data

Operational data from an example plant are given in Table 3.43. The data refer to a water miscible release agent (1:40 dilution factor), based on synthetic polymer and polysiloxane. Each die-casting machine is equipped with a separate suction hood and an EP. The hot and cleaned air is blown back into the hall (i.e. for heat recovery).

Table 3.43: Emission data from ESP-cleaned HPDC off-gas

Compound	Half hourly measured values (mg/Nm ³)	Mass – flow (g/h)
Dust	1.5 – 4.3	5.5
Organic substances (values in total carbon) (mg/m ³)	4 – 6	9
<i>Source: [100, TWG 2002]</i>		

Cross-media effects

Capture and collection of the mist requires the consumption of energy.

Technical considerations relevant to applicability

Generally applicable.

Economics

Extraction of off-gases entails energy consumption.

Driving force for implementation

- Legal requirements.
- Minimisation of diffuse emissions and legislation on the emission of oil mist (e.g. in Sweden).
- Local conditions.

Example plants

Widely used. In the SF data collection the following plants reported this technique:

- Continuous casting: DE072.
- Gravity die casting and tilt casting: AT013, EL080, FR112, FR114 and IT127.
- High pressure die-casting: AT005, AT014, ES087, FR116, IT122, IT123, IT133 and SE148.

Reference literature

[100, TWG 2002], [120, TWG 2003], [169, TWG 2021]

3.2.1.12.7 Fabric filter

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.

Technical description

This type of separator is widely applied in various parts of the foundry process, due to its good efficiency and low emission values. It can achieve good efficiencies in controlling the fine particulate matter found in melting operations. Sub-micron particles such as metallic oxides may be separated as well. For proper operation, the following measures need to be taken: flue-gas cooling ($T = 130 - 160\text{ }^{\circ}\text{C}$) and separation of sparks (using a cyclone). The post combustion of organic material (to reduce the fire risk) may be applied for an off-gas with a high VOC content. Post combustion as a 'firewall' for bag filter protection has been reported in some cases for off-gas from the unpacking of drums. This technique is not applied in general; instead waste gas streams with high dust loads are mixed with gas streams with increased VOC contents to prevent the filter and the exhaust ducts from becoming sticky. A view of the inside and outside of a bag filter unit is given in Figure 3.57.



Source: [132, HUT 2003]

Figure 3.57: Bag filter units; inside (L) and outside (C, R) views

Achieved environmental benefits

Reduction of emissions to air.

Environmental performance and operational data

Fabric filters are used alone or in combination with other off-gas treatment techniques.

Reported data from three plants using fabric filters show a range for dust emissions from 0.2 mg/Nm^3 to 3.4 mg/Nm^3 with all but one value lower than 1.2 mg/Nm^3 . [169, TWG 2021]

See also Technical description above. Further information is provided in the CWW BREF [179, COM 2016].

Cross-media effects

- Energy consumption.
- Disposal of the dust, if it is not used.

Further information is provided in the CWW BREF [179, COM 2016].

Technical considerations relevant to applicability

Generally applicable.

Further information is provided in the CWW BREF [\[179, COM 2016\]](#).

Economics

Information is provided in the CWW BREF [\[179, COM 2016\]](#).

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

EL080, IT133 and SE148.

Reference literature

[\[132, HUT 2003\]](#), [\[169, TWG 2021\]](#), [\[179, COM 2016\]](#)

3.2.1.12.8 Electrostatic precipitator

Description

Electrostatic precipitators (ESPs) operate such that particles are charged and separated under the influence of an electrical field. Electrostatic precipitators are capable of operating under a wide range of conditions. Abatement efficiency may depend on the number of fields, residence time (size), and upstream particle removal devices. They generally include between two and five fields, but may contain up to seven fields for the most advanced ESPs. Electrostatic precipitators 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.

Technical description

Electrostatic precipitation is used to remove dust, both as a recovery and as an abatement technique. Removal efficiencies for dust typically range from 97 % to more than 99 %. [\[179, COM 2016\]](#)

Further information is provided in the CWW BREF [\[179, COM 2016\]](#).

Achieved environmental benefits

- Reduced emissions to air.
- Possible material recovery.

Environmental performance and operational data

Electrostatic precipitation is used alone or in combination with other waste gas treatment techniques.

Reported data from two plants (4 EPs) using an ESP show a range for dust emissions from 1.3 mg/Nm³ to 5.3 mg/Nm³. [\[169, TWG 2021\]](#)

Cross-media effects

- Energy consumption.
- Disposal of the dust, if it is not used.

Further information is provided in the CWW BREF [\[179, COM 2016\]](#).

Technical considerations relevant to applicability

Generally applicable.

Further information is provided in the CWW BREF [\[179, COM 2016\]](#).

Economics

Further information is provided in the CWW BREF [179, COM 2016].

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

AT005 and ES087. [169, TWG 2021]

Reference literature

[169, TWG 2021], [179, COM 2016]

3.2.1.12.9 Thermal oxidation

See Section 3.2.1.9.21.

3.2.1.12.10 Wet scrubbing

See Section 3.2.1.13.4.

3.2.1.13 Emissions to air from finishing

3.2.1.13.1 Extraction of off-gases generated from finishing as close as possible to the emission source

Description

Off-gases generated from finishing operations, such as deburring, abrasive cutting, fettling, slide grinding, shot blasting, welding, chiselling, needling, are appropriately extracted using, e.g.:

- enclosure of the finishing process area;
- roof ventilation or dome-shaped roofs;
- rigid or adjustable extraction hoods;
- extraction arms.

Technical description

Considerable amounts of fume have to be captured and extracted when using thermal separation techniques. The work area may be as enclosed as much as possible, but ensuring the freedom of movement and that the inhaled air supply of the worker can be assisted. Dust collection techniques during abrasive cutting and grinding are differentiated between stationary machines and hand machines. Rigid hoods are customary at stationary machines, partly in connection with partial housings.

For stationary grinding machines, the tightly limited abrasive blast goes into an extracting funnel and is extracted. In the case of abrasive cutting-off stations, it is sensible to additionally extract emissions from the cabin in the interest of worker's health and safety. Handheld machine emissions are occasionally extracted via the splint protection hood. This is an effective but unpopular method, as it increases the weight of the machine and impairs its manageability. Normally hand grinding and hand cutting-off machines are housed in cabins (i.e. partial housings).

Collection of the dust takes place via extracting walls, roof domes, moveable hoods or extraction work benches. An effective aid when collecting emissions are hot-air curtains which direct additional air into the cabin. The additional air used may be cleaned recycled extraction air, in

order to economise on heating energy. However, it should be noted, that a portion of fresh air will still always need to be provided from the outside.

Dust or pollutant collection is in most cases not needed for sawing, rapping, pressing, chiselling, stamping and milling. Screens may sometimes be used to protect the operator against rough particles. Welding is divided into processes with and without additional materials. Work protection regulations requiring extraction exist for most processes.

A rough estimation of the emission levels by applied finishing technique is provided in the following paragraphs.

- *Blasting*: Blasting generates a lot of dust. Off-gas capture is unproblematic due to the total enclosure of the blasting process in a closed cabin. Customary exhaust air decontamination processes are wet washing and dry filters, usually with a cyclone as a pre-filter.
- *Slide grinding, drumming*: Both processes do not require emission reduction in normal conditions. Aerosols that can form in quickly moving drums can be neglected.
- *Cutting*: All thermal separation processes generate emissions. Exhaust capture is achieved through enclosing the work place and carrying out an intensive extraction of the arising fume. It is important to place the capture elements as close as possible to the emission source, but without hindering the operating process. In some cases it has proven beneficial to combine a mobile arm for direct extraction and additional cabin extraction. By carefully arranging the extraction elements, the dust-filled air can be guided away from the breathing area of the worker. The usual exhaust air decontamination processes are wet washing and dry filters. It should be noted that the systems are set up for the smaller grain sizes of the emitted fumes. Inertia force separators are applied as pre-separators.
- *Abrasive cutting*: Stationary abrasive cutting installations are extracted. Customary exhaust air decontamination processes are cyclones, wet washing and dry filters
- *Sawing, rapping, pressing*: These handling processes cause few emissions and do not require reduction measures in normal conditions.
- *Chiselling, needling*: In these processes mainly coarse particles are produced which are difficult to remove through extraction. The work is mainly carried out in cabins for safety reasons. In special cases, e.g. when removing burnt-on sand, the generated dust may be extracted by an extraction arm. The exhaust air is decontaminated in cyclones, wet washing and dry filters.
- *Grinding*: Emission capture when grinding on stationary machines takes place in a similar way as with abrasive cutting, i.e. via fixed funnels into which the abrasive blast is directed. An enclosed work place is used for manual grinding and abrasive cutting. Extraction walls can then be applied in the housing. Air decontamination processes are cyclones, wet washing and dry filters.
- *Stamping, milling*: These handling processes cause few emissions and do not require reduction measures in normal conditions.
- *Welding*: More or less emissions occur according to the type of the selected welding process, which is usually best collected by extraction arms. For exhaust air cleaning, wet washing and dry filters and occasionally electrostatic filters are used.

As indicated in the following table, some finishing techniques may not generate dust and consequently may not necessitate an off-gas collection system.

Table 3.44: Use of dust capture techniques for various finishing operations

	Roof ventilation	Dome-shaped roof	Rigid hood	Adjustable hood	Housing
Abrasive cutting			x	x	x
Burning	x	x	x	x	x
Chiselling, needling	Off-gas collection seldom necessary				
Fettling		x	x	x	x
Milling	No off-gas collection necessary				

	Roof ventilation	Dome-shaped roof	Rigid hood	Adjustable hood	Housing
Rapping, pressing	No off-gas collection necessary				
Sawing	No off-gas collection necessary				
Slide grinding	x	x	x	x	x
Shot blasting					x
Stamping	No off-gas collection necessary				
Welding	x		x	x	x

Source: [14, CAEF 1997], [120, TWG 2003]

Achieved environmental benefits

Reduction of diffuse emissions of metallic particles and dust.

Cross-media effects

The collection and extraction of dust-laden off-gas consumes energy.

Technical considerations relevant to applicability

Generally applicable.

Economics

Extraction of off-gases entails energy consumption.

Driving force for implementation

- Regulations on dust emissions and occupational health and safety.
- Legal requirements.
- Local conditions.

Example plants

The technique is applied in the vast majority of the European foundries.

Reference literature

[14, CAEF 1997], [79, Assofond 2002], [169, TWG 2021]

3.2.1.13.2 Cyclone

See Section 3.2.1.9.18

Environmental performance and operational data

Cyclones can be used alone, but are often used in combination with other waste gas treatment techniques (e.g. combined with post-treatment by absorption or filtration). Removal efficiencies for dust typically range from 90 % to more than 99 % [179, COM 2016].

Reported data from seven plants (14 EPs) using cyclones show a range for dust emissions from 0.2 mg/Nm³ to 11.6 mg/Nm³ with a median value of 3 mg/Nm³. [169, TWG 2021]

Example plants

ES087, ES089, ES090, IT071, PL135, PT139 and PT139 [169, TWG 2021]

Reference literature

[14, CAEF 1997], [79, Assofond 2002], [169, TWG 2021], [179, COM 2016]

3.2.1.13.3 Fabric filter**More information on the technique**

See Section 3.2.1.12.7.

Environmental performance and operational data

Fabric filters are used alone or in combination with other off-gas treatment techniques.

Reported data from 79 plants (192 EPs) using fabric filters show a range for dust emissions from 0.02 mg/Nm³ to 62.3 mg/Nm³ with a median value of 1.1 mg/Nm³ and an average value of 2.8 mg/Nm³ [169, TWG 2021]

Example plants

Widely used. The vast majority of plants that reported emissions from finishing reported the use of fabric filters as an off-gas treatment technique. [169, TWG 2021]

Reference literature

[169, TWG 2021], [179, COM 2016]

3.2.1.13.4 Wet scrubbing**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

Wet scrubbers are typically used to remove water-soluble organic and inorganic compounds as well as dust. Alkaline scrubbers are typically used to remove acid gases, such as hydrogen chloride, hydrogen fluoride and hydrogen sulphide, while acid scrubbers are typically used to remove ammonia.

Wet scrubbers are mostly used as an abatement technique, although they are sometimes also used to recover gaseous organic compounds (e.g. benzene) as well as dust. In most cases, packed-bed scrubbers and spray towers are used. Further information is provided in the CWW BREF [179, COM 2016].

Achieved environmental benefits

- Reduced emissions to air.
- Possible material recovery.

Environmental performance and operational data

Wet scrubbing is used alone or in combination with other waste gas treatment techniques.

Reported data from three plants (6 EPs) using wet scrubbing show a range for dust emissions from 0.2 mg/Nm³ to 35.6 mg/Nm³ with 4 out of 6 EPs with emission levels below 1 mg/Nm³ [169, TWG 2021]

Cross-media effects

Absorption generates a spent scrubbing liquid that usually requires further treatment or disposal. Further information is provided in the CWW BREF [179, COM 2016].

Technical considerations relevant to applicability

Generally applicable. The use of absorption is subject to the availability of a suitable scrubbing liquid. Further information is provided in the CWW BREF [179, COM 2016].

Economics

Absorption is relatively inexpensive in comparison with some other techniques, e.g. thermal oxidation. There is also the potential benefit of material recovery which depends on the

concentration of the compound concerned in the waste gas. Further information is provided in the CWW BREF [179, COM 2016].

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

CZ025, DE035 and DE036. [169, TWG 2021]

Reference literature

[169, TWG 2021], [179, COM 2016]

3.2.1.14 Emissions to air from sand reconditioning and reclamation

3.2.1.14.1 Use of a fuel or a combination of fuels with low NO_x formation potential

More information on the technique

See Section 3.2.1.7.4.

3.2.1.14.2 Use of a fuel or a combination of fuels with low sulphur content

More information on the technique

See Section 3.2.1.7.5.

3.2.1.14.3 Extraction of off-gases generated from reclamation as close as possible to the emission source

Description

Off-gases generated from sand reclamation are extracted using an enclosure or a hood for example. This includes extraction of the flue-gases generated from fluidised bed furnaces, rotary kilns or multiple-hearth furnaces, etc. used in thermal sand regeneration.

Technical description

Further information by applied sand reconditioning and regeneration technique is provided in Section 3.2.1.4.4.

Achieved environmental benefits

- Reduction of emissions to air.
- Possible material recovery.

Environmental performance and operational data

Further information by applied sand reconditioning and regeneration technique is provided in Section 3.2.1.4.4.

Cross-media effects

Extraction of off-gases consumes energy.

Technical considerations relevant to applicability

Generally applicable.

Economics

No information provided.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

Widely used. The vast majority of plants participated in the SF data collection reported this technique. [169, TWG 2021]

Reference literature

[169, TWG 2021]

3.2.1.14.4 Cyclone**More information on the technique**

See Section 3.2.1.13.2.

Environmental performance and operational data

Cyclones can be used alone, but are often used in combination with other waste gas treatment techniques.

Reported data from six plants (8 EPs) using cyclones show a range for dust emissions from 0.04 mg/Nm³ to 19.4 mg/Nm³ with a median value of 1.54 mg/Nm³ and an average value of 2.9 mg/Nm³ [169, TWG 2021].

Example plants

BE023, BE028, DE028, DE039, FR109, PT139 and PT141. [169, TWG 2021]

Reference literature

[169, TWG 2021], [179, COM 2016]

3.2.1.14.5 Fabric filter**More information on the technique**

See Section 3.2.1.12.7.

Environmental performance and operational data

Fabric filters are used alone or in combination with other off-gas treatment techniques.

Reported data from 75 plants (118 EPs) using fabric filters show a range for dust emissions from 0.03 mg/Nm³ to 103.3 mg/Nm³ with a median value of 1.7 mg/Nm³, an average value of 4.6 mg/Nm³, a 90th percentile value of 16.36 mg/Nm³ and a 10th percentile value of 0.29 mg/Nm³ [169, TWG 2021].

Example plants

Widely used. The vast majority of plants reported the use of fabric filter as off-gas treatment technique. [169, TWG 2021]

Reference literature

[169, TWG 2021], [179, COM 2016]

3.2.1.14.6 Wet scrubbing**More information on the technique**

See Section 3.2.1.13.4.

Environmental performance and operational data

Wet scrubbing is used alone or in combination with other waste gas treatment techniques.

Reported data from four plants (8 EPs) using wet scrubbing show a range for dust emissions from 0.61 mg/Nm³ to 27 mg/Nm³ with a median value of 2.9 mg/Nm³ and an average value of 7.18 mg/Nm³ [169, TWG 2021].

Example plants

CZ026, DE043, DE062 and FR114. [169, TWG 2021]

Reference literature

[169, TWG 2021], [179, COM 2016]

3.2.1.14.7 Thermal oxidation

More information on the technique

See Section. 3.2.1.9.21.

Environmental performance and operational data

Reported data from one plant using regenerative thermal oxidation show a TVOC emission level of 12 mg/Nm³. [169, TWG 2021]

See also Section 3.2.1.9.21.

Example plants

AT011. [169, TWG 2021]

Reference literature

[169, TWG 2021], [179, COM 2016]

3.2.1.15 Odour

Odour emissions are mainly associated with processes involving sand binders. The actual odorous products of pyrolysis may vary according to the type of system used, but generally the phenolic breakdown products, i.e. cresols and xylenols, are the most common source of odour complaint, due to their very low odour detection thresholds. The dispersion of odours during casting, cooling and shake-out involves mixing with large volumes of air, which makes collection and treatment difficult. The use of inorganic binders, such as sodium silicate, can substantially reduce emissions. No totally effective proven method of eliminating foundry generated odour is known to be currently available. A general approach is to ensure good ventilation (see Section 3.2.1.15.4) and a rate of air change that ensures that emissions are quickly and efficiently dispersed to the atmosphere. Process-integrated measures include substitution techniques (see Section 3.2.1.9) End-of-pipe techniques are discussed in Section 3.2.1.10.

3.2.1.15.1 Odour management plan

Description

An odour management plan (OMP) is part of the environmental management system (EMS) of the installation (see Section 3.1.1.1) and includes elements to prevent or reduce odorous nuisances.

Technical description

The OMP 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.

In foundries, there are a number of diffuse emission sources that may cause odourous nuisances. Typically, emissions originate from several phases of the process, such as the melting, especially cupola furnaces but also induction furnaces, moulding during the pouring and mould cooling stages, core-making, especially the 'hot box' system and core curing kilns, casting, die casting in aluminium foundries, shake-out, and sand reclamation areas. The odours are caused by the diffuse emissions of organic chemicals which are used as binders in the moulding and core-making process, as surface treatment agents or other additives. Besides, odours may also originate from the breakdown of these chemicals when molten metal is poured into the moulds. There are a very high number of binder formulations, but typical formulations contain phenol, furan, formaldehyde, urethane and sometimes oil. In core-making, some formulations require the use of tertiary amine catalysts. Other additives may include coal, cereals, starches, clay and refractory minerals. Due to the high number of possible diffuse emission sources, it is necessary to establish comprehensive measures in foundries that help to prevent and minimise odour emissions.

The potential impact of malodorous emissions arising from the plant should be evaluated from the nature, size and frequency of operation and the distance of neighbours from the plant. Identified sources of malodorous emissions can be further characterised by quantitative measurements of odour concentration, flow rate, temperature, humidity, chemical analysis and the pH.

Reduction measures, suitable abatement technologies and innovative cleaning technologies to abate large amounts of odour emissions resulting from foundries have been tested. The technologies tested included regenerative catalytic oxidation (RCO), regenerative thermal oxidation (RTO), a concentrator and RTO system, biofiltration and adsorption. The results show that, RTO, RCO, biofiltration and a two-stage adsorption process are all suitable abatement technologies for foundries, with oxidation having the greatest cleaning efficiency. Biofilters proved to be the most cost-effective system when low concentrations of odours are present in emissions. [218, COM 2014]

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

No information provided.

Cross-media effects

No information provided.

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

No information provided.

Driving force for implementation

Legal requirements.
Local conditions.

Example plants

No information provided.

Reference literature

[218, COM 2014]

3.2.1.15.2 Periodic odour monitoring

Description

Odour can be monitored using:

- 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 OU_E/m^3 , 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 CWW BREF.

Achieved environmental benefits

The achieved environmental benefit is the minimisation of odorous emissions.

Environmental performance and operational data

See the ROM and CWW BREF.

Cross-media effects

None.

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 CWW BREF.

Driving force for implementation

The driving forces for implementation include legislation and complaints occurring in the vicinity of the installation/site.

Example plants

Odour emissions were reported by three plants (in total 5 emission points): DE041, DE062 and IT127. [169, TWG 2021]

Reference literature

[169, TWG 2021], [174, COM 2018], [179, COM 2016].

3.2.1.15.3 Substitution of chemicals containing alcohol-based or aromatic solvents**Description**

This includes techniques such as:

- the use of water-based coatings;
- the use of alternative solvents in cold-box core-making.

Technical description

For further information on these techniques, refer to Sections 3.2.1.9.12 and 3.2.1.9.8.

Technical considerations relevant to applicability

Applicability of water-based coatings may be restricted due to the type of raw material or product specifications (e.g. big moulds/cores, water glass-bonded sands, Mg castings, production of manganese steel with MgO coating).

3.2.1.15.4 Good ventilation of areas where binders are used**Description**

Where process air extraction and treatment is not applied, good ventilation and a rate of air change that ensures that odour emissions are quickly and efficiently dispersed to the atmosphere.

Technical description

No totally effective proven method of eliminating foundry generated odour is known to be currently available. However, a general approach is to ensure good ventilation and a rate of air change that ensures that emissions are quickly and efficiently dispersed to the atmosphere.

Achieved environmental benefits

The achieved environmental benefit is the minimisation of odorous emissions.

Environmental performance and operational data

No information provided.

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable.

Economics

No information reported.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

Widely used.

Reference literature

No reference literature provided.

3.2.1.15.5 Collection and treatment of amine emissions from the cold-box core-making process

Description

Off-gases containing amines, generated from the gassing of cold-box cores, are extracted and treated using, for example, wet scrubbing, a biofilter, thermal or catalytic oxidation.

Technical description

The gassing of cold-box cores produces off-gases that need cleaning before emission into the atmosphere. In order to safeguard the working atmosphere, the core shooting machines are enclosed and cores are flushed with air to remove all the gas residues before the machine is opened up to take out the freshly made core.

Exhaust capture systems may be installed to secure good working conditions during the checking, handling and storage of the freshly made cores. For this, hoods or extraction systems are installed, for example at the checking table, above the handling area and above the temporary storage area (the waiting area for the tray of ready cores).

The exhausted amine vapour requires treatment to prevent an odour nuisance. One of the following methods may be used:

- *Adsorption on activated carbon:* This process is very efficient, but the operational costs are excessive, so it may only be feasible if the exhausted volume is small
- *Combustion:* For this process to be efficient, the afterburner chamber must be correctly designed, to ensure a temperature of at least 800 °C, with a minimum dwell time of 2 seconds. Energy consumption is high and the process is therefore expensive to operate. In foundries operating a cupola furnace, the exhaust gas may be fed to the cupola for combustion.
- *Chemical scrubbing:* Amines are strong bases, and react with sulphuric or phosphoric acid. The pH of the solution is normally controlled to below 3. As a consequence, the scrubbing solution is replaced from time to time to remove concentrated salts, which subsequently require disposal as a hazardous waste. It is technically possible to process the scrubbing solution to reclaim the amine for re-use. This is discussed in Section 3.2.1.4.3.6.
- *Biofilter:* See Section 3.2.1.10.7.

Furthermore, innovative cleaning technologies and suitable abatement technologies to abate large amounts of odour emissions resulting from foundries have been tested. The technologies tested included regenerative catalytic oxidation (RCO), regenerative thermal oxidation (RTO), a concentrator and RTO system, biofiltration, ignition and adsorption. The results show that, RTO, RCO, biofiltration and a two-stage adsorption process are all suitable abatement technologies for foundries, with oxidation having the greatest cleaning efficiency. [218, COM 2014]

In winter, it may be necessary to heat the exhaust air in order to prevent amine condensation inside the ductwork. This may be done using waste heat from compressors or from other nearby devices.

Achieved environmental benefits

Exhaust capture allowing a reduction in amine emissions and related odour emissions.

Environmental performance and operational data

Whatever the treatment method applied, amine emissions can be kept lower than 5 mg/Nm³.

Emission data for a cold-box core-making shop using an acid scrubber are given in Table 3.45. The scrubber uses a 75 % phosphoric acid solution. In normal operation, 15 kg amine is disposed per day through the scrubber solution. The solution is saturated and stored in a tank for external treatment or disposal. The installation operates at 35.5 kW power and for 2 000 h/yr.

Table 3.45: Emission data for a cold-box core-making shop, using an acid scrubber

Compound	Emission level mg/m ³
Dust	0.42
Amine	2.4
Phenol	0.53
Oxygen	21 %
Exhaust gas volume	25100 m ³ /h
<i>Source: [13, Batz, R. 1986]</i>	

Cross-media effects

When using acid scrubbers, the amine is transferred to the scrubbing solution, which then needs further treatment. However, recovery of the amine from the solution is possible. This is discussed in Section 3.2.1.4.3.6.

Technical considerations relevant to applicability

The technique applies for all existing and new cold-box core-making shops.

Economics

Operational costs for the installation mentioned in the ‘operational data’ section are EUR 6.3/tonne good casting.

The investment cost for an example installation, using a wet scrubber is given in Table 3.46.

Table 3.46: Specification and investment cost for an amine scrubber on cold-box core-shop exhaust data for Portugal, 2003

Property	Value
Exhaust airflow	30 000 m ³ /h
Crude gas amine concentration	150 mg amine/Nm ³
Cleaned gas amine concentration	<1 mg amine/Nm ³
Power supply	45 kW
Investment cost	EUR 187000

As mentioned above (see Technical description), biofilters are considered a cost-effective odour abatement system when low concentrations of odour are present in emissions [218, COM 2014]

Driving force for implementation

- To ensure workers health and to prevent odour emissions.
- Legal requirements.
- Local conditions.

Example plants

The technique is generally applied for foundries using cold-box binders.

Reference literature

[13, Batz, R. 1986], [14, CAEF 1997], [5, Gwiasda, F. 1984], [169, TWG 2021], [218, COM 2014]

3.2.1.15.6 Collection and treatment of VOC emissions from chemically bonded sand preparation, pouring, cooling and shake out

Description

Off-gases containing VOCs, generated from the preparation of chemically bonded sand, pouring, cooling and shake-out are extracted and treated using, for example, wet scrubbing, a biofilter, thermal or catalytic oxidation.

Technical description

VOC emissions (mainly solvents, BTEX, and to a lesser extent phenol, formaldehyde, etc.) result from chemically bonded sand preparation and also, further along the process, from pouring, cooling and shake-out. These compounds are noxious and generate odour emissions.

The abatement of VOCs is hindered by the fact that large volumes of ambient air are entrained by the collection systems (e.g. canopy hoods) used.

The following techniques are applicable for the removal of VOCs:

- adsorption to activated carbon;
- post-combustion;
- biofilter.

For adsorption to activated carbon, the exhaust gas flows through a carbon bed. Upon saturation, the carbon is thermally regenerated. Activated carbon has a very high adsorption (and abatement) efficiency. For benzene, the efficiency is > 99 %. Nevertheless, it has the following disadvantages:

- the high flue-gas volumes require large amounts of activated carbon
- dust and aerosols need to be filtered out of the off-gas before the carbon adsorption. Since very fine dust particles show a tendency to stick, the filtering is only possible using wet dedusting techniques and this thus generates a waste water flow.

To successfully exploit post combustion to eliminate VOCs from off-gases, specific minimum concentrations are necessary. These limit values are compound-specific and depend on the chosen technique. Post-combustion is possible for the exhaust gas from shell moulding. Generally, the exhaust gas from the casting shop does not have high enough VOC levels to operate post combustion. One alternative to post-combustion is to use exhaust air from the core blowers as combustion air for the cupola.

The use of biofilters is discussed in detail in Section 3.2.1.10.7.

Achieved environmental benefits

Reduction of VOC emissions to air.

Environmental performance and operational data

See Technical description above.

Technical considerations relevant to applicability

Generally applicable.

Economics

Biofilters are considered a cost-effective system when low concentrations of odours are present in emissions. [218, COM 2014]

Cross-media effects

Energy is consumed in the collection of the off-gas flow, which may also involve entraining large volumes of ambient air.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

The technique is widely applied.

Reference literature

[9, Gapp, H. 1989], [38, Vito 2001] [169, TWG 2021], [218, COM 2014]

3.2.1.16 Water consumption and waste water generation**3.2.1.16.1 Water management plan and audits****Description**

A water management plan and audits are part of the EMS (see Section 3.1.1.1) and include:

- flow diagrams and water mass balances of the plant as part of the inventory of inputs and outputs mentioned in Section 3.1.1.2;
- establishment of water efficiency objectives;
- implementation of water optimisation techniques (e.g. control of water usage, reuse/recycling, detection and repair of leaks).

Audits 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

Some water optimisation techniques to consider are as follows:

a) Controlling water consumption

A prerequisite of any programme to prevent unnecessary use of water is to firstly collect information on the installation and the volumes consumed in the various processes, as part of the collection of information on types, quantities, composition and sources of all waste water streams.

As with water consumption, data at site level are already a good benchmark in determining whether water consumption is excessive and is a good baseline against which to measure improvements. In order to allow a process-specific analysis, water use is monitored and recorded at machine/process level and water meters are regularly maintained and calibrated.

b) Reducing water consumption**By improved working practices**

Production procedures are established and the personnel is trained, in order to avoid inappropriate working practices, especially when there are not automated control systems, that can lead to significant wastage of water.

By technical modifications

See for example techniques in Sections 3.2.1.16.5 and 3.2.1.16.6.

By optimising water supply and treatment system

See for example the technique in Section 3.2.1.16.2.

By reuse and/or recycling of water

See for example the technique in Section 3.2.1.16.3.

Achieved environmental benefits

Reduction in water consumed and waste water discharged.

Environmental performance and operational data

No information provided.

Cross-media effects

None.

Technical considerations relevant to applicability

The level of detail of the water management plan and water audits will generally be related to the nature, scale and complexity of the plant.

Economics

- Staff time.
- Cost of any additional metering required.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

This technique is usually applied by the majority of IED plants.

Reference literature

No reference literature provided.

3.2.1.16.2 Segregation of water streams

Description

Water streams (e.g. surface run-off water, process 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 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 [179, COM 2016].

Achieved environmental benefits

Reduction in water consumption and waste water discharge.

Environmental performance and operational data

Separate discharge is recommended to avoid a dilution effect of the treated waste water. The more concentrated the effluents that result from separation, the more generally effective their downstream treatment.

Cross-media effects

None.

Technical considerations relevant to applicability

Applicability to existing plants may be restricted by the layout of the water collection system.

Economics

Retrofitting costs associated with the separation/segregation of waste waters can be significant at existing plants. Waste water separation/segregation systems can be installed efficiently at new plants. Savings may be made from the reduction in the water-holding capacity needed on the site.

Driving force for implementation

- Cost savings for water-holding capacity and waste water discharge.
- Legal requirements.

Example plants

This technique is usually applied by the majority of IED plants. It was reported by 26 plants in the SF data collection. [169, TWG 2021]

Reference literature

[169, TWG 2021], [179, COM 2016]

3.2.1.16.3 Water reuse and/or recycling**Description**

Water streams (e.g. process water, effluents from wet scrubbing or cooling water) are reused and/or recycled in closed or semi-closed circuits, if necessary after treatment (see Section 3.2.1.17).

Technical description

In order to reduce costs, plants will strive to reuse and/or recycle water as much as possible. Hence, water streams (e.g. process water, effluents from wet scrubbing or cooling water) are reused and/or recycled in closed or semi-closed circuits. If necessary (based on the content of impurities), collected water is treated before recycling/reuse – see Section 3.2.1.17 where the waste water treatment techniques are discussed.

Waste water from acid scrubbers may be externally treated and thus not discharged. In those cases, the waste water from the acid scrubbers is collected (e.g. in containers) and transported to an external (off-site) waste treatment plant (BE-49 comment at [210, TWG 2022]).

Achieved environmental benefits

- Reduction of water consumption.
- Reduction of the volume of waste water generated.

Environmental performance and operational data

No information provided.

Cross-media effects

None.

Technical considerations relevant to applicability

The degree of water reuse and/or recycling is limited by the water balance of the plant, the content of impurities and/or the characteristics of the water streams.

Economics

- Investment and operation cost for the water recycling/reuse system.
- Savings due to the reduced water consumption and the reduced volume of discharged waste water.

Driving force for implementation

- Legal requirements.

Example plants

This technique is usually applied by the majority of foundries. In particular:

- 49 plants reported the internal recycling of process water
- 14 plants reported the multiple use of treated waste water.

[169, TWG 2021]

Reference literature

[169, TWG 2021], [179, COM 2016], [210, TWG 2022]

3.2.1.16.4 Prevention of waste water generation from process and storage areas

Description

See Section 3.1.1.4.2 related to ‘Structuring and management of process areas and raw material storage areas’.

3.2.1.16.5 Use of dry dedusting systems

Description

This includes techniques such as fabric filters and dry ESPs.

More information on the techniques:

See Section 3.2.1.12.7 (fabric filter) and Section 3.2.1.12.8 (ESP).

Achieved environmental benefits

No waste water generation from the off-gas treatment.

Example plants

Widely used. The use of dry dedusting systems was reported by 40 foundries in the SF data collection.

Reference literature

[169, TWG 2021].

3.2.1.16.6 Separate spraying of release agent and water in high-pressure die-casting

See Section 3.2.1.4.3.1.

3.2.1.16.7 Use of waste heat for the evaporation of waste water

Description

When waste heat is available on a continuous basis, it can be used to evaporate waste water.

Technical description

Use of excess (waste) heat to evaporate waste water; the evaporated waste water (water vapour) is then released to the environment. This is achieved by directing a portion of the flue-gases into the evaporator (usually a drying vessel). In the evaporator, the heat in the flue-gases is transferred to the waste water and evaporate it.

Achieved environmental benefits

Reduction of generation of waste water.

Environmental performance and operational data

No information provided.

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable.

Economics

- Investment and operation costs for the needed equipment (evaporator).
- Savings in terms of efficient use of waste energy and reduction of waste water volume.

Driving force for implementation

- Savings (see Economics above).
- Legal requirements.

Example plants

DE049 and DE051 [169, TWG 2021].

Reference literature

[169, TWG 2021].

3.2.1.17 Emissions to water

The identified waste water treatment techniques are mentioned in this section. Detailed data on the associated emissions to water are presented in Section 2.3 (Current consumption and emission levels).

3.2.1.17.1 Equalisation

Further information is provided in the CWW BREF [179, COM 2016].

Example plants

FI101, IT157 and IT158. [169, TWG 2021]

3.2.1.17.2 Neutralisation

Further information is provided in the CWW BREF [179, COM 2016].

Example plants

AT001, AT013, DE035, DE036, DE037, DE038, DE050, DE062, EL080, FR116 and SE150. [169, TWG 2021]

3.2.1.17.3 Physical separation, e.g. using screens, sieves, grit separators, grease separators, hydrocyclones, oil-water separators or primary settlement tanks

Further information is provided in the CWW BREF [179, COM 2016].

Example plants

AT001, AT008, AT010, AT015, BE021, DE035, DE036, DE037, DE038, DE050, DE051, ES087, ES098, FR102, FR105, FR113, FR114, FR115, FR116, IT127, IT128, IT131, IT132, IT134, IT155, IT158, SE152 and SE153. [\[169, TWG 2021\]](#)

3.2.1.17.4 Adsorption

Further information is provided in the CWW BREF [\[179, COM 2016\]](#).

3.2.1.17.5 Chemical precipitation

Further information is provided in the CWW BREF [\[179, COM 2016\]](#).

Example plants

DE033, DE036, DE037, DE038, DE051, DE062, EL080, ES087, FII01, FR114 and FR115. [\[169, TWG 2021\]](#)

3.2.1.17.6 Evaporation

Further information is provided in the CWW BREF [\[179, COM 2016\]](#).

Example plants

AT007, CZ025, DE033, IT123, IT154 and SE148. [\[169, TWG 2021\]](#)

3.2.1.17.7 Activated sludge process

Further information is provided in the CWW BREF [\[179, COM 2016\]](#).

Example plants

AT003. [\[169, TWG 2021\]](#)

3.2.1.17.8 Membrane bioreactor

Further information is provided in the CWW BREF [\[179, COM 2016\]](#).

Example plants

FR116. [\[169, TWG 2021\]](#)

3.2.1.17.9 Coagulation and flocculation

Further information is provided in the CWW BREF [\[179, COM 2016\]](#).

Example plants

AT001, AT013, AT015, DE035, DE036, DE037, DE038, DE050, DE051, DE062, EL080, ES087, FR114, FR115, FR116, FR119, IT129 and SE144. [\[169, TWG 2021\]](#)

3.2.1.17.10 Sedimentation

Further information is provided in the CWW BREF [\[179, COM 2016\]](#).

Example plants

AT001, AT005, AT015, BE020, BE022, DE035, DE036, DE037, DE038, DE046, DE050, DE051, DE060, DE062, DE065, EL080, FI102, FR118, FR119, IT071, IT125, IT154, IT155 and PT140. [169, TWG 2021]

3.2.1.17.11 Filtration, e.g. sand filtration, microfiltration, ultrafiltration, reverse osmosis

Further information is provided in the CWW BREF [179, COM 2016].

Example plants

AT001, DE033, DE035, DE036, DE037, DE038, DE051, DE060, EL080, FR114, FR115, FR116, IT154, PT143 and SE148. [169, TWG 2021]

3.2.1.17.12 Flotation

Further information is provided in the CWW BREF [179, COM 2016].

Example plants

FR116. [169, TWG 2021]

3.2.2 Techniques to consider in the determination of BAT for iron foundries**3.2.2.1 Energy efficiency****3.2.2.1.1 Increase of shaft height in CBC furnaces****Description**

Increasing the shaft height in cold blast cupola furnaces enables combustion gases to remain in contact with the charge for longer, resulting in a higher heat transfer.

Technical description

The required shaft height for cupolas at various melting rates is given in Table 3.47. These shaft heights optimise the preheat for the descending burden. However, if the gas is to be burned at the charge-hole, a shorter shaft height may be considered. In general, the shorter the shaft, the hotter the top gas and the greater the ease of combustion – either spontaneous or assisted by an afterburner.

Technical considerations relevant to applicability

Only applicable to new plants and major plant upgrades.

Applicability to existing plants may be restricted by building and other structural constraints.

Table 3.47: Shaft height requirements

Melting rate of Cupola (tonne/h)	Height from tuyères to charging door sill (m)
Up to 5	4.9
5 – 8	5.8
>8	6.7

The thermal efficiency of the cold blast cupola furnace can be improved by increasing the shaft height. In general, the higher the furnace shaft, the longer the combustion gases remain in contact with the charge, and the more heat is transferred to the charge.

Depending on the installation type, optimised shaft heights in CBC furnaces allow burn-out of the gases and efficient heating of the charge.

Achieved environmental benefits

Increased energy efficiency.

Environmental performance and operational data

Operational data are given in Table 3.48. The modification involves a doubling of the upper zone volume. This results in a reduction of coke consumption from 140 kg/tonne to 115 kg/tonne, which is a relative reduction of 18 %. It should be noted that in general an optimal shaft height follows the rule-of-thumb: 'height = 5 x diameter at tuyères'. The initial situation in the example furnace was therefore sub-optimal.

Table 3.48: Example data for the change in coke consumption upon shaft height increases

	Cupola before modification	Cupola after modification
Diameter		
- melting zone (m)	1.4	1.4
- upper zone (m)	1.4	1.7
Height over tuyères (m)	5	6.5
Coke ratio (kg/tonne)	140	115
<i>Source: [100, TWG 2002]</i>		

Cross-media effects

None.

Technical considerations relevant to applicability

Optimisation of the furnace height needs to be performed at the design stage of the furnace, otherwise height increases will usually only be performed during major re-building works of the furnace.

Driving force for implementation

To increase the efficiency of the furnace operation.

Example plants

Operational data are taken from an example plant in France.

Reference literature

[14, CAEF 1997], [20, ETSU 1993], [100, TWG 2002], [169, TWG 2021]

3.2.2.1.2 Oxygen enrichment of the combustion air**Description**

Oxygen enrichment of the combustion air is realised either directly at the blast supply or through injection of oxygen into the coke bed, or via the tuyères.

Technical description

The thermal efficiency of the cold blast cupola furnace can be improved by oxygen enrichment of the combustion air. This gives rise to a higher combustion temperature of the coke. In this way coke consumption can be decreased or higher temperatures of the tapped metal can be obtained.

Compared with normal operation, the continuous use of oxygen enables one of the following improvements to be made:

- a higher metal temperature, higher carbon pick-up and lower melting loss of silicon for the same coke consumption, or
- a lower coke consumption for a given metal temperature, with no increase in carbon pick-up or reduction in the melting loss of silicon, or
- an increased output from an existing cupola, as a result of the increased melting rate.

Oxygen injection provides the possibility of reacting quickly to process drifts, and then compensating for small changes in process conditions. Thus, oxygen injection is often used intermittently, usually whenever the process requires adjustment.

The effectiveness of the oxygen depends on the method by which it is introduced into the cupola. Three processes have been developed:

- *Direct enrichment of the blast supply:* Oxygen is fed into the main blast, this technique is applied in the majority of the cold blast cupolas.
- *Injection into the well:* Oxygen is injected into the coke bed from a ring-main which supplies water-cooled injectors, whose number depends on the cupola size. Oxygen used in this way is at least twice as effective as when it is used to enrich the blast supply directly. However, this type of injection is confined to continuously-tapped cupolas, since with intermittent tapping there is a risk that slag and or metal may rise to the level of the injectors. The technique was developed in the UK but it has not found widespread application.
- *Injection at the tuyères:* Oxygen is introduced into the cupola through injectors inserted into each tuyère or into alternate tuyères. The effectiveness of this method lies between direct blast injection and well injection methods. This technique is used in 20 – 30 % of cases, but more in hot blast operation.

The principles of oxygen injection are depicted in Figure 3.58.

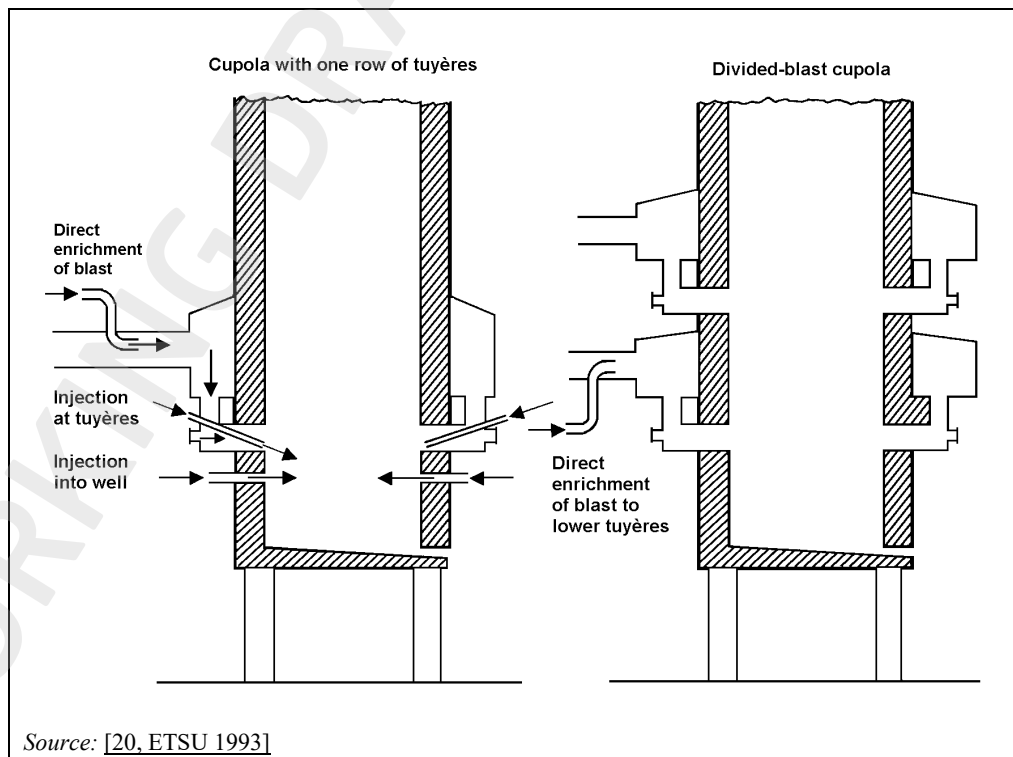


Figure 3.58: Various methods of oxygen injection

Achieved environmental benefits

The application of oxygen results in a reduced coke consumption and a better process control. Additionally, a reduction in the emission of dioxins and furans from cold blast cupolas have been reported.

Environmental performance and operational data

Compared to conventional cold blast operation with one row of tuyères, the increase in tapping temperature obtained for a given charge of coke, can be expected to be as follows:

- blast enrichment + 15 °C;
- well injection + 85 °C;
- tuyère injection + 40 °C.

Divided blast operation with a direct enrichment of blast air, results in an increase in the tapping temperature of 85 °C compared to cold blast operation. In divided blast operation, neither well injection nor tuyère injection give any greater benefit than the simple method of direct injection.

An important application of oxygen has been to increase the melting rate of an existing cupola, well beyond its usual optimum melting capacity. In divided blast cupolas, the melting rate increases by around 6.8 % and the tapping temperature by about 20 °C for each 1 % of direct oxygen enrichment in the blast air. If an increase in temperature is not required and the coke charge is reduced, an even greater increase in the melting rate can be obtained for the same blast rate and oxygen enrichment.

Cross-media effects

The technique requires oxygen which is produced off site and involves a consumption of electric energy.

Technical considerations relevant to applicability

Today, almost all European hot blast cupolas inject oxygen through the tuyères. For cold blast furnaces, the use of oxygen enrichment can be considered as the standard technique. In this case, enrichment of the blast supply is usually applied, if applicable. The oxygen level of the oxidising air mixture is usually between 22 % and 25 % (i.e. an enrichment of 1 % to 4 %).

Economics

The effect that using oxygen has on melting costs greatly depends on the price of oxygen, which in turn is related to the amount used. Foundries with larger outputs can generally buy oxygen more cheaply. The economic case for using oxygen has to be established on a case-by-case basis.

The substantial increase in outputs obtainable has enabled foundries to increase outputs without high capital investments in new plant, and to reduce costs and overtime payments, so much so that the overall reduction in costs amply justify the cost of oxygen. Such improvements must take into account the related core and mould making capacity.

Driving force for implementation

- To optimise the efficiency and control of the melting process.
- Legal requirements.

Example plants

This technique is commonly applied in European foundries using cupola furnaces.

Reference literature

[14, CAEF 1997], [59, Godinot 2001]

3.2.2.1.3 Superheating of HBC blast air

Description

Increase of the flame temperature by superheating the blast air to 800-900 °C either by injection of air plasma or by using resistance heaters.

Technical description

An alternative technique for increasing the flame temperature is to superheat the blast air to 800 – 900 °C. For this, injection of an air plasma, or heating in tubular resistance heaters is applied. Experience has shown that increasing the blast temperature by 200 °C, from 550 °C to 750 °C, which takes 60 kWh per tonne of iron, saves 10 kg of coke per tonne melted. The main benefit, more important even than saving coke, is the flexibility: the hourly output can be increased by 30 % without modifying the melting bed. Additionally, the application of (plasma) superheating allows a change in raw material from clean cast iron to steel, with a subsequent positive economic effect.

Achieved environmental benefits

Reduced coke consumption and increased efficiency of the process.

Environmental performance and operational data

The heating of the blast air produces a lower flue-gas volume as compared to hot blast long campaign operation. As compared to oxygen injection, the flue-gas volume and electricity consumption is larger.

Cross-media effects

Electrical heating causes an increase in electricity consumption (58 kWh/tonne).

Technical considerations relevant to applicability

The technique applies to new and existing HBC furnaces.

The technique (both with electrical and plasma heating) achieves a similar effect as injection of oxygen through the lances, but can be applied in a more complex installation and produces a larger flue-gas volume. Additionally, oxygen injection allows make-up for leaks in the air circuit.

Economics

No information provided.

Driving force for implementation

- To optimise the efficiency and to control the melting process.
- Legal requirements.

Example plants

PSA, Sept-Fons, France

Three foundries in France apply tubular resistance heating.

Reference literature

[59, Godinot 2001]

3.2.2.1.4 Minimal blast shut-off periods for HBC furnaces

Description

Minimisation of blast shut-off periods by programming the schedules of the moulding and casting processes to ensure a reasonably constant demand for metal.

Technical description

A cupola blown just intermittently will not operate efficiently, and will result in a reduced metal tapping temperature, as shown in the following figure.

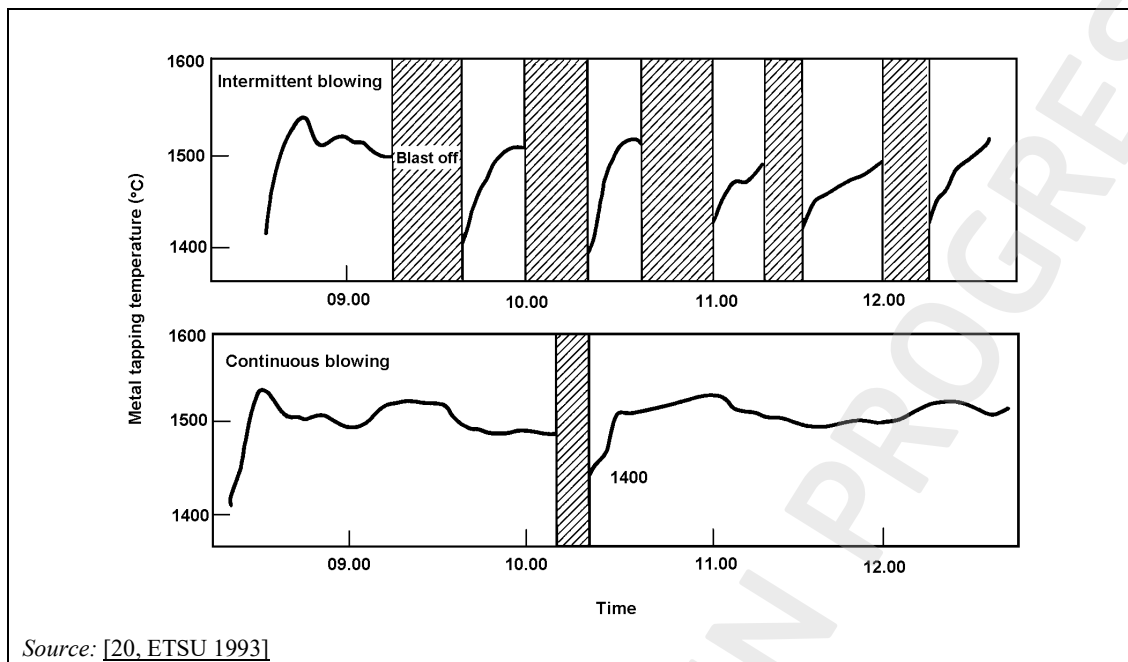


Figure 3.59: Effect of blast shut-off periods on tapping temperature in a post-blast cupola

Frequently shutting-off the blast due to only intermittent demands for metal:

- reduces the average tapping and pouring temperatures and increases the extent of their variations, with a consequent risk of producing defective castings;
- increases the variation in metal composition, particularly the carbon and silicon content, with a danger of then producing ‘off-grade’ metal;
- increases the coke consumption, through the operators’ attempt to adjust the tapping temperature;
- affects the degree of nucleation in the iron and increases its shrinkage tendencies.

Moulding and casting schedules are therefore programmed to produce a reasonably constant demand for metal, thereby minimising or even eliminating the need for blast shut-off periods or for large variations in the blast rate.

Where large fluctuations in demand are unavoidable, the installation of an electric holding furnace might be considered. This can provide a large buffer reservoir for metal, to take up variations in demand, so that the cupola can be operated continuously at a reasonably consistent blast rate. It can also be used to help even out variations in temperatures and composition.

Achieved environmental benefits

- Reduction of coke consumption.
- Higher process energy efficiency.

Environmental performance and operational data

No information provided.

Cross-media effects

Operating the electric holding furnace incurs a higher energy consumption.

Technical considerations relevant to applicability

This technique is applicable to all new and existing cupola furnaces.

Economics

The economics of installing a holding furnace must be very carefully considered, particularly in foundries with relatively low production rates.

Driving force for implementation

- To increase the efficiency of the foundry process.

Example plants

The applicable blasting regime is part of the operational considerations in all European foundries using cupola furnaces.

Reference literature

[20, ETSU 1993]

3.2.2.1.5 Long-campaign cupola**Description**

The cupola furnace is set up for long campaign operation to minimise maintenance and process changes. This may be achieved by using more resistant furnace refractory linings in the shaft, bottom and hearth, by using water cooling of the furnace wall and with water-cooled blasting pipes penetrating deeper in the furnace shaft.

Technical description

This is a long-term cold blast cupola which also has oxygen injection. The adjustment of the amount of blasted air to the current operating conditions is done with the aid of an air flow volume measurement, an air flow control system and a frequency control for the air fan. Unlike the pre-existing furnace, the molten iron is not continuously stored in the interior of the long-campaign cupola. For this purpose, a non-heated forehearth has been installed, which absorbs the leaking melt.

In normal operation, molten iron is continuously leaking. Here it is collected over iron gutters in the unheated tray forehearth with a crane ladle and then transported to the already existing, electrically heated furnace or heat-retaining furnace, or, if necessary, transported directly to the mould system for casting. The slag is separated in the siphon and then flows into a slag bucket below the furnace platform, which cools it before it is directed to the next step in solid form for recycling/disposal.

The main difference between the two former shaft furnaces, whose feed had to be replenished every day, is that the long-time cupola furnace has a water-cooling system for the blast furnace that the blast nozzles extend into. The water-cooling system prevents the nozzle from melting quickly due to the high temperature in the furnace, which was linked in this area to a strong erosion of the furnace lining. This will prolong the life of the furnace lining considerably, so that the furnace can be operated over a period of several weeks before the furnace has to be relined.

The dust extraction system consists of the radiator, two cyclones, the dry cleaning system and dust filter with radial fan, exhaust silencer and steel chimney. In the combustion process in a cupola furnace, stack gas is produced in all phases of operation (start-up, normal operation, low-melting). The gas is fully captured in the furnace head and fed to the cupola dust extraction.

The deposited dust in the filter bags is cleaned by backwashing, then collected in the dust collection hopper and fed to a dust container and disposed of therein. The cleaned air is discharged with a residual dust content of $< 10 \text{ mg/m}^3$ in the atmosphere.

As an additional measure for improvement, the warehouse and the charge make-up of the starting materials are housed in a separate hall. This reduces the noise emissions and fugitive dust

emissions greatly and, in addition, loss of starting material quality due to weather conditions can be avoided.

Achieved environmental benefits

- Long-term cold blast cupola:
 - Protecting the environment by reducing the consumption of materials (furnace lining) and the amount of waste (furnace waste). Before changing furnace, the lining life time was 1 day; afterwards (long-term cupola) it was more than 2 months. The demand in terms of fire resistant lining before changing was 25 – 30 kg/t liquid iron and afterwards 1.6 kg/t liquid iron (data for an example plant (Hermann Reckers GmbH & Co)).
 - Reduced dust emissions and waste volumes due to the less frequent start-up and shutdown, and the renewal of the furnace lining (before: 1 day; afterwards: more than 2 months).
 - Reduction of odour emissions by 60 % (before: 167 MGE/h; 4 400 GE/m³; afterwards: 65 MGE/h; 1 700 GE/m³).
- Feedstock storage in a warehouse:
 - Reduction of fugitive emissions during storage and charge makeup of the starting materials.
 - Reduced moisture in feedstock and coke.
- Reduction of noise at the delivery and in charging/make-up of substances.

Environmental performance and operational data

Long campaign furnaces are operated in a continuous production.

If a cold blast cupola furnace is operated discontinuously (e.g. melting 3 days a week in one shift), the lining would break down very quickly as a result of the cooling and heating steps. Typically, a long-term cold blast cupola should be operated in at least two shifts, because during non-operating time (night shift) it is not completely shut down. This phase takes too long (i.e. in one-shift operation) and, in this case the long-term cold blast cupola would be uneconomical.

The following operational data were reported for an example plant (Hermann Reckers GmbH & Co).

Table 3.49: Operational data for a long-campaign cold blast cupola

Operating times cupola furnace	Monday to Friday in 2-shift operation from 5:00 to 22:00
Melting capacity (liquid iron)	Before: Up to 8 t/h After: Up to 12 t/h
Furnace lining lifetime	Before: 1 day After: more than 2 months
Fire resistant demand	Before: 25 – 30 kg/t Liquid After: 1.6 kg/t Liquid iron
Odour emissions	Before: 167 MGE/h; 4 400 GE/m ³ After: 65 MGE/h; 1 700 GE/m ³
Exhaust gas volume cupola furnace, coke, oxygen demand, the amount of dust (waste disposal)	No changes
NB: MGE/h: mega odour units per hour, unit for defining the odour emission rate. GE/m ³ : Dutch odour unit - 1 GE/m ³ corresponds to 20 ppbv of n-butanol according to the Dutch NVN2820:1990 standard. Source: [133, DE UBA 2014]	

Cross-media effects

No significant cross media effects (slightly increased power consumption from cooling equipment might occur).

Technical considerations relevant to applicability

Generally applicable.

Economics

The following economic data were reported for the example plant:

- investment for storage hall: approximately EUR 900 000;
- investment for long-term cupola: approximately EUR 1 200 000.

Table 3.50: Economic aspects for a long-term cold blast cupola

Operating costs:	Old cupola	New cupola
lining material	3.61 €/t Fe	2.10 €/t Fe
disposal costs	1.23 €/t Fe	0.04 €/t Fe
labour costs	5.76 €/t Fe	4.38 €/t Fe
Sum:	10.60 €/t Fe	6.52 €/t Fe
<i>Source: [133, DE UBA 2014]</i>		

Reconstruction requires a significant investment (reconstruction of the cupola furnace and warehouse).

Driving force for implementation

- Environmental benefits.
- Increased competitiveness by reducing costs related to refractory and furnace waste disposal.
- Possibility to extend the operating hours of the melting operation to three shifts.
- Improvement in workload and job security by significantly reducing physically stressful work in the hot and narrow furnace shaft.

Example plants

Hermann Reckers GmbH & Co. KG Eisengießerei, Rheine – Mesum, DE.

Reference literature

[133, DE UBA 2014]

3.2.2.1.6 Gas-fired coke-cupola**Description**

Partial replacement of coke with natural gas in a cupola furnace.

Technical description

The principle of the coke-gas cupola is to replace part of the coke with gas. There are two techniques for burning natural gas in the cupola:

- using air-gas burners, located above the tuyères;
- using oxygas burners, located in the tuyères.

At present, the coke/air-gas cupola furnace finds limited implementation in Europe. This may be attributed to the difficulty in controlling the process and the increased complication of the furnace shell.

The oxygas burner was introduced in 1994. Besides oxygas firing, it allows the introduction of dust into the tuyères for recirculation, although in practice this option is not applied. The oxygas burners are placed in 1/3 – 1/2 of the tuyères. About 10 % of the coke energy is replaced by natural gas, leading to a gas consumption of 8 Nm³/tonne to 16 Nm³/tonne. This is associated with a total

oxygen consumption (burners + lances) of 40 Nm³/tonne to 60 Nm³/tonne. The application of this technique allows a greater flexibility in the production and/or metallurgy.

The effect and use of the oxygas burner depends on the cupola concerned. In cold blast cupola furnaces, the technique is used to ensure easy restarts or to reduce the proportion of coke. In hot blast operation, the technique is used to increase the furnace capacity without modifying the melting bed. The replacement of part of the coke with CH₄ results in a reduction in flue-gas volume. This is used as a means of increasing the furnace capacity, without over-saturating the installed flue-gas cleaning system.

The technique results in an increase in the carbon content of the melt and allows an increase in the amount of steel in the charge. The process provides a means of injecting FeSi, which is less expensive in powder form than as ore. These properties result in a beneficial economic effect.

Achieved environmental benefits

The replacement of part of the coke with CH₄ results in a reduction in the flue-gas volume. In addition, the flue-gas is made more combustible due to the higher CO and H₂ contents. If post combustion is present, the resulting flue-gases will show lower levels of organic compounds and CO.

The partial replacement of coke by natural gas reduces the emission levels of SO₂.

The technique allows the possibility of recirculating cupola dust into the melt.

Reducing the level of coke in the cupola increases the risk of bridging.

Environmental performance and operational data

The AGA-Rayburn Foundry (Coalbrookdale, UK) equipped 3 out of 8 tuyères of their cold blast cupola with oxygas burners. This allowed a reduction in the overall proportion of coke from 15 % to 10 %. There was a resultant drop in the sulphur content of the produced iron, this then allowing a reduction to be made in the amount of pig iron used, and thus yielding an economic gain.

Fritzwinter foundry (DE) equipped three out of six tuyères of their 20-25 tonne/h hot blast cupola with oxygas burners. This allowed an increase in production capacity to 28 tonnes/h, without the need to change the melting bed, nor the flue-gas cleaning system. The effect on the flue-gas composition before burning is given in the following table.

Table 3.51: Effect of oxygas burners on the flue-gas composition for a hot blast cupola values in %

	With oxygen without oxygas burners	With oxygen with oxygas burners
H ₂	0.8 – 1.2	2.2 – 2.4
CO	14 – 15	19
O ₂	2	2
<i>Source: [83, Godinot, P. et al. 2002]</i>		

Cross-media effects

In the case that oxyfuel burners are used, cross-media effects associated with the production, storage and use of oxygen are discussed in Section 3.2.1.3.7.

Technical considerations relevant to applicability

The technique may be applied on both cold blast and hot blast cupolas in both new and existing installations. The advantages drawn from the application (increased flexibility, economical benefit, reduced flue-gas volume, increased capacity) will depend on the specific melting conditions of the installation under consideration. The technique has been reported to cause

difficulties for controlling the process and also increases the complication of the furnace shell required.

Economics

Operational costs before and after switching a cold blast cupola to oxygas operation for the above-mentioned Aga-Rayburn foundry (UK) are given in the following table. Prices are forecasts as calculated by CTIF (FR).

Table 3.52: Operational costs for cold blast cupola with and without oxygas burners

Input	Units	Unit price	Without burners		With burners	
		EUR	Consumption per tonne	Cost EUR/tonne	Consumption per tonne	Cost EUR/tonne
Coke	Tonne	198	0.15	29.7	0.1	19.8
Gas	Nm ³	0.15	0	-	16.5	2.5
Oxygen	Nm ³	0.38	14	5.4		
		0.23			40	9.2
Pig iron	Tonne	164.6	0.2	32.9	0	-
Scrap iron	Tonne	125.8	0.2	37.7	0.5	62.9
Total	EUR/tonne			105.7		94.4

NB: All values per tonne of molten metal
 Source: [83, Godinot, P. et al. 2002]

Operational costs decrease from EUR 105/tonne to EUR 94/tonne molten metal. The economic gain can mainly be attributed to the reduced proportion of pig iron. This also stresses the fact that the balance will differ for each specific foundry.

Driving force for implementation

To increase flexibility of the foundry and/or to increase the production capacity of existing installations without changing the installation layout.

Example plants

- AGA-Rayburn Foundry (Coalbrookdale, UK)
- Fritzwinter foundry (DE)

Reference literature

[59, Godinot 2001], [83, Godinot, P. et al. 2002]

3.2.2.1.7 Post-combustion of off-gases

Description

Post-combustion of CO and other organic compounds contained in furnace off-gases is used to reduce emissions and for heat recovery. The generated heat is recovered with a heat exchanger and used for blast air preheating or other internal purposes. In HBC furnaces, post-combustion takes place in a separate post-combustion chamber preheated with a natural gas burner. In CBC furnaces, post-combustion takes place directly in the cupola shaft. In rotary furnaces, post-combustion is carried out using an afterburner installed between the furnace and the heat exchanger.

Technical description

Post-combustion in cupola furnaces

Post-combustion of the waste gases is used to optimise heat recovery (chemically bonded as CO) and to provide cleaner exhaust gases. In burning CO, any residual carbonaceous material is simultaneously oxidised to CO₂ and H₂O. The generated heat can be recovered using a heat-exchanger and then transported to an internal user (e.g. blast air preheating).

Typical arrangements are:

- a post-combustion chamber placed before (bag filter) or after (wet filter) the dedusting unit (for below charge-hole offtake);
- (natural gas) burners or controlled air injection in the cupola shaft (for above charge-hole offtake).

The design of the system needs to ensure that the waste gases remain at a temperature above 800 °C and with a suitable residence time, i.e. 2 seconds, to guarantee the complete oxidation of the waste gases. The different systems are fully described and discussed below.

Post-combustion in HBC furnaces

A post combustion chamber with a burner is installed after the cupola. Normally a separate post combustion unit has to be preheated with a natural gas burner. Once the cupola is up and running either a smaller burner sustains the combustion of the waste gases or the gases self-ignite.

The type and position of the chamber can vary according to the process composition. Both horizontal and vertical combustion chamber types exist.

- *Hot blast cupola with a recuperator and wet scrubber* (Figure 3.60): In this arrangement, the gases are dedusted prior to combustion. This reduces dust build-up in the recuperator, which improves the rate of heat transfer. One disadvantage is the higher energy consumption in the post combustion unit, caused because the gases are cooled down in the wet scrubber. Early cooling of the offtake gases is continuously carried out to reduce the size of the dedusting unit.

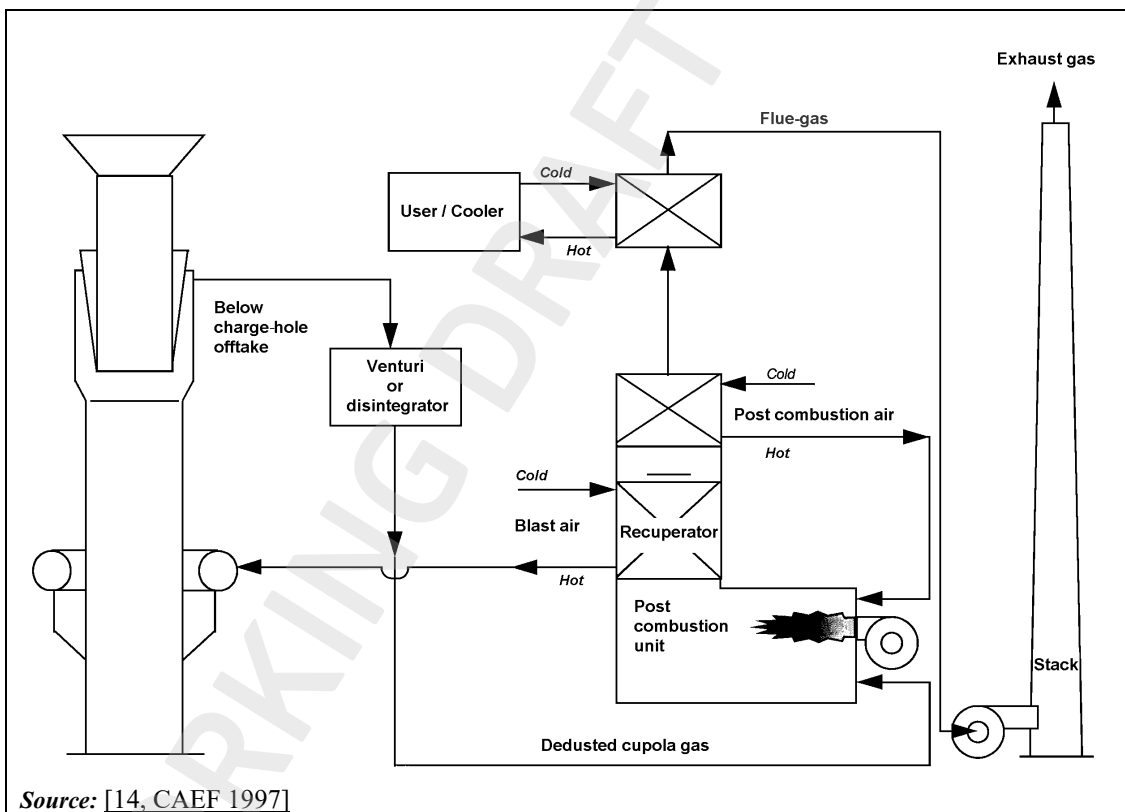


Figure 3.60: Hot blast cupola with a recuperator and wet scrubber

- *Hot blast cupola with a recuperator and bag filter* (Figure 3.61): The hot, dust laden, top gases are fed directly into the post combustion unit. Close process control is necessary to prevent sintering of the dust particles to the walls of the recuperator, which need to be cleaned

regularly. The gases need further cooling before entering the bag filter since they leave the recuperator at temperatures of 500 °C to 600 °C.

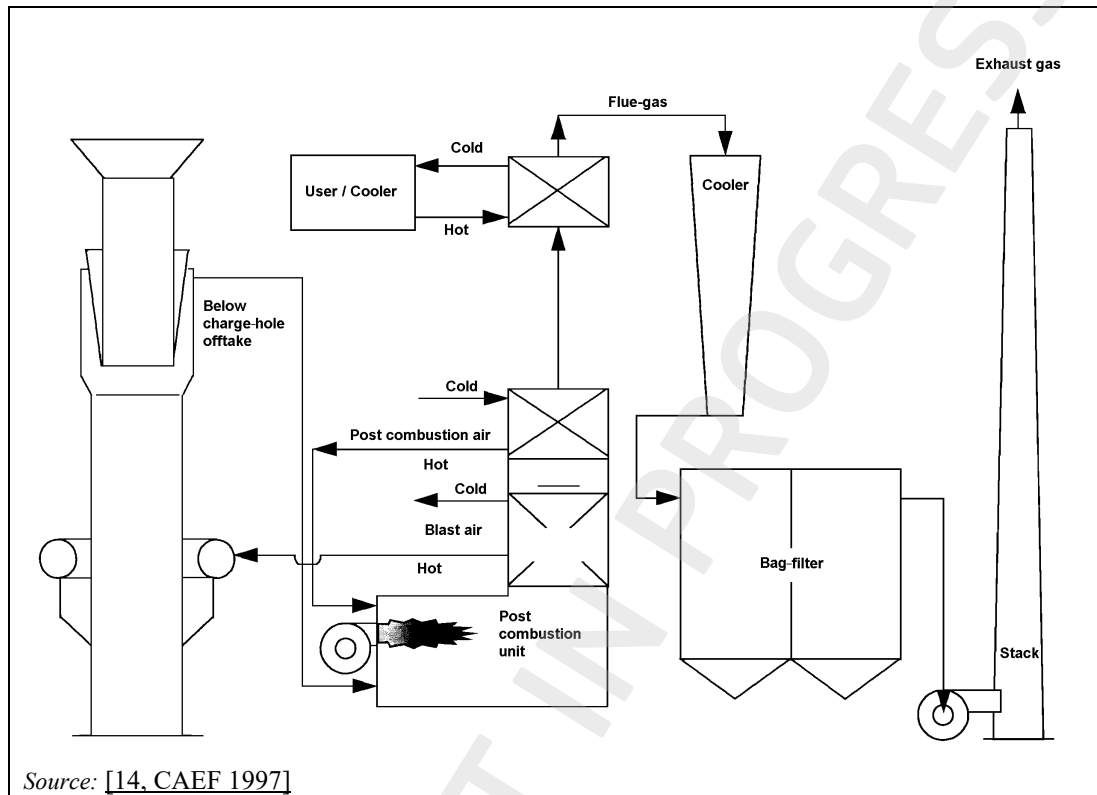


Figure 3.61: Hot blast cupola with a recuperator and bag filter

Post-combustion in the cupola shaft

The gases are combusted by an injection of air into the upper part of the charge or at a position above the charge top level. The airflow is adjusted so that the off-gases ignite spontaneously, due to their CO content and temperature. The injection nozzles can be placed on one or two levels. The partitioning of the airflow over the various levels, the choice of diameter and the position of the nozzles is based on experience. The goal of the optimisation is to burn the CO without ignition of the coke. The draught will also suck in air from the charge door. This air excess allows a more complete burn-out of the CO.

A supporting burner may be provided to maintain the flame. When using very low coke charges (i.e. < 6 – 8 %) the precautionary measure is reasonable.

Post combustion of the off-gas must be combined with a gas cooling, if a bag filter is used. For hot blast cupolas, the cooling is combined with a blast air preheating. In cold blast operation, a rapid cooling may be applied using water injection in the furnace shaft. Alternatively, an (off-gas – air) heat-exchanger may be used. This is illustrated in Figure 3.62.

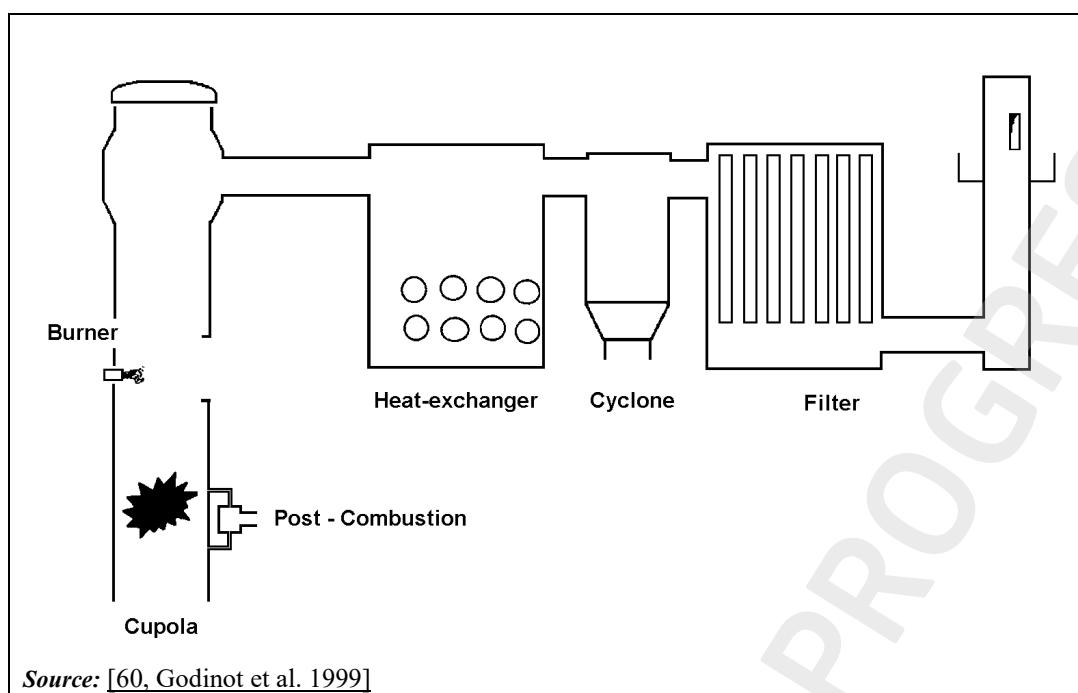


Figure 3.62: Principle of post-combustion and off-gas cooling in cold blast cupolas

Installing post-combustion on cold blast cupolas can be combined with a full retrofit to hot blast operation. In general, this choice is based on operational considerations. The characteristics of hot blast and long campaign furnaces are discussed in Sections 2.2.4.1.2 and 2.2.4.1.3.

Post-combustion in rotary furnaces

The application of an afterburner allows the reduction of organic carbon emissions and combustible particles. This technique may also be effective in reducing the risk of dioxin formation upon cooling of the gases. The afterburner is installed after the furnace and before the heat-exchanger. One of the following afterburner types may be used:

- thermal incinerator: combustion in an open flame;
- catalytic incinerator: combustion at lower temperatures through the use of a catalyst, resulting in a higher efficiency and lower NO_x emissions;
- recuperative incinerator: combustion with a heat recovery for preheating the combustion air, resulting in a higher thermal efficiency and lower fuel consumption;
- catalytic recuperative incinerator: a combination of the previous two types.

Achieved environmental benefits

Post combustion limits the emissions of CO and eliminates the majority of organic compounds. If not combusted, these would be captured in the dust or emitted through the chimney. Furthermore, post combustion reduces the risk of fire in the filter.

This technique is known to avoid explosion risks under certain circumstances. The positive environmental effect is maximised to those cases when the off-gas is burning autothermally most of the time. Otherwise, the increase in energy consumption may counterbalance the CO reduction.

Environmental performance and operational data

In Section 2.3, recent detailed information submitted in the frame of the SF data collection is presented.

In the following table, an overview of reported CO and TVOC emission concentrations from post-combustion in cupola furnaces (CBC and HBC) is presented.

Table 3.53: Reported concentrations of CO and TVOC for post combustion in cupola furnaces

Furnace type	Number of EPs	CO median/average of reported max. concentrations (mg/Nm ³)	TVOC median/average of reported max. concentrations (mg/Nm ³)
CBC	1	86/-	-/-
HBC	7	61/191	14/23
<i>Source: [169, TWG 2021]</i>			

Post-combustion in HBC furnaces

Operational data for hot blast cupolas are given in Table 3.54. Data for two example plants are given below:

1. Foundry G is a 3 shifts/days and 5 days/week operated foundry with a melting capacity of 50 t/h. The off-gas is collected below the charge-hole and combusted in a recuperator. The waste gas is then separated: one part goes to hot blast production (T = 600 °C), another part goes to a steam boiler. The steam is fed into a turbine, which powers a generator or compressor. The residual heat is used for preheating the combustion air of the recuperator. Waste gas is then cleaned in a bag filter. A concept drawing and further discussion of the installation is given in Section 3.2.1.3.12. Dust is recycled into the cupola, after mixing with petcoke. This is discussed in Section 3.2.1.4.5.6.
2. Foundry H is a 3 shifts/day and 5 days/week operated foundry with a melting capacity of 70 t/h. The off-gas is collected below the charge-hole and washed in a disintegrator, before post combustion in a recuperator. Heat is used for blast air preheating and goes to a further heat recovery, before leaving through the stack at a temperature of 220 °C. Further discussion of the heat recovery installation is given in Section 3.2.1.3.12. Waste water is re-circulated after settling. The circulating water volume is 440 m³/h. The sludge from the settling tank is dried in a filter press to a 50 % DS content, before disposal. Some 80 m³/day of waste water are disposed to the municipal waste water treatment.

Table 3.54: Operational data of hot blast cupola furnaces using a bag filter and a disintegrator for dust capture

	Units	Plant G	Plant H
Melting capacity	tonne/h	50	50
Waste gas flow	Nm ³ /h	75000	55000
Hot blast temperature	°C	600	570
Exhaust gas temperature	°C	127	220
Year of construction of the flue-gas treatment		1989	1983
Date of the measurements		10/1990	Control measurement 09/1993
Emissions	mg/Nm ³		
- Dust			
• Raw gas		1300 – 4300	8000 – 20000
• Clean gas: average ¹		1.1	6.1
maximum		1.8	7.3
- Gaseous ²			
• SO ₂		33	15.6
• NO _x		44	52.5
• C _{total}		<5	28.6 (FID)
• CO		32	<100
• O ₂	%	12.2	6.4
Heavy metal emission	mg/Nm ³	Clean gas ³	Clean gas
- Cr		<0.001	<0.0022
- Cr _{total}		<0.001	n.d
- Pb		<0.001	0.11

	Units	Plant G	Plant H
- Zn		<0.011	0.36
- Ni		n.d	<0.004
PCDD/F-emissions ¹			
• Clean gas ⁴	ng TEQ/Nm ³	0.048	0.003
• Emission factor	µg TEQ/tonne Fe	0.089	0.004
Filter dust/sludge		Dust recycling	Filter cakes to disposal
- solitary quantity	kg/tonne Fe	4.5	5.5
- PCDD/F-content	µg TEQ/kg	0.176	1.4
Waste heat utilisation		Hot blast air, steam for electricity production up to 3 MW electric	Hot blast air, thermal oil for the conversion of the waste heat for heating and drying purposes up to 21 MW
Investment cost	DEM '000	26400	22700 in 1980/81
Operational cost	DEM/tonne good casting	See data in the text for foundry G	See data in the text for foundry H
¹ Dust average is calculated on basis of 5 - 6 half-hour measurement data and 2x2 hour values for PCDD/F. ² The concentrations of sulphur dioxide, nitrogen oxide, total carbon, carbon monoxide and carbon dioxide are calculated averages from continuous measurements over several hours during sampling for dust or PCDD/F. ³ At the time of measurement, the dust recycling was not operational. ⁴ Sampling time of 2 hours. n.d: no data. note: Raw gas sampling was performed before the bag filter in G and before the disintegrator for H; clean gas sampling was performed after the bag filter for G and after the recuperator for H. Source: [7, Strauß 1983], [12, Kran, H.-P. et al. 1995], [100, TWG 2002]			

Burning the fumes in the post-combustion chamber does not consume much energy, providing there is sufficient carbon monoxide in the fumes, which is generally the case. But the whole system for treating the fumes (combustion chamber + heat-exchanger + filter or wet scrubber + fans) also needs electrical energy and regular maintenance. Table 3.55 gives some examples of energy consumption for hot blast cupolas.

Table 3.55: Energy consumption of hot blast cupolas

Hourly rate of the cupola	Type of dedusting	Gas consumption for the combustion chamber (kWh/t charged)	Electricity consumption for the fume treatment system (kWh/t charged)
12	Filter	59	46
12	Filter	124	72
26	Filter	42	n.d
17	Electro filter (wet)	16	38

Post-combustion in the cupola shaft

Two configurations of (in-shaft post-combustion and) cooling on cold blast cupolas were studied on an industrial scale and compared by CTIF; cupola I was equipped with a water injection in the cupola shaft, a cyclone and a bag filter, cupola J was equipped with a gas-air heat-exchanger, a cyclone and a bag filter. Operational data are given in Table 3.56. Results of the measurement campaigns and reference to the applicable legislation are given in Table 3.57.

Table 3.56: Environmental performance and operational data of two example configurations using post-combustion with water cooling (I), and air cooling (J)

Parameter	Units	Foundry I	Foundry J
Melting capacity	tonne/h	10.3	9.2
Primary + secondary airflow	Nm ³ /h	7389	6484

Parameter	Units	Foundry I	Foundry J
Post combustion airflow	Nm ³ /h	2372	1549
Water flow	l/h	2678	
Flue-gas flow (chimney)	Nm ³ /h	26780	39179
Residence time combustion to bag filter	s	10.5	12.3
Residence time cooling stage	s	<1.7	6.01
Overall CO combustion efficiency	%	66	96.5

Source: [60, Godinot et al. 1999]

Table 3.57: Analytical results and applicable (French) legislation, for post-combustion in a cold blast cupola with water cooling (I), and the air cooling (J) of flue-gases

Compound	Foundry I		Foundry J		Arrêté du 02/02/98	
	analysis	flux	analysis	flux	limit value	limit for consideration *
Dust	1.7 – 2.8 mg/Nm ³ 3 – 5 g/t	0.04 – 0.07 kg/h	1 mg/Nm ³ 34 g/h		100 mg/Nm ³ 200 g/t	<1 kg/h melt = 8 tonne/h
CO	450 Nm ³ /h	560 kg/h	35 Nm ³ /h	44 kg/h		50 kg/h
HCl	22 mg/Nm ³	0.4 kg/h	9.2 mg/Nm ³	0.35 kg/h	50 mg/Nm ³	1 kg/h
HF	13 mg/Nm ³	0.24 kg/h	4.8 mg/Nm ³	0.18 kg/h	5 mg/Nm ³	0.5 kg/h
HCN	<0.007 mg/Nm ³	0.13 g/h	<0.01 mg/Nm ³	0.38 kg/h	5 mg/Nm ³	50 g/h
NH ₃	0.61 mg/Nm ³	12 g/h	0.10 mg/Nm ³	3.8 g/h	50 mg/Nm ³	100 g/h
NO _x	9 mg/Nm ³	0.17 kg/h	15 mg/Nm ³	0.57 kg/h	500 mg/Nm ³	25 kg/h
VOC non-methane	13 mg/Nm ³	0.25 kg/h	6 mg/Nm ³	0.23 kg/h	110 mg/Nm ³	2 kg/h

*: If the flux is below the limit of consideration, the measured value may exceed the limit value.
Source: [60, Godinot et al. 1999]

The water spray cooling achieves a CO-destruction efficiency of 66 % and allows compliance with the applicable legislation. Flue-gas cooling over a heat-exchanger provides better efficiency (98 %).

Post-combustion in rotary furnaces

An afterburner can be expected to achieve between 80 % and 98 % efficiency for burning the combustible particulates emitted from the rotary furnace. Hot gases from the afterburner can be ducted through a recuperator and can assist in preheating the combustion air to the main furnace burner. Recuperators offer an energy saving of up to 15 %.

Cross-media effects

Dry dedusting techniques produce dust for disposal (4 – 12 kg/t liquid iron). The dust may be re-circulated into the cupola. Wet systems produce a sludge fraction.

In cold blast cupolas, if the cupola off-gas does not ignite spontaneously, the installation of ignition or support burners is necessary. These incur a significant power use and increase the overall flue-gas volume.

Technical considerations relevant to applicability

Generally applicable.

During the design stage, considerable care has to be taken to minimise the total flow of the gases to be treated. The combustion air intake has to be kept to a strict minimum. This is the reason why a separate combustion unit is always installed in conjunction with a below charge-hole offtake. For economic reasons (see below), the post-combustion chamber is only used on hot blast cupolas. However, a post-combustion system for cold blast furnaces, without the complexity of a hot blast

installation, has also been developed. This system is currently in operation in France. ‘In-shaft’ post-combustion therefore applies to both hot blast and cold blast cupola operation.

To change the offtake system of an existing cupola from above to below the charge-hole system is in most cases impossible. Post-combustion of the waste gases in the furnace shaft therefore is a more viable solution for cupolas with an above charge-hole offtake.

In the Czech Republic, the whole range of cold blast cupola installations was studied for applicability of in-shaft post-combustion. The combustion was not spontaneous in any of the set-ups over the whole melting period. In each case, it was necessary to install ignition burners of significant power. The cupola emission volume also increased.

Concerning rotary furnaces, this technique is applicable to all new and existing rotary furnace installations, both in ferrous and non-ferrous foundries.

Economics

The high energy consumption of the post-combustion is only economically reasonable if the released heat of the waste gases can be re-used, as it is in the recuperative hot blast cupola. However, switching from a cold blast to a hot blast cupola for the sole reason of gas combustion might encounter economical limitations in certain situations. Hot blast cupolas, preferably in a long campaign configuration, involve higher investment costs and are only used with production rates of 10 tonne Fe/h or more. In smaller foundries, this production method might not be the right choice.

Table 3.54 gives economic data for the example plants. For foundry G, the investment costs for a hot blast cupola with bag filter and extensive heat recovery are given. The operational costs for 1994 (after refurbishment of the melting shop) were 25 % lower than those for 1985, i.e. with the old melting furnace. For foundry H, investment costs for 1980 – 1981 are given. After refurbishment, the operational costs went down by 2 % per tonne of liquid iron.

The investment cost for a twin cold blast cupola of 850 mm internal diameter, which produces 4.5 tonnes an hour, 10 hours a day, 5 days a week is in the order of EUR 300 000.

Driving force for implementation

Legal requirements: Emission limit values and continuous monitoring of CO and emission limit values for organic compounds.

Example plants

CBC: DE058 and DE067.

HBC: BE021, BE022, CZ024, DE046, DE051, DE061 and DE076. [169, TWG 2021]

Reference literature

[7, Strauß 1983], [12, Kran, H.-P. et al. 1995], [14, CAEF 1997], [60, Godinot et al. 1999] [100, TWG 2002], [54, ETSU 1998], [11, Brettschneider et al. 1992], [64, UK Environment Agency 2002], [169, TWG 2021]

3.2.2.1.8 Foamy slag practice

Description

Simultaneous injection of oxygen and carbon (in the form of coal dust) into the slag at the end of the melting cycle in electric arc furnaces. This injection generates CO bubbles, forming a layer of foamy slag which insulates the molten metal and protects the furnace refractory lining.

Technical description

The *foamy slag practice*, currently in use in the steel production industry, consists in simultaneously injecting oxygen and carbon (in the form of coal dust) into the slag at the end of the melting. The foam of slag is produced by the action of CO bubbles. The CO gas comes from

the oxidation of carbon in the metal by the injected oxygen and also from the reduction of the iron oxides (FeO) by the injected carbon.

Creating a foamy slag improves the heat transfer to the charged units and protects the refractory material inside the furnace. Because of the better arc stability and less radiation effects, slag foaming leads to a reduction in energy consumption, electrode consumption, noise levels and increased productivity.

Achieved environmental benefits

Reduction of energy consumption and electrode consumption, lower noise levels and reduction of flue-gas volume.

Environmental performance and operational data

Table 3.58 gives the operational data for a 60-tonne arc furnace and indicates the mains savings in energy, time, refractory and electrodes.

Table 3.58: Energy and temperature data for EAF furnace melting with normal slag and foamy slag

	Units	Normal slag	Foamy slag
Total power	MW	25	30
Radiation loss arc to flue-gas	MW	6	0
Flue-gas flow	m ³ /h	41000	28000
Final temperature	°C		
- metal		1630	1630
- slag		1603	1753
- flue-gas		1463	1607
- refractory		1528	1674
Energy-input	kWh/tonne		
- electricity		50.8	37.7
- fossile (coal)		37.1	22.6
Energy-output	kWh/tonne		
- metal (ΔH)		10.4	10.4
- slag (ΔH)		1.1	9.4
- furnace losses		20.7	14.1
- flue-gas losses		53.6	24.8
- other losses		2.5	1.6
Heating time 1584 - 1630 °C	min	11min 45sec	7min 30sec
Heating rate	°C/min	3.9	6.1
<i>Source: [100, TWG 2002]</i>			

Slag density is reduced from 2.3 tonne/m³ to 1.15-1.5 tonne/m³.

Cross-media effects

As the volume of the slag rises so larger slag buckets may be needed. After tapping, the slag degasses again. There is no reported adverse impact on the possibilities for reuse of the slag.

Technical considerations relevant to applicability

This technique applies to new and existing EAF foundries that practice oxygen injection.

Driving force for implementation

- Increasing the efficiency of furnace operation.

Example plants

No specific example plants were reported, but the technique finds application in several European foundries.

Reference literature

[14, CAEF 1997], [100, TWG 2002], [109, COM 2013]

3.2.2.2 Emissions to air from thermal processes**3.2.2.2.1 Emissions to air from metal melting**

3.2.2.2.1.1 Control of coke quality

Description

Coke is purchased based on important quality specifications (e.g. fixed carbon, ash, volatile matter, sulphur and moisture content, mean size diameter) which are systematically controlled before use.

Technical description

The quality of the coke used has a direct bearing on the efficiency of cupola operations. It particularly affects the initial temperature carbon pick-up and the sulphur content of the iron. Specifying the foundry coke involves testing the following contents:

- *Fixed carbon*: The higher the carbon content, the higher the calorific value.
- *Ash content*: A high ash content is undesirable since it lowers the calorific value of the coke and generates a greater volume of slag in the cupola.
- *Volatile matter*: Volatile matter is undesirable since it reduces the fixed-carbon content, and thus the calorific value of the coke.
- *Sulphur*: Sulphur is well known as an unwanted element in any type of cast iron and leads to SO₂ emissions. The lower the sulphur content of the feedstock coke, the better. The sulphur content of the coke depends on the sulphur content of the feedstock coal. The main desulphurisation processes include: chemical desulphurisation, leaching, extraction, flotation, oxydesulphurisation and biodesulphurisation. As an example, the inorganic bound sulphur (pyrite) is mechanically separated from the dry or wet finely ground coal, or the organically bound sulphur is reduced with hydrogen under pressure to hydrogen sulphide and separated (SRC (solvent-refined coal) process). The inorganically bound sulphur (pyrite) can also be removed according to the Meyers process by oxidising it with Fe(III) sulphate and atmospheric oxygen to elemental sulphur.
- *Moisture*: Moisture in the coke when dispatched from the coke oven is undesirable, since it reduces the amount of carbon available by weight. However, it is necessary for the coke to contain some moisture, to avoid fires on conveyer belts and in lorries and wagons.
- *Size*: The size of the foundry coke directly affects the coke consumption per tonne of iron melted and also the melting rate. To achieve optimum performance the coke size dispatched from the coke oven generally needs to be sized such that the furnace coke has a mean size diameter greater than 90 mm, with no more than 4 % smaller than 50 mm. The content of fines will influence emissions of dust during (un)loading and handling.

Achieved environmental benefits

Optimising the coke input results in a higher process efficiency.

Environmental performance and operational data

Typical properties of foundry coke are given in Table 3.59.

Table 3.59: Typical properties of foundry cokes

Property	Typical value (%)	Limit value (%)
Ash	5.8 – 5.9	6.5 max.
Volatile matter	0.3 – 0.4	0.8 max.
Sulphur	0.68 – 0.70	0.75 max.
Moisture	1.5 – 2.5	3.0 max.

Property	Typical value (%)	Limit value (%)
Strength		
M80 Micus index	81 – 82	78.0 max.
M10 Micus index	8 – 8.5	9.0 max.
Fixed carbon	93.7 – 93.8	93.0 min.
Higher calorific value	32200 kJ/kg	31800 kJ/kg
<i>Source: [95, Nalonchem 2002]</i>		

The data in Table 3.59 are taken from supplier specifications. Local standards may use higher limit values.

Cross-media effects

None.

Technical considerations relevant to applicability

The technique is applicable to all new and existing cupola installations.

Economics

In general, low-sulphur feedstocks are more expensive.

Driving force for implementation

- To improve the efficiency of the foundry process.
- Legal requirements.

Example plants

This technique is commonly applied in European foundries using cupola furnaces.

Reference literature

[20, ETSU 1993], [120, TWG 2003]

3.2.2.2.1.2 Adjustment of the slag acidity/basicity

More information on the technique

See Section 3.2.1.4.5.4.

3.2.2.2.1.3 Increase of shaft height in CBC furnaces

More information on the technique

See Section 3.2.2.1.1.

3.2.2.2.1.4 Oxygen enrichment of the combustion air

More information on the technique

See Section 3.2.2.1.2.

3.2.2.2.1.5 Superheating of HBC blast air

More information on the technique

See Section 3.2.2.1.3.

3.2.2.2.1.6 Minimal blast shut-off periods for HBC furnaces

More information on the technique

See Section 3.2.2.1.4.

3.2.2.2.1.7 Long-campaign cupola

More information on the technique

See Section 3.2.2.1.5.

3.2.2.2.1.8 Off-gas extraction and cooling as close as possible to the emission source

Description

In cupola furnaces, the off-gases are extracted either:

- above the charge-hole offtake at the end of the cupola stack using ductwork and a downstream fan; or
- below the charge-hole offtake using an annular ring.

After extraction, the off-gases are cooled for example using:

- long ducts to decrease the temperature by natural convection;
- air/gas or oil/gas heat exchangers;
- water quenching.

For induction furnaces, off-gases are extracted, for example using:

- hood extraction (e.g. canopy or side-draught hoods);
- lip extraction;
- cover extraction.

For rotary furnaces, off-gases are extracted, for example using hood extraction.

For EAFs, off-gases are extracted, for example using:

- roof-mounted hood extraction;
- canopy or side-draught hoods;
- partial furnace enclosures (mobile or fixed) mounted around the furnace and tapping area;
- total furnace enclosure using a complete room enclosure around the furnace and tapping area equipped with a moveable roof for charging/tapping operations.

Technical description

Collection, cooling and dedusting in cupola furnaces

The design of the collection and gas cleaning system is based on the conditions occurring during blow-down, as these are often the most severe conditions experienced during the system operation. At the end of a melting campaign, the furnace is no longer filled with charge materials. Gas temperatures will increase gradually since they are no longer cooled by a cold charge in the stack. In contact with oxygen, CO will burn automatically. Temperatures can therefore reach up to 1 200 °C, or even higher. The off-gas collection and treatment system has to be able to cope with these severe conditions.

Collection

Two systems are in use for top gas collection:

- *Above charge-hole offtake:* The exhaust gases are withdrawn at the end of the cupola stack by means of ductwork and a fan placed downstream. The opening above the charge-hole allows an important inflow of air, necessary to prevent cupola gases being emitted from the area. This volume of extra air may be many times the cupola gas flow. This increases the size and cost of the collection and cleaning system. Reducing charge-hole sizes may have some merit but this option may be limited because of the explosion hazard present when too little oxygen is mixed with the CO containing cupola gases (pulsating combustion).
- *Below charge-hole offtake:* The cupola top gases are collected through an annular ring below the charge-hole. No air inflow is required since the gases cannot be emitted out of the hole, provided the control system is sensitive enough to function properly during the variation of the blowing rate of the cupola. Too little offtake rate can result in the emission of uncleaned gases through the cupola stack, too great an offtake flow can result in air ingress, leading to combustion and overheating of the gases (i.e. an explosion hazard).

Cooling

Following collection, the gases may need cooling depending on the dust abatement system used. In the hot blast operation, the heat recovered from cooling may be used for preheating the blast air.

Several options are possible for cooling the collected gases, including:

- *Using tube coolers:* Running the collected gases through long ducts, decreases the temperature by natural convection and radiation. This system is simple but takes up a lot of space and does not offer controlled cooling (therefore there is a risk of condensation).
- *Using a forced air/gas heat-exchanger:* Cold ambient air is forced through an arrangement of tubes or plates to cool down the gases. Dust collection and the subsequent need for cleaning the heat-exchanging surfaces may lead to a complex and expensive design of the system. One advantage of this system is the possible use of the heated air for external heating purposes. Recuperative hot blast cupolas are equipped with a post combustion unit and a heat-exchanger (recuperator) to heat the blast air.
- *Using an oil/gas heat-exchanger:* This is similar to the above system but more expensive because of the need for a secondary cooling system. The heat-exchanger is generally cooled with a circulation of mineral oil. Cooling with a water/gas heat-exchanger is not (or only very rarely) practised.
- *Saturation with water:* Here the gases are cooled by the evaporation of the water sprayed into the gas stream. Wet scrubbers perform better if the gases are cooled in a saturation chamber prior to cleaning. When using fabric filters only, partial saturation is possible to prevent clogging of the fabric due to the condensation of water. A good control system is necessary to guarantee correct functioning of the system. Quenching the gases has the advantage that rapid cooling reduces the risk of dioxin formation.

Dedusting

Dust capture equipment of various types can be used to remove particulate matter from the waste gases. Generally wet scrubbers have low capital costs and maintenance, but require a high energy input to achieve acceptable collection efficiencies. The removal of the sludge is difficult and the scrubber water has to be treated prior to discharge. Dry collection systems have more expensive capital costs and need better control of the inlet gas conditions (temperature, condensation of water or organic vapours, CO:O₂ ratio, sparks) but usually use less energy than that needed for wet scrubbing. Furthermore, dry cupola dust can be recycled into the cupola (see Section 3.2.1.4.5.6).

Both venturi scrubbers and disintegrators are used with cupola systems. Scrubber towers are used for dedusting of non-melting off-gas. Compared to dry systems, the wet systems have the following disadvantages: higher energy consumption, higher maintenance (corrosion, bacteria), and they result in waste water and a sludge for disposal. Advantages are the capture of water-soluble compounds (such as SO₂, chlorides), quick cooling - which prevents dioxin reformation, low investment costs, and less restriction on input temperature.

- *Venturi scrubbers*: Water is sprayed into the gases as they pass through a venturi. The acceleration of the gas flow in the venturi throat causes an intensive mixing of both media. The dust particles are damped, making them heavier, so that they can be separated in a cyclone or other system placed downstream. If the gas flow drops, the venturi throat is adjusted to maintain the collection efficiency.
- *Disintegrators*: These so-called dynamic scrubbers consist of concentric rotor and stator mounted pins through which the gas stream is driven by means of a fan placed downstream or by fan blades at the outer end of the rotor. Water injected into the centre of the rotor, is broken into fine droplets by the pins and dispersed in the gas stream. The wet particles impinge on the stator walls and are collected at the bottom of the disintegrator. The system works efficiently when the gas flow is reduced.

A separator to remove small particles entrained in water droplets is located after the wet scrubber.

With regard to dry systems, the following remarks can be made:

- *Multicyclones*: These are often used in conjunction with a fabric filter, acting as coarse dust arrestors. They help to prevent incandescent coke particles reaching the filter cloth. Provided refractory lining and high grade steel are used in the design of the cyclone, they can operate at high temperatures. Note, the collection efficiency from cyclones alone is not sufficient to meet today's regulations, hence they are usually used in combination with other dedusting systems.
- *Bag filters*: These are ideal when the gases are burned prior to the dedusting. This avoids problems of the deposition of carbonaceous material or fire hazards. Bag filters can be designed to provide good efficiency for collecting metallurgical fume particles such as ZnO.
- *Electrostatic precipitators*: These systems are less common in the European foundry industry. This system is best suited to more or less constant working conditions, such as in long campaign cupolas, because of its sensitivity to variations in gas temperature, flow and humidity. There is an explosion hazard when dedusting unburned gases mixed with air, due to the relatively large volume of the precipitator. The precipitator therefore needs to be flushed before applying electrical power.

A schematic representation of a cold blast cupola with heat recovery and a bag filter is given in Figure 3.63.

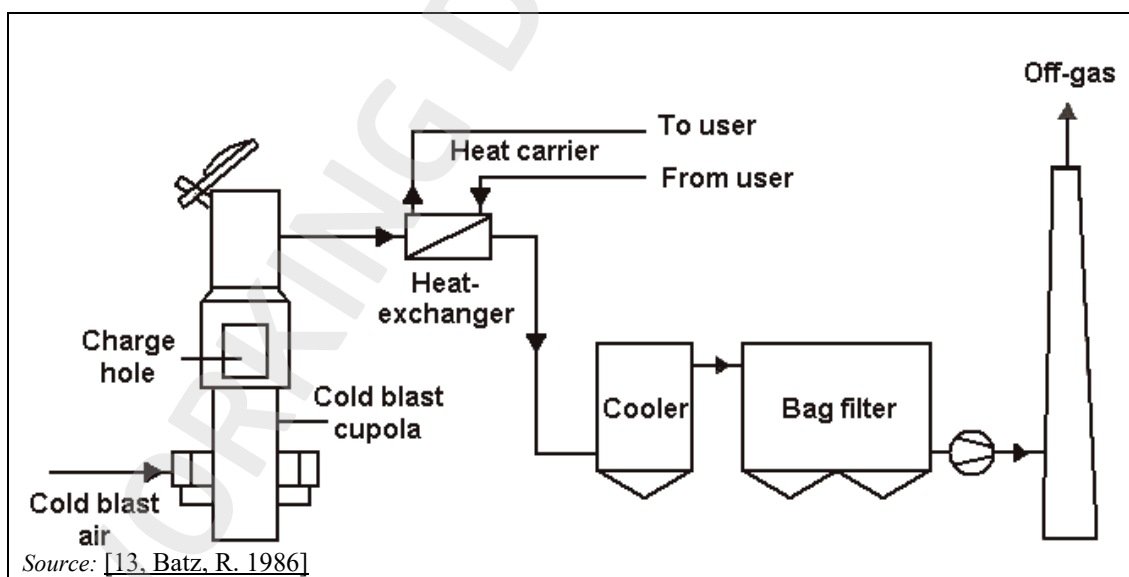


Figure 3.63: Flow sheet of cold blast cupola with heat recovery, cooling and a bag filter

In addition, Figure 3.64 gives a comparison of the operational conditions for hot blast cupola furnaces with a wet and dry dedusting system. The main differences are the temperature profile of the flue-gas and the energy consumption.

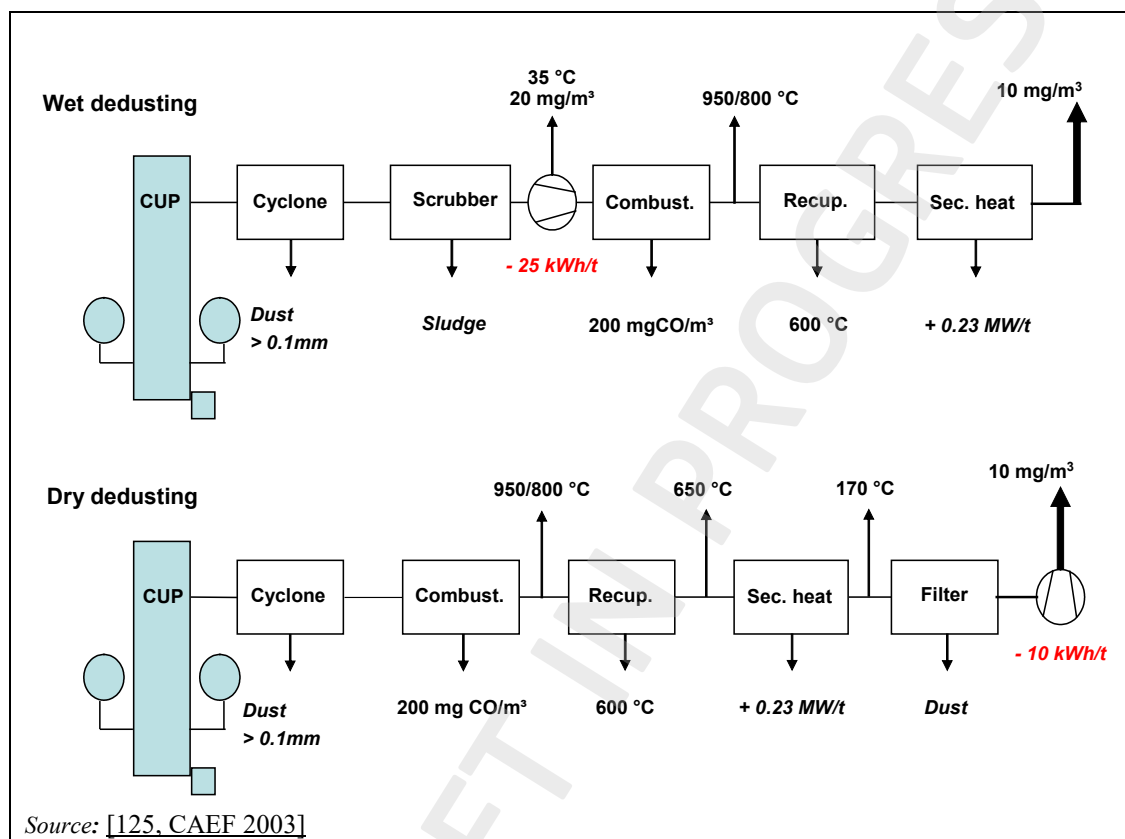


Figure 3.64: Operational conditions for wet and dry dedusting of hot blast cupola off-gas

After dedusting, post-combustion of the waste gases in cupola furnaces is used to optimise heat recovery (chemically bonded as CO) and to provide cleaner exhaust gases. This is further described in Section 3.2.2.1.7.

Induction furnaces

The capture of smoke and dust is the most difficult problem to solve when installing an off-gas collection system on a coreless induction furnace, since there is no exhaust shaft. Several methods have been developed in the past decade, each with advantages and disadvantages.

- *General ventilation of the workplace:* A combination of wall mounted louvers and roof mounted ventilators situated over the furnace platform are used to increase the natural convection of smoke and fumes and to direct them outside. Even with baffles suspended from the roof and using high extraction rates the efficiency is often poor and easily disturbed by draughts.
- *Canopy hood extraction:* Since lower placed hoods will interfere with crane charging systems, larger hoods have to be installed above the charger. This creates a large gap between the furnace and the extraction system, making it difficult to control the rising smoke and dust, even when using high extraction rates. Cross-draughts can seriously distort the collection efficiency of the system. These disadvantages make the use of these collection systems unattractive.
- *Swing aside hoods:* These hoods are more efficient when used in conjunction with vibrating feeders. Cut-outs in the hood can facilitate charging. During tapping, the hood is swung over the ladle, allowing efficient fume extraction.

- *Side-draught hoods:* Placing the extraction hood beside the furnace offers the advantage of good furnace accessibility and no interference with the charging systems. Due to the high buoyancy of the exhaust gases, large extraction rates are achieved, therefore giving good efficiency, especially when the hood is placed outside the furnace platform. In this case extraction control is poor during tapping. Attachment to the furnace platform overcomes this problem but may interfere with charging operations. The efficiency can be improved by installing airjets at the opposite side of the hood to blow the dust and fumes into the hood. Unfortunately, this facility does not work if there are any interferences in the airstream, which is the case during charging.
- *Lip extraction:* A suction ring is placed on top of the furnace and arranged so that it moves with the furnace during deslagging or tapping operations. This system does not interfere with the charging operations. With the lid closed, lip extraction offers very good control, since it is as near to the emission source as possible and involves the lowest extraction rates. The fumes do not pass through the breathing zone of the furnace operators. However, the extraction control decreases significantly when the furnace lid is opened, for instance during charging. The design of this extraction equipment has been subjected to many studies. Suppliers offer solutions to overcome some of the disadvantages.
- *Cover extraction:* The gas is exhausted through the furnace cover. This method is very effective. It is used by the majority of furnace producers. Exhaustion is managed according to furnace regime: melting, charging, pouring.

Attention has to be paid to the material used for hoods and ducts since the gases may be at high temperatures when the intake of the collection system is positioned close to the furnace. The heating transferred by radiation or convection from the molten metal bath needs to be taken into account in the design stage. Proper maintenance in combination with heat-sensors reduces the risk of fire.

Again scrap cleanliness plays an important role. When the scrap contains organic matter, collected gas temperatures may rise due to the combustion of the material, thus requiring the use of heat resistant steel or even refractory linings. Oily deposits, formed by condensation of oil vapour in the ductwork, accumulate dust and can present a fire hazard if not removed regularly. When using clean scrap, a mild steel construction is adequate and does not need accessibility for cleaning.

Rotary furnaces

In most cases, dedusting equipment is needed to meet the applicable regulations. Generally, bag filters are installed for this purpose, but it is also technically possible to use wet dedusting techniques.

In order to lower the temperature of the exhaust gases, they are diluted with ambient air. This is achieved by the intake of air through a gap between the furnace exhaust and the elbow shaped exhaust pipe. This gap is always present as it allows the furnace body to be able to rotate and tilt. Often the exhaust pipe is retractable. In general, dilution for emission reduction is unacceptable. If dilution is used (and is necessary) for cooling, the end-of-pipe technology should have the right dimension for the larger gas flow. Sometimes the diluted waste gases are then fed through an air-gas heat-exchanger for further cooling. This way the gas temperature is reduced from the initial 1 500 °C to 200 °C, or lower. At this temperature, the gases can be introduced into a bag filter for dedusting.

The application of an afterburner allows the reduction of organic carbon emissions and combustible particles. This is discussed in Section 3.2.2.1.7.

Electric arc furnaces (EAFs)

See Section 3.2.3.1.3.

Achieved environmental benefits

- Flue-gas capture allows the controlled evacuation and treatment of the flue-gas stream, and results in a minimisation of both fugitive and channelled emissions.

- In cupola furnaces, exhaust capture and cleaning is a necessary measure to reduce the emission products from coke combustion such as NO_x, SO₂, HF, PCDD/Fs and dust.
- To reduce dust and acidifying emissions from induction melting furnaces.

Environmental performance and operational data

Cold blast cupola furnaces

Fabric filters have an efficiency of over 99 %. Daily average dust emission values stay well below 10 mg/Nm³. The sum of Pb, Zn, Cr, Cu, Mn, V, Sn, Cr, Ni, As, and Cd reaches about 20 % of the total dust content. The data represented in Table 3.60 were gathered within the framework of investigations of the Federal Environmental Agency in Germany of operational plants. Data for 3 example plants are given.

Table 3.60: Operational data of cold blast cupola furnaces with a bag filter for dust abatement

	Units	Plant D		Plant E	Plant F
		Initial	After rebuild		
Melting capacity					
- design value	t/h	7.5 – 8	12.0	6 – 7	4 – 5
- actual value	t/h	7.0	11.0	5.5	3.7
Exhaust gas stream					
- design value	Nm ³ /h	25000	30000	20000	n.d
- actual value	Nm ³ /h	19800	22300	17400	14300
Year of construction of the filter		1981	1995	1988	1985
Last filter cloth change		n.d	1995	1988	1993
Date of the measurements		07/1981	11/1997	03/1993	03/1993
Emissions	mg/Nm ³				
- dust					
- raw gas		1623 – 2674		n.d	n.d
- clean gas					
• average ¹		21.5	<1	3	3
• min.		18.0	<1	1	2
• max.		25.4	<1	5	4
- gaseous ²					
• SO ₂		288	n.d	174	227
• NO _x		43	n.d	24	31
• C _{total}		n.d	n.d	22	7
• CO		700	n.d	11890	18980
• CO ₂	%	7	n.d	4.9	3.9
Heavy metal emissions	mg/Nm ³	Raw	Clean	Clean gas	n.d
- Cd		0.0184	0.0019	0.00313 (ΣCu, Mn, Cr, V)	n.d
- Cr		0.7287	0.0384		
- Pb		29.895	0.2952	0.00057	n.d
- Zn		16.464	0.2862		
- Ni		0.2024	0.0077		
- As		0.7665	0.0149		
- Mo		0.2672	0.0420		
PCDD/F-emissions				n.d	
- clean gas ³	ngTEQ/Nm ³			0.512	0.085
- emission factor	µg TEQ/t Fe			1.620	0.330
Filter dust					
- collected amount	kg/t Fe	6.5 disposal	8.2 re-use		
- PCDD/F-Gehalt	µg TEQ/kg			4.850	0.960

	Units	Plant D		Plant E	Plant F
		Initial	After rebuild		
Filter material		Polyester cloth with PA coating	Synthetic fibre	Polyester	Needle cloth
Filter cleaning		Pulse jet	Medium pressure counter flow	Pneumatical with pressure drop control	
Capital cost	EUR '000	385 (1981)	370 (1995/96)	n.d	350
Operating cost	EUR/tonne good casting	9.8 (1982) = 3 % of the casting costs	9.04 (1998) = 2.8 % of the casting costs	n.d	n.d

¹ Dust average is calculated on basis of 3 – 5 half-hour measurement data.
² The concentrations of sulphur dioxide, nitrogen oxide, total carbon, carbon monoxide and carbon dioxide are calculated averages from continuous measurements over several hours during sampling for dust or PCDD/F.
³ Sampling time of 6 hours.
n.d: no data.
Source: Data taken from [19, Batz, R. 1996] and [100, TWG 2002], [120, TWG 2003]

Hot blast cupola furnaces

Data for hot blast cupolas are given in Section 3.2.2.1.7.

Induction furnaces

Cleaning of the captured gases is generally performed using filters. Daily average dust emission values stay well below 10 mg/Nm³.

Table 3.61 gives the operational data for a German cast iron foundry in which a centralised flue-gas capture system is installed, with dedusting carried out using a bag filter. The system collects exhaust gas from the various parts of the foundry, including: the four induction furnaces (each with lip extraction and canopy hood), the scrap storage and preheating, the metal treatment, the sand regeneration, and the casting areas. Data are given for the raw melting of the furnace off-gas, the raw combined gas flow and the cleaned gas flow.

Table 3.61: Emission data for a cast iron foundry, using induction melting and a centralised exhaust system with a bag filter

Compound	Melting off-gas	Combined exhaust gas	Cleaned gas*
Dust	89.3	237	<1
NO _x	1.6	8.3	7.9
CO	2.2	4.2	3.8
SO ₂	3.5	3.9	3.7
Total C	21.8	34.7	34.9
PCDD/F		0.036 x 10 ⁻⁶	0.0027 x 10 ⁻⁶

* NO_x, CO, SO₂ and total C are not captured in the bag filter. The difference between raw and cleaned gases are due to the slightly changed gas mix after the ID fan.
Melting capacity 14 tonne/h, total flue-gas flow 240 000 m³/h.
All data in mg/Nm³.
Source: [8, Rademacher, H. 1993]

Through the use of specific capture systems, such as side-draught hoods, movable extraction hoods and partial housing of the furnace, a capture efficiency of more than 95 % is possible.

Operational experience in a German cast iron foundry showed that the furnace lid is open on average during 25 % of the working time of the furnace. During the opening periods, dust-generating process steps such as the feeding of additives, deslagging and pouring are performed. The lip extraction system installed on the furnace lid, does not allow extraction of the generated fumes. Installation of a telescopic canopy hood allowed an efficient exhaust capture during the opening of the furnace lid.

Rotary furnaces

For ferrous rotary furnaces operating with simple air/fuel burners and an afterburner, dust emissions peak at about 250 mg/m³ for short periods (between 3 seconds continuously but also intermittently over a period of a minute) during the solid phases of the melt cycle. Thereafter, once the charge starts to become liquid, the dust emissions reduce to less than 30 mg/m³ during normal running. Emissions may remain as high as 150 – 200 mg/m³ continually during the solid phase of the melt. 40 % combustible emissions are common. Peak emissions from rotary furnaces consist of at least 80 % unburned fuel and occur during charging operations when the main furnace burner is extinguished and then re-lit. The mentioned emissions only apply if at all times, including during charging, the fumes are ducted via the afterburner, which is kept fully operational [64, UK Environment Agency 2002]. The following raw gas dust levels have been reported for an oxygas rotary furnace without an afterburner: an average dust load of 400 – 450 mg/Nm³ over the two distinct melting phases. These phases are a solid phase with dust emission levels of 150 mg/Nm³, and a liquid metal phase with peak levels up to 1 500 mg/Nm³ at the start of the rotation and 600 – 700 mg/Nm³ during normal operation. [102, Carnicer Alfonso, P. L 2001]

Operational emission data after abatement are given in Section 2.3 and in the following table.

Table 3.62: Reported dust emission levels from rotary furnaces

Plant/ Emission Point	Abatement technique applied	Minimum	Average	Maximum	ELV
		mg/Nm ³			
BE020_a {1}	Fabric filter + cyclone	0.1	1.3	2.0	20
ES088_a {1}	Fabric filter	1.0	1.4	2.0	20
AT005_a {1}	Fabric filter	2.1	2.1	2.1	10
IT127_a {7}	Fabric filter	0.8	1.4	2.1	20
IT132_a {5}	Fabric filter	2.3	3.0	4.2	10
BE020_a {2}	Fabric filter + cyclone	0.9	10.1	26.0	20
Source: [169, TWG 2021]					

Cross-media effects

Cupola furnaces

Dedusting systems produce a residual dust for disposal. 5 – 13 kg of dust are produced per tonne of liquid iron. The dust may be recirculated into the cupola. This is discussed in Section 3.2.1.4.5.6.

Technical considerations relevant to applicability

Generally applicable.

Economics

Cupola furnaces

Table 3.60 shows emission values and economic data. The most important operational cost factors are the electrical energy requirements for overcoming the pressure drop and for the filter material.

For a melting installation incorporating two cold blast cupolas with a melting rate of 4.5 t/h, a sales quotation was made with the following details:

- abatement equipment to treat up to 12 400 m³/h blast, with combustion chamber at a temperature of 820 °C accepting up to:
 - VOC – 1 g/Nm³;
 - CO – 59100 g/Nm³;
- two burners to be used with methane – Power/burner 390 kW

Installation and start-up price: EUR 350 000.

Foreseen running cost, considering a 4 500 tonne casting production, 5-year payment period plus 10 % for energy and maintenance per year: EUR 23.3/t.

Induction furnaces

The cost and consumption data for a bag filter installation on a melting unit of crucible induction furnaces, melting 15 t/h, able to treat 120 000 Nm³/h are given in Table 3.63.

Table 3.63: Investment cost and power consumption for a bag filter unit on induction furnaces, with varying final dust emission levels

Dust emission level (mg/Nm ³)	Investment cost (EUR)	Power consumption (kW)
<5	350 000	250
<20	200 000	150
NB: Data for Portugal 2003. Source: [120, TWG 2003]		

Driving force for implementation

Legal requirements.

Example plants

The mentioned techniques are generally applied in all European foundries.

Reference literature

[13, Batz, R. 1986], [14, CAEF 1997], [38, Vito 2001], [100, TWG 2002], [120, TWG 2003], [8, Rademacher, H. 1993], [102, Carnicer Alfonso, P. L 2001], [11, Brettschneider et al. 1992], [64, UK Environment Agency 2002]

3.2.2.2.1.9 Primary control measures to minimise PCDD/F emissions

Description

Primary control measures to minimise PCDD/F emissions (dioxins) in metal melting include the following:

- *Maximisation of the off-gas residence time and optimisation of the temperature in the post-combustion chamber in cupola furnaces:* In cupola furnaces, the temperature of the post-combustion chamber is optimised ($T > 850$ °C) and continuously monitored while the off-gas residence time is maximised (> 2 s).
- *Rapid off-gas cooling:* The off-gas is cooled rapidly from temperatures above 400 °C to below 250 °C before dust abatement to prevent the *de novo* synthesis of PCDD/F. This is achieved by appropriate design of the furnace and/or the use of a quench system.
- *Minimising dust build-up in heat exchangers:* The build-up of dust along the cooling trajectory of the off-gases is minimised, especially in the heat exchangers, e.g. by using vertical exchanger tubes, efficient internal cleaning of the exchanger tubes, high-temperature de-dusting.

Technical description

Dioxins are relevant for thermal processes which have metals present. Dioxins or their precursors may be present in some raw materials and there is a possibility of *de-novo* synthesis in furnaces or abatement systems. Dioxins are easily adsorbed onto solid matter and may be collected by all environmental media as dust, scrubber solids and filter dust. Field tests have shown that the formation of dioxins in cupola furnaces cannot be correlated to one (or a few single) operational parameter(s). A combination of measures is needed to minimise the risk of dioxin formation.

In-process or primary measures to prevent dioxin emissions include the following:

- Post combustion of the furnace off-gas in the CBC shaft or in a HBC combustion chamber. Combustion of cupola off-gas is fully described in Section 3.2.2.1.7.
- Continuous temperature monitoring and control in the HBC combustion chamber ($T > 850\text{ °C}$) and maximising of the residence time (preferably $>2\text{ s}$).
- Maintaining the particulate matter concentration in the recuperator at a level $< 20\text{ mg/m}^3$, this is possible for HBC when using wet dedusting.
- Providing quick quenching of the dust laden off-gases, through the *de-novo* synthesis temperature range of $250 - 450\text{ °C}$.
- Preventing or minimising the build-up of dust along the cooling trajectory of the flue-gas, especially in the heat-exchanger, e.g. using vertical exchanger tubes, efficient internal cleaning, high temperature de-dusting.
- Melting clean scrap. This technique is described in Section 3.2.1.7.2.
- Using oxygen injection to ensure complete combustion. This technique is described in Section 3.2.2.1.2.

Although dioxins are destroyed at high temperature (i.e. above 850 °C) in the presence of oxygen, the process of *de-novo* synthesis is still possible as the gases are cooled through the reformation window ($250-450\text{ °C}$). This window can be present in heat-exchangers or abatement systems and in cooler parts of the furnace, e.g. the feed area. Care must be taken in the design of cooling systems to minimise the residence time in the temperature window and to avoid dust build-up, in order to prevent *de-novo* synthesis. An alternative is to dedust the off-gas by quick quenching using a wet system. Sufficient oxygen also needs to be present in the hot gases and for this oxygen injection can be used to ensure complete combustion. Nevertheless, excess oxygen should be prevented since this may support *de-novo* synthesis.

Sulphur has an inhibiting effect on the formation of dioxins, through depletion of molecular chlorine. The use of coal with a higher sulphur content in large combustion plants has been shown to provide lower PCDD/F concentrations. The reducing inhibiting effect is related to the S/Cl ratio, with a critical ratio of 0.64. A further increase does not result in less dioxins and furans. This effect has not been demonstrated in foundries, but may be studied. [126, UNEP 2003]

The great spreading and big variability in the dioxin emission levels (even for the same installation) show that primary measures alone may not allow a stable and low dioxin emission value. Therefore, besides primary measures, secondary measures such as adsorption (see Section 3.2.2.2.1.12) may be employed.

Achieved environmental benefits

Reduction of the emission of dioxins and furans to air.

Environmental performance and operational data

In-process measurements of dioxins in a hot blast cupola with dry dedusting have shown that high PCDD/F levels (5 ngTEQ/Nm^3) occur in the heat-exchanger. Other parts of the flue-gas system show much lower values. Reduction measures should therefore aim at minimising the contact between dust and flue-gas in this zone, by minimising dust or reducing the dust residence time.

For a flue-gas rate of $8\ 000\text{ m}^3/\text{h}$ at a blast rate of $3\ 000\text{ m}^3/\text{h}$, quick quenching of the cupola off-gas from 800 °C to 150 °C requires a water consumption of $4\text{ m}^3/\text{h}$.

A PCDD/F emission level of 0.5 ng TEQ/Nm^3 can be achieved by using primary measures; and better than 0.5 ng TEQ/Nm^3 can be achieved by using one or more of these techniques. A German survey concluded that without secondary measures the level of 0.1 ng TEQ/Nm^3 is passed only in a limited number of installations and then only by a limited extent.

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable.

Economics

Primary measures do not involve additional investment costs. Operational costs are restricted to the use of oxygen or a higher price for cleaner scrap.

Driving force for implementation

- Regulation limiting PCDD/F emissions from the melting of metals.
- Reduction of organic and other hazardous gases in cupola emissions.
- Legal requirements.

Example plants

Widely used.

Reference literature

[1, COM 2017], [63, UK Environment Agency 2002], [100, TWG 2002], [119, Helber et al. 2000], [125, CAEF 2003], [169, TWG 2021]

3.2.2.2.1.10 Post-combustion of off-gases

More information on the technique

See Section 3.2.2.1.7.

3.2.2.2.1.11 Cyclone

More information on the technique

See Section 3.2.1.13.2.

Environmental performance and operational data

Cyclones can be used alone, but are often used in combination with other waste gas treatment techniques.

Reported data from 23 plants (30 EPs) using cyclones show a range for dust emissions from 0.1 mg/Nm³ to 62 mg/Nm³ with a median value of 1.4 mg/Nm³ and an average value of 3.31 mg/Nm³. [169, TWG 2021]

Example plants

Widely used.

Reference literature

[169, TWG 2021]

3.2.2.2.1.12 Adsorption

Description

The removal of pollutants from a process off-gas or waste gas stream by retention on a solid surface (activated carbon is typically used as the adsorbent). Adsorption may be regenerative or non-regenerative.

In foundries, this technique concerns in particular the end-of-pipe abatement techniques used to reduce PCDD/F emissions from metal melting.

General information on this technique is also provided in the CWW BREF [179, COM 2016].

Technical description

Besides primary measures to control PCDD/F emissions from metal melting, the following abatement measures may be considered:

- *Injection of additive powders* into the gas stream, such as activated carbon, open-hearth furnace coke or zeolite, so that dioxins are absorbed onto the surface. High efficiency dust filtration is then used to remove the dust and dioxins. The additive is injected into the off-gas stream before filtration. The adsorption process mainly takes place while the adsorbents adhere to the filter bag. The filter dust may be recirculated back to the flue-gas to attain a higher efficiency. When using a carbon-based additive, special measures should be taken to prevent fire and explosion risk. The collected dusts may have high dioxin concentrations and will need to be disposed of or treated carefully (a detailed example is presented below).
- *Catalytic oxidation* systems are available for the destruction of dioxins. Fabric filters that incorporate a catalytic layer are used for the destruction of dioxins. In other sectors (e.g. steel, municipal waste incineration) this technique has been implemented successfully and implementation in the foundry industry is considered feasible. However, in order to prevent deactivation of the catalyst layer, a prior removal of coarse dust particles may be needed.

Example of adsorbent injection (activated carbon) in an iron foundry in Germany

Adsorbents can be injected directly into the flue gasses upstream of a bag filter. Figure 3.65 shows such a plant (an iron foundry in Germany). The adsorbents are composed of a mixture of activated carbon and calcium hydroxide.

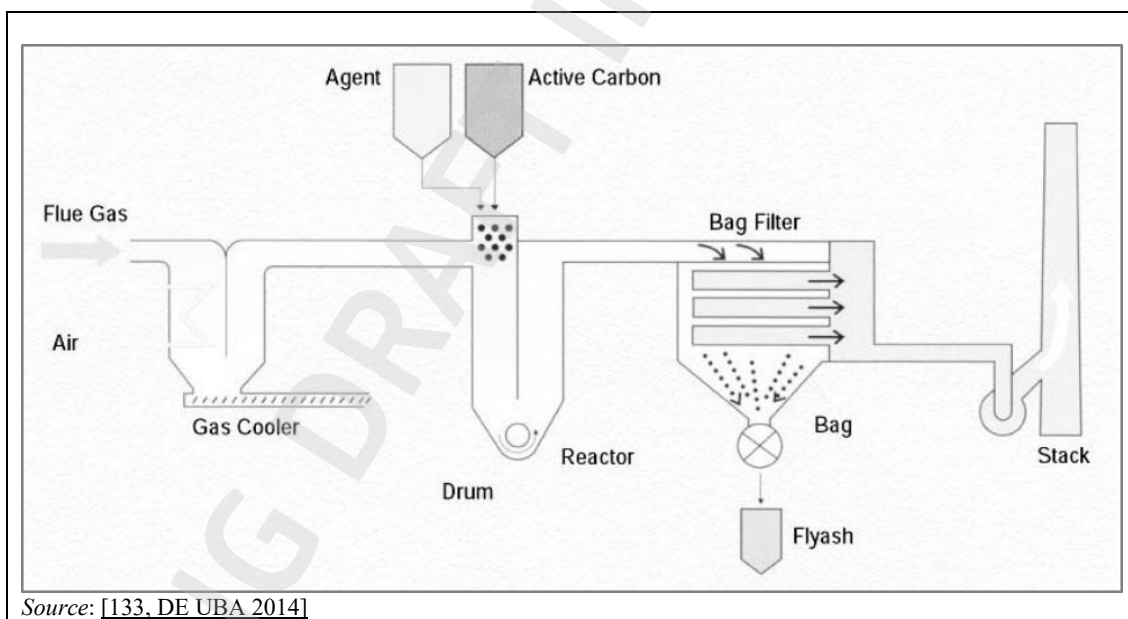


Figure 3.65: Injection of adsorbents

The injection system consists of a hopper with a dosing screw, which regulates the amount of adsorbent dosed to the gases. To facilitate the installation, the dosing system is placed at ground level. By means of a small blower and a flexible pipe, the adsorbents are transported into the flue-gas (Figure 3.66).



Source: [133, DE UBA 2014]

Figure 3.66: View of an installation for adsorbent injection

Achieved environmental benefits

Reduction of the emissions of PCDD/Fs to air.

Environmental performance and operational data

The injection of additives into the flue-gases of a cupola furnace results in a significant reduction of PCDD/Fs in the off-gases. In addition, the concentration of other hazardous substances such as heavy metals is also reduced due to the subsequent fabric filter dust abatement system.

The dose of additives were optimised during a research project (DIOFUR) where the addition dose was fixed at 150 mg/Nm³ (dry). In particular, activated carbon injection was tested in the project using a coke-based adsorbent with a high ash content suitable for high-temperature applications. PCDD/F emissions were measured after the heat exchanger (before adsorbent injection) and at the stack (after adsorbent injection). The results are summarised in Table 3.64.

Effective adsorption of PCDD/Fs was achieved; in addition, the adsorbent did not induce any safety issues (e.g. glow fires). The burning behaviour of this material at 20 °C and 100 °C was reported as ‘brief ignition and rapid extinction’ and its ignition temperature was 800 °C. This material was not glowing at temperatures up to 450 °C, therefore minimising potential safety concerns from the use of organic substances in high-temperature waste gas streams. [180, DIOFUR, 2010]

Table 3.64: PCDD/F and dust emission measurements after the heat exchanger and at the stack in the case of active carbon injection for a cupola furnace

Measurement date	13/11/2007		14/11/2007		15/11/2007	
Parameter	After heat exchanger	Stack	After heat exchanger	Stack	After heat exchanger	Stack
Total PCDD/Fs (ng I-TEQ/Dry Nm ³)	6.7	0.11	2.7	0.04	11.9	0.21
Dust (mg/Dry Nm ³)	NI	32	NI	107	NI	106

In the case of the German iron foundry (presented above) with a cold blast cupola and a capacity of 12 – 14 t liquid iron per hour, the injection rate of additive was 0.1 kg to 0.4 kg per tonne of liquid iron. The energy consumption was 4 kW for blowing 500 m³/h air containing the adsorbents into the raw gases of the cupola furnace.

Cross-media effects

The adsorption of dioxins and furans on activated carbon generates a PCDD/F-loaded dust stream. In order to prevent the explosion risk in the bag filter, mixing of the activated carbon with lime may be needed. This will increase the total amount of residue for disposal (in the case of the German iron foundry described previously, the amount of dust for disposal rose from 0.1 kg to 0.4 kg per t of liquid iron) and limits the possibility to reuse the filter dust.

The DIOFUR project concluded that the contribution of adsorbents to the overall dust amount originating from the gas cleaning is negligible. This means that the disposal costs for filter dust do not rise significantly from the use of adsorbent.

Technical considerations relevant to applicability

General additive injection is considered a technique that is compact, efficient and can be easily integrated in new and existing installations when space requirements are fulfilled. It is also applicable in hot and cold blast cupolas.

The application of catalytic filtration involves the least technical modification for existing plants, since only the filter bags need to be replaced by the catalytic type.

Economics

Economic data from the DIOFUR project showed that the investment costs for the installation of an activated carbon injection unit (2009 prices) were estimated at EUR 35 000 for a plant with a production capacity of 45 000 t per year. In this estimation, the following elements were not included:

- work of civil engineering such as the building of concrete bases, mural drilling etc.;
- protection of the material (electric instruments, detections etc.);
- the access for the crane and the elevators (nacelles) on the building site;
- the cable of power for electrical equipment box.

Driving force for implementation

- Regulation limiting PCDD/F emissions from the melting of metals.
- Reduction of organic and other hazardous gases in cupola emissions.
- Legal requirements.

Example plants

Foundry Fiday Gestion (France) [180, DIOFUR, 2010]

Reference literature

[1, COM 2017], [63, UK Environment Agency 2002], [100, TWG 2002], [119, Helber et al. 2000], [125, CAEF 2003], [133, DE UBA 2014], [180, DIOFUR, 2010]

3.2.2.2.1.13 Dry scrubbing

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. SO₂) to form a solid, which is removed by filtration (e.g. fabric filter).

Further information is provided in the CWW BREF [179, COM 2016].

Environmental performance and operational data

Reported data from two plants (2 EPs) using dry lime injection show a range for SO₂ emissions from 57 mg/Nm³ to 214 mg/Nm³. [169, TWG 2021]

Example plants

DE076, FR111 and FR120.

Reference literature

[169, TWG 2021], [179, COM 2016]

3.2.2.2.1.14 Fabric filter

More information on the technique

See Section 3.2.1.12.7.

Environmental performance and operational data

Fabric filters are used alone or in combination with other off-gas treatment techniques.

Reported data from 81 plants (112 EPs) using fabric filters show a range for dust emissions from 0.02 mg/Nm³ to 26 mg/Nm³ with a median value of 1 mg/Nm³ and an average value of 2.1 mg/Nm³ [169, TWG 2021].

Example plants

Widely used.

Reference literature

[169, TWG 2021]

3.2.2.2.1.15 Wet scrubbing

More information on the technique

See Section 3.2.1.13.4.

Environmental performance and operational data

Wet scrubbing is used alone or in combination with other waste gas treatment techniques.

Reported data from nine plants (12 EPs) using wet scrubbing show a range for dust emissions from 0.8 mg/Nm³ to 62 mg/Nm³ with two outlier values of the order of 1 120 mg/Nm³ and 2 560 mg/Nm³ [169, TWG 2021]

Example plants

AT015, DE041, DE046, DE050, DE051, DE062, DE070, PL138 and SE150.

Reference literature

[169, TWG 2021]

3.2.2.3 Emissions to air from nodularisation of cast iron

3.2.2.3.1 Nodularisation with no magnesium oxide emissions

Description

Use of the in-mould process whereby the magnesium alloy is added as a tablet, directly into the mould cavity, and the nodularisation reaction takes place during moulding.

Technical description

The in-mould process is the only nodularisation technique without flue-gas production. In this process, the magnesium alloy is added as a tablet in the mould cavity. The reaction takes place *in situ* and no magnesium oxide emissions are generated.

Achieved environmental benefits

No emissions of magnesium oxide during the nodularisation of cast iron.

Environmental performance and operational data

No data reported.

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable.

Economics

No information provided.

Driving force for implementation

Reduction of magnesium oxide emissions from nodularisation of cast iron.

Example plants

BE021, IT 126

Reference literature

[63, UK Environment Agency 2002], [38, Vito 2001]

3.2.2.3.2 Off-gas extraction as close as possible to the emission source**Description**

When magnesium oxide emissions are generated from the nodularisation technique used (e.g. sandwich, ductilator), off-gases are extracted as close as possible to the emission source using a fixed or movable extraction hood.

Technical description

The type of exhaust collection applied depends on the technique used for nodularisation (see Section 2.2.4.12.4). Depending on the technique, significant amounts of MgO can be released as a white smoke. Properties of the various nodularisation techniques are given in Table 2.14. In general techniques with a higher take-up efficiency result in lower emissions.

For 'in-ladle' nodularisation, techniques using a lid or cover result in a significant reduction of the emission.

If the nodularisation off-gas is not captured, this could result in the melting shop filling-up with a white smoke, and MgO dust drop out. Exhausting without filtration can result in a visible emission from the foundry. A large volume of visible particulate can be generated in a relatively short period of time, but usually only lasts for a short duration (5 to 10 minutes for each batch treated).

In-ladle nodularisation may be performed at a specific stand or location in the melting shop. The ladle with the molten metal is brought to this point after pouring, but before taking it to the casting furnace or station. This allows the installation of a fixed hood for exhaust capture.

The collection of the MgO fume is hampered by the fact that the gases are very hot and that the intensive Mg reaction causes sparks. Due to the high upward velocity and temperature large quantities of surrounding air need to be extracted as well. This requires a large-sized, and high cost, installation.

Dry filtration (using bag filters) of the exhaust gas results in a MgO powder that may be re-used in pigments or for refractory material production.

Achieved environmental benefits

- Reduced emissions of magnesium oxide during the nodularisation of cast iron.
- Mg has no harmful effect on the environment and is an essential nutrient for animals and plants in small concentrations. In the UK, the occupational exposure limits give a long-term exposure limit (8-hour TWA) of 4 mg/m³ for MgO dust and respirable fume (expressed as Mg).

Environmental performance and operational data

A typical addition rate for magnesium to the melt is around 0.1 % of the melt weight, measured as magnesium (the actual addition of magnesium containing alloy, such as magnesium ferrosilicon, could be up to 2 % of the melt weight according to the alloy used).

This addition provides about 0.05 % of the magnesium in the melt, most of the remainder oxidises and escapes to atmosphere as MgO, where it will agglomerate fairly rapidly in the air. Where there is no fume capture, the fumes can spread through the foundry and a proportion will drop out in the foundry as dust. There is no accurate information available on this amount but a reasonable figure may be 50 % of the fume released. Therefore, for each tonne of metal treated there would be around 500 g of magnesium released to air at the ladle as MgO (i.e. 833 g of MgO released per tonne of metal treated) and about 400 g of MgO released to the external atmosphere.

Emissions data from plants in the data collection are summarised in Section 2.3.

Cross-media effects

Capture of the magnesium oxide fume requires an increased energy use and therefore results in increased emissions from energy production.

Technical considerations relevant to applicability

The technique of exhaust capture and filtration applies for foundries using in-ladle nodularisation techniques.

Economics

In applying this technique, the extraction required to successfully capture most of the MgO emissions from the treatment ladle would be around 280 m³/min. The combined capital and installation costs per foundry would be around EUR 180 000.

Table 3.65 below summarises the financial data for an ‘average foundry’, with the costs amortised over the presumed 10-year lifespan of the extraction and abatement equipment.

Table 3.65: Cost calculation for MgO fume abatement

Extraction rate m ³ /min	Production rate tonne/h	Costs EUR		Power kW	Costs EUR/tonne of iron treated		
		Capital	Civil		Running	Financial	Total
280	0.5	180280	23514	50	21.95	29.35	51.30
	(1000 tonnes per year)						

Note:

Civil costs are taken as 15 % of capital costs. Running costs are based on maintenance and waste disposal costs and are equivalent to 10 % of capital costs and power at EUR 0.06/kWh. Financial costs are based on the plant being amortised over ten years with interest charges of 10 %.

Source: [63, UK Environment Agency 2002]

The costs for abatement of the magnesium oxide fume emissions are estimated at about EUR 51.30 per tonne of metal treated.

Driving force for implementation

Legal requirements.

Example plants

- Ductilator method: AT004.
- Core wire injection: AT017, IT132, PL138, BE022, BE023, DE042, DE045, DE056, ES100, FR110, IT071, IT124 and PL135.
- Sandwich method: PT141, PT140, IT130, FR104, ES095, DE060, FI102 and ES088.
- Tundish cover method: AT009, DE039, ES082, FR109, IT131, IT158, SE144, SE145 and SE152.
- G Fisher converter method: DE050, DE049 and DE051.
- Pour over method: BE019, CZ156, DE041, DE048, ES091 and IT 124.

Reference literature

[63, UK Environment Agency 2002], [38, Vito 2001], [169, TWG 2021]

3.2.2.3.3 Fabric filter**More information on the technique**

See Section 3.2.1.12.7.

Description

The magnesium oxide collected may be reused for the production of pigments or refractory materials.

Environmental performance and operational data

Fabric filters are used alone or in combination with other off-gas treatment techniques.

Reported data from five plants (5 EPs) using fabric filters show a range for dust emissions from 0.4 mg/Nm³ to 4.2 mg/Nm³ with 4 out of 5 EPs with values lower than 1 mg/Nm³ [169, TWG 2021].

Example plants

BE022, DE039, ES088, IT071 and IT132.

Reference literature

[169, TWG 2021]

3.2.3 Techniques to consider in the determination of BAT for steel foundries

3.2.3.1 Emissions to air from thermal processes

3.2.3.1.1 Rapid off-gas cooling

Description

The off-gas is cooled rapidly from temperatures above 400 °C to below 250 °C before dust abatement to prevent the de novo synthesis of PCDD/F. This is achieved by appropriate design of the furnace and/or the use of a quench system.

More information can be found in Section 3.2.2.2.1.9.

3.2.3.1.2 Minimising dust build-up in heat exchangers

Description

The build-up of dust along the cooling trajectory of the off-gas is minimised, especially in the heat exchangers, e.g. by using vertical exchanger tubes, efficient internal cleaning of the exchanger tubes, high-temperature de-dusting.

More information can be found in Section 3.2.2.2.1.9.

3.2.3.1.3 Off-gas extraction as close as possible to the emission source

Description

The off-gases from induction furnaces are extracted, for example using:

- hood extraction (e.g. canopy or side-draught hoods);
- lip extraction;
- cover extraction.

The off-gases from EAFs are extracted, for example using:

- partial furnace enclosures (mobile or fixed) mounted around the furnace and tapping area;
- total furnace enclosure using a complete room enclosure around the furnace and tapping area equipped with a moveable roof for charging/tapping operations;
- hood extraction (e.g. roof-mounted, canopy or side-draught hoods);
- direct extraction through the fourth hole in the furnace roof.

Technical description

Induction furnaces

Off-gas extraction systems for induction furnaces are described in Section 3.2.2.2.1.8.

Electric arc furnaces (EAFs)

Particulate matter from an EAF is very fine and difficult to capture. The capture of smoke and dust is the most difficult problem to solve when installing a dust arrestment system on an electric arc furnace. There are several methods that offer different advantages and disadvantages. Figure 3.67 depicts the principle of roof mounted hoods, side-draught hoods and fourth-hole evacuation.

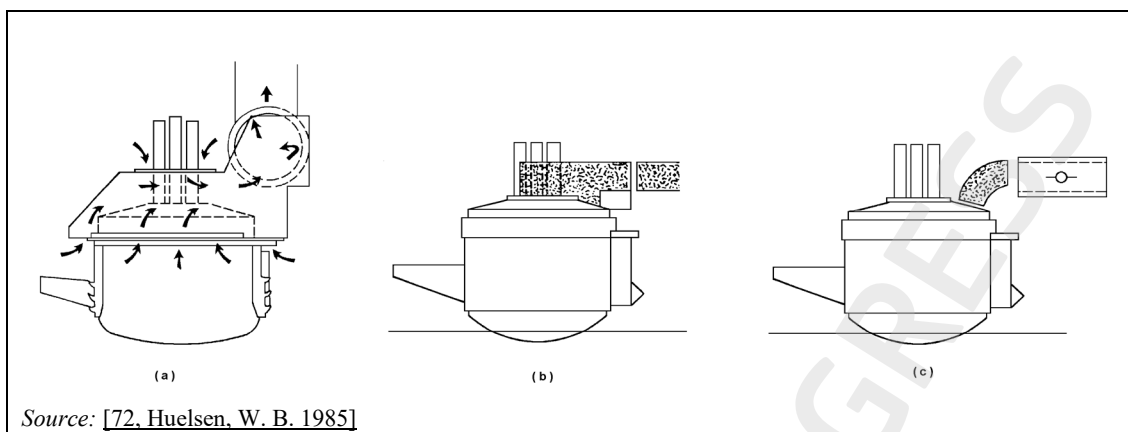


Figure 3.67: Principle drawings of (a) a roof mounted hood, (b) a side-draught hood, and (c) direct evacuation through a fourth-hole

- Roof mounted hoods:** A hood is fixed on the furnace roof and collects fumes through a gap between the furnace shell and the roof. In addition, fumes arising from the working door and the tap-hole are also captured. Roof mounted hoods are heavy and subject to distortion from heat. If fitted to an existing EAF, problems may arise due to increased structural load of the roof lifting and rotating mechanism. Typical extraction rates for this system are 7 500 Nm³/tonne to 15 000 Nm³/tonne.
- Side-draught hoods:** A hood is mounted on the furnace roof and collects the fumes emitted through the electrode ports. Vanes direct the airflow towards the hood. Additional hoods above the working door and the tapping-hole are used to capture emissions at these locations. Higher extraction rates are necessary here, compared to roof mounted hoods, as high air draught velocities are needed to capture the fumes. Some leakage of pollutants to the plant atmosphere can be expected, unless a tight seal is maintained. It has been reported that side-draught hoods increase electrode consumption.
- Canopy hoods:** A large exhaust hood is placed over the complete furnace, and above the charging system. This creates a large gap between the furnace and the extraction system, making it difficult to control the rising smoke and dust, even when using high extraction rates. Cross-draughts can seriously distort the collection efficiency. These disadvantages make the use of these collection systems unattractive.
- Direct furnace or 'fourth-hole' extraction:** The fumes are collected through a water-cooled or refractory-lined duct connected to a fourth-hole in the furnace roof. Ambient air is aspirated through a joint in the ductwork, thus providing oxygen to burn the CO gas in the undiluted and hot offtake gas. This prevents explosions in the dust collecting system. The dimensions of the combustion chamber are very critical in order to guarantee sufficient combustion at all stages of the melting cycle. The burnt gas (900 °C) is cooled downstream by dilution with ambient air, water injection, heat-exchangers (water jackets) or by the use of long ducts. This cooling process is needed to protect the dust filter equipment. The use of a pressure control system in the furnace allows a relatively small extraction rate at the furnace at 2 000 Nm³/tonne to 4 000 Nm³/tonne. Electrode consumption is generally higher due to the effect of oxidation. Direct furnace evacuation using a fourth-hole is usually limited to big electric arc furnaces, as the roof must be big enough to accommodate a fourth-hole without any structural weakening. The technique is not applied for iron melting, because the in-flow of fresh air generates an excessive oxidation of carbon.
- Partial furnace enclosure:** Mobile or fixed enclosures are mounted around the furnace and tapping area. The former are retracted in order to accommodate charging and tapping, while the latter are equipped with a mobile roof and side-walls for the same purpose. Exhaust gases are collected through a main exhaust duct at the top of the enclosure, assisted by fans inside the duct to guide the fumes to the exhaust. With these types of system collection, efficiencies of up to 98 % are possible.
- Total furnace enclosure:** This system consists of a large fixed evacuated room completely surrounding the melting furnace and ladle pit. The enclosure is equipped with a movable roof

and/or with side panels to accommodate both charging and tapping operations. These may be equipped with air curtains to reduce gas losses. Disadvantages of the technique are the high temperatures and noise levels inside the enclosure. However, the advantages include low outside noise levels and low energy consumption. The energy consumption is estimated to be 30 % to 50 % less than that required for a canopy hood.

Achieved environmental benefits

Flue-gas capture allows the controlled evacuation and treatment of the flue-gas stream, and results in a minimisation of both fugitive and channelled emissions.

Environmental performance and operational data

Table 3.66 provides typical exhaust flow rates and removal efficiencies for various capture systems.

Table 3.66: Typical exhaust flowrates (in m³/s) and particulate removal efficiency of EAF exhaust capture systems

	Exhaust flowrate for given furnace capacity			Particulate removal efficiency (%)	
	3.9 t/h	9.1 t/h	22.7 t/h	Range	Typical max.
Side-draught hood	12.9	19.8	50.00	90 – 100	99
Roof hood	7.7	11.9	30.00	95 – 100	99
Direct evacuation	3.2	5.0	12.5	90 – 100	99
Total enclosure			35 – 42		
<i>Source: [72, Huelsen, W. B. 1985]</i>					

In a Polish foundry, the installation of a total enclosure over two EAFs with a capacity of 8.5 tonnes each resulted in a reduction of the noise level from melting from 91 dBA to less than 85 dBA.

Cross-media effects

Capturing the exhaust increases the energy consumption. As it allows the cleaning of the exhaust gas, it will also generate dust for disposal or reuse.

Technical considerations relevant to applicability

Generally applicable.

Economics

The construction and assembly of a doghouse over two EAFs with a capacity of 8.5 tonnes each, involved an investment of EUR 275 000 (1996 prices), excluding costs for further refurbishment of the ducting and filtration system.

Driving force for implementation

- Workers-health-related prevention measures. It allows application of a gas cleaning technique by guiding the exhaust gas flow.
- Legal requirements.

Example plants

Doghouse: Metalodlew Foundry, Krakow (PL)

Off-gas collection: Metso Lokomo Steels and Sulzer Pumps Karhula Foundry (FI)

Reference literature

[13, Batz, R. 1986], [14, CAEF 1997], [72, Huelsen, W. B. 1985], [97, Metalodlew s.a. 2002], [169, TWG 2021]

3.2.3.1.4 Cyclone

More information on the technique

See Section 3.2.1.13.2.

Environmental performance and operational data

Cyclones can be used alone, but are often used in combination with other waste gas treatment techniques.

Reported data from two plants (2 EPs) using cyclones show a range for dust emissions from 8.7 mg/Nm³ to 11.6 mg/Nm³. [169, TWG 2021]

Example plants

ES089 and PL135.

Reference literature

[169, TWG 2021]

3.2.3.1.5 Fabric filter

More information on the technique

See Section 3.2.1.12.7.

Environmental performance and operational data

Fabric filters are used alone or in combination with other off-gas treatment techniques.

Reported data from 15 plants (18 EPs) using fabric filters show a range for dust emissions from 0.02 mg/Nm³ to 8.7 mg/Nm³ with a median value of 0.7 mg/Nm³ and an average value of 1.24 mg/Nm³ [169, TWG 2021].

Example plants

AT011, AT016, CZ156, DE043, DE044, DE068, DE069, DE073, ES097, FI103, FR104, IT129, PL135, SE146 and SE149.

Reference literature

[169, TWG 2021]

3.2.3.2 Emissions to air from steel refining

3.2.3.2.1 Off-gas extraction as close as possible to the emission source

Description

Off-gases from steel refining (e.g. from Argon Oxygen Decarburisation (AOD) or Vacuum Oxygen Decarburisation (VOD) converters) are extracted using for example a direct extraction hood or a roof canopy combined with an accelerator stack. Extracted off-gases are treated using a fabric filter (see Section 3.2.3.2.2).

Technical description

Fume control hoods for AOD vessels come in a great variety of shapes and sizes. The alternative to the direct extraction hood is the roof canopy. Roof canopies are in use in several AOD plants and efficiently capture both AOD process fumes and smoke from other operations such as charging and tapping. These roof canopies may be used in conjunction with accelerator stacks over the AOD mouth. The accelerator stack performs several useful functions, including forming a more coherent plume out of the AOD, reducing the size of canopy required, and shielding the surrounding equipment and personnel from the sometimes intense radiation of the AOD flame.

The main advantage of the roof canopy is the capture of both process and fugitive effluents in the same hood.

Achieved environmental benefits

Flue-gas capture allows controlled evacuation and treatment of the flue-gas stream, and results in a minimisation of both fugitive and guided emissions.

Environmental performance and operational data

See data summarised in Section 2.3.

Cross-media effects

Exhaust gas cleaning increases the energy consumption. The dedusting of the exhaust gas generates dust for disposal or re-use.

Technical considerations relevant to applicability

This technique is applicable to all new and existing AOD installations.

Driving force for implementation

Legal requirements.

Example plants

- AOD converters: FR104, DE068, AT017.
- VOD converter: FI103.

Reference literature

[100, TWG 2002]

3.2.3.2.2 Fabric filter

More information on the technique

See Section 3.2.1.12.7.

3.2.4 Techniques to consider in the determination of BAT for NFM foundries

3.2.4.1 Energy efficiency

3.2.4.1.1 Molten metal circulation in reverberatory furnaces

Description

A pump is installed on reverberatory furnaces to force the circulation of molten metal and minimise the temperature gradient throughout the molten bath (from top to bottom).

Technical description

The addition of a molten metal circulation pump can considerably improve the performance of reverberatory furnaces as heat is transferred from the surface of the metal bath throughout the bath more efficiently. Forcing circulation will result in lower temperature variations. It is claimed that the typical temperature variation (from top to bottom) in a 1-metre-deep reverberatory furnace without molten metal circulation ranges from 50 °C to 85 °C, and it can be decreased by 3-7 °C with the addition of a circulation pump. Since the metal is melted faster, energy can be saved or the capacity increased.

Another benefit from the use of a circulation pump is the reduced melt loss; dross formation will decrease due to the lower surface bath temperature. Metal melt loss can be decreased by about 1 %. In addition, sludge formation also decreases due to the greater temperature homogeneity.

Achieved environmental benefits

- Increased energy efficiency.
- Decreased dross formation.

Environmental performance and operational data

Molten metal circulation has the potential to decrease the energy use by 10 – 15 %.

Energy use in a well-designed and fully utilised fuel-fired, radiant roof-fired furnace with 100 % cold metal charging is about 830 kcal/kg (33 % efficiency). Enhancing the lining, adding a slow preheat hearth and molten metal circulation can decrease the energy use to about 680 kcal/kg (41 % efficiency). In addition, adopting recuperative burners will reduce the energy use to 600 kcal/kg (46 % efficiency) while adopting regenerative burners will reduce the energy use further to 520 kcal/kg (53 % efficiency).

In the case of an electric radiant roof reverberatory furnace with an energy use of 420 kcal/kg, the addition of molten metal circulation will reduce the energy use to about 380 kcal/kg.

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable.

Economics

The typical cost of adding a pump well to a large furnace ranges between EUR 24 500 and EUR 31 500 (2011 data) depending on the size of the furnace. The cost of the circulation pump adds another EUR 24 500 to EUR 30 000 (2011 data). The return on investment for a typical circulation pump and a well is estimated from 24 to 28 months.

Driving force for implementation

Energy efficiency.

Example plants

No information provided.

Reference literature

[145, US EPA 2016]

3.2.4.1.2 Minimisation of energy losses by radiation in crucible furnaces**Description**

Crucible furnaces are covered using a lid and/or equipped with radiant panel linings to minimise energy losses by radiation.

Technical description

About 60 % of the energy input in gas-fired crucible furnaces is lost due to radiation. In cases where furnaces are unsealed, covering the furnace with a lid would result in a significant reduction in energy losses. This measure is relatively easy to implement and will reduce melting time and energy use significantly.

Where radiation losses cannot be controlled by sealing the crucible furnace with a lid, an option is to equip the furnace with radiant panels. Radiant panels are made from alumina and reduce the radiation that leaves the crucible. The alumina panels have a special structure with a high surface area and need to be backed up with insulation material, such as alumina, that exhibits high thermal conductivity.

Achieved environmental benefits

Increased energy efficiency.

Environmental performance and operational data

It was predicted that radiant panels might improve furnace energy efficiency by 30 %. A study by Case Western Reserve University showed that the energy efficiency of a natural-gas-fired crucible was raised from 8 % to 16 % by installing improved gas burners and radiant panels. It was estimated that each of the two measures were equally responsible for the efficiency improvement. This means that the installation of radiant panels reduced natural gas consumption by 4 – 8 %.

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable.

Economics

The installation costs for the panels were about EUR 2 800 per crucible (2007 data). Whether this can be economically justified needs to be evaluated on a case-by-case basis.

Driving force for implementation

Energy efficiency.

Example plants

No information provided.

Reference literature

[145, US EPA 2016]

3.2.4.2 Emissions to air from thermal processes

3.2.4.2.1 Emissions to air from metal melting

3.2.4.2.1.1 Rapid off-gas cooling

Description

The off-gas is cooled rapidly from temperatures above 400 °C to below 250 °C before dust abatement to prevent the de novo synthesis of PCDD/F. This is achieved by appropriate design of the furnace and/or the use of a quench system.

More information can be found in Section 3.2.2.2.1.9.

3.2.4.2.1.2 Minimising dust build-up in heat exchangers

Description

The build-up of dust along the cooling trajectory of the off-gas is minimised, especially in the heat exchangers, e.g. by using vertical exchanger tubes, efficient internal cleaning of the exchanger tubes, high-temperature de-dusting.

More information can be found in Section 3.2.2.2.1.9.

3.2.4.2.1.3 Off-gas extraction as close as possible to the emission source

Description

Off-gases from shaft, crucible, resistance, reverberatory (hearth-type) and radiant roof furnaces are extracted using hood extraction (e.g. canopy hoods). The extraction equipment is fitted in such a way that it enables the capture of emissions during pouring.

Off-gases from induction furnaces are extracted, for example using:

- hood extraction (e.g. canopy or side-draught hoods);
- lip extraction;
- cover extraction.

Off-gases from rotary furnaces are extracted, for example using hood extraction.

Technical description

Induction furnaces

See Section 3.2.2.2.1.8.

Shaft, crucible, resistance, reverberatory and radiant roof furnaces

Off-gases are collected using hood extraction (e.g. canopy hoods). For tilting furnaces (e.g. reverberatory, rotary), the extraction system is fitted to accommodate the capture of emissions when tapping the furnace.

Rotary furnaces

See Section 3.2.2.2.1.8.

Achieved environmental benefits

Flue-gas capture allows controlled evacuation and treatment of the flue-gas stream, and results in a minimisation of both fugitive and channelled emissions.

Cross-media effects

Some aluminium foundries melt material recovered from the electrolysis of aluminium. In this instance, inorganic pollutants such as hydrogen fluoride may be formed. These can be cleaned from the flue-gas using a chemisorption step, which can be added onto the dust abatement system. In this treatment, calcium hydrate or aluminium oxide can be used as the adsorbant.

Technical considerations relevant to applicability

Generally applicable.

Economics

No information provided.

Driving force for implementation

- Regulations concerning emissions to air.
- Legal requirements.

Example plants

Some NFM example plants from the SF data collection are summarised below [169, TWG 2021]:

- Induction furnaces (electric coreless): DE078, ES081, PL137 and SE148.
- Crucible furnaces: AT007, AT008, DE034, DE072, ES086, ES093, FI101 and PT142.
- Resistance furnaces: ES099, FR108 and FR116.
- Reverberatory (hearth-type): AT002, DE075, , ES086, ES087 and IT133.
- Radiant roof: FR116 and IT154.
- Rotary furnaces: AT005 and IT127.

Reference literature

[169, TWG 2021].

3.2.4.2.1.4 Cyclone

More information on the technique

See Section 3.2.1.13.2.

Environmental performance and operational data

Cyclones can be used alone, but are often used in combination with other waste gas treatment techniques.

Reported data from three plants (5 EPs) using cyclones show a range for dust emissions from 0.6 mg/Nm³ to 30.7 mg/Nm³ with 3 out of 5 EPs with values lower than 4.7 mg/Nm³ [169, TWG 2021].

Example plants

DE064 and SE148.

Reference literature

[169, TWG 2021]

3.2.4.2.1.5 Dry scrubbing

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. SO₂) to form a solid, which is removed by filtration (e.g. fabric filter).

Further information is provided in the CWW BREF [179, COM 2016].

Example plants

DE034.

Reference literature

[169, TWG 2021], [179, COM 2016]

3.2.4.2.1.6 Fabric filter

More information on the technique

See Section 3.2.1.12.7.

Environmental performance and operational data

Fabric filters are used alone or in combination with other off-gas treatment techniques.

Reported data from eight plants (18 EPs) using fabric filters show a range for dust emissions from 0.4 mg/Nm³ to 15.4 mg/Nm³ with a median value of 6.5 mg/Nm³ and an average value of 6.12 mg/Nm³ [169, TWG 2021].

Example plants

AT008, DE048, DE064, DE072, FR116, IT127, IT154 and PL137.

Reference literature

[169, TWG 2021]

3.2.4.2.1.7 Wet scrubbing

More information on the technique

See Section 3.2.1.13.4.

Environmental performance and operational data

Wet scrubbing is used alone or in combination with other waste gas treatment techniques.

Reported data from 4 plants (5 EPs) using only wet scrubbing show a range of reported maximum concentrations for dust emissions from 11 mg/Nm³ to 42 mg/Nm³ [169, TWG 2021].

Example plants

AT015, DE041, DE070 and SE150.

Reference literature

[169, TWG 2021]

3.2.4.3 Emissions to air from the treatment and protection of molten metal

3.2.4.3.1 Optimised degassing/cleaning of molten aluminium

Description

A mobile or fixed rotary impeller degassing station is used to remove hydrogen gas from the melt. In most cases, this is achieved through a simple degassing treatment using argon or nitrogen gas without chlorine gas.

In a combined degassing and cleaning process, gas mixtures of argon and chlorine or nitrogen and chlorine are introduced into the melt. In this case, the chlorine concentration in the carrier gas is optimised to ensure good cleaning and low chlorine emissions..

Technical description

The degassing of aluminium is needed to remove hydrogen from the melt. The removal or reduction of small amounts of undesirable elements and impurities necessitates treatment of the melt with halogens, such as chlorine, fluorine or bromine. This treatment is referred to as cleaning, and is usually combined with the degassing treatment.

Adequate degassing with physically operating treatment processes does not achieve sufficient cleaning in most aluminium castings. Vacuum degassing achieves a very low hydrogen content in the melt but, at the same time, the lower number of nuclei means that crystallisation is less effective.

In a combined degassing and cleaning process, gas mixtures of argon and chlorine or nitrogen and chlorine are introduced into the melt. The chlorine concentration in the carrier gas must be optimised in order to ensure good cleaning as well as low emissions. In most cases, only a degassing treatment is necessary. This treatment is done without Cl₂-gas. Depending on the treatment vessel, the efficiency of the degassing can be improved with porous plugs and impellers.

In some isolated cases, an Ar/SF₆-mixture has been used. The latter is a greenhouse gas with a high global warming potential, which falls under the Kyoto protocol.

Achieved environmental benefits

The use of an impeller with Ar/Cl₂ or N₂/Cl₂ avoids the use of hexachloroethane in the cleaning treatment of aluminium. The use of hexachloroethane has been banned since 30 June 2003 in the EU.

Environmental performance and operational data

A mixture of nitrogen with 3 % Cl₂ is generally used for combined degassing and cleaning. For degassing only, Cl₂ is not necessary.

A mobile impeller station can be used for holding furnaces and ladles of 50 – 250 kg of Al. The treatment takes 3 to 5 minutes. A metal treatment unit is used for capacities from 400 kg to 1000 kg Al. The melt is treated for 1.5 to 5 minutes with a gas flow between 8 litres/minute and 20 litres/minute. The graphite rotor has a life of 100-150 treatments, depending on the temperature of the melt.

Cross-media effects

None.

The application of this type of degassing unit has allowed an end to using hexachloroethane for degassing and cleaning purposes.

Technical considerations relevant to applicability

Generally applicable.

Impeller stations have been developed for holding furnaces and ladles from 50 kg to 1 000 kg of molten aluminium.

Economics

Investment costs are given Table 3.67.

Table 3.67: Investment costs for an impeller station

Description	Cost (EUR)
Impeller plant including accessories	15 000
Facilities for mixing of argon gas with chlorine	40 000
Total	55 000
<i>Source: [77, Wenk, L. 1995]</i>	

Driving force for implementation

- European Directive 97/16/EC prohibiting the use of hexachloroethane in the manufacturing or processing of non-ferrous metals.
- Legal requirements.

Example plants

The technique is commonly applied in aluminium foundries.

In the SF data collection, the following informations were reported: [169, TWG 2021]

- two plants (IT154 and SE148) reported the use of Ar-Cl₂ as a degassing agent;
- one plant (DE048) reported the use of N₂-Cl₂ as a degassing agent.

Reference literature

[74, Brown, J. R. 1999], [77, Wenk, L. 1995], [169, TWG 2021]

3.2.4.3.2 Selection of oxidation control agents with a low global warming potential in magnesium melting

Description

Oxidation control agents (covering gases) used in magnesium melting are selected by considering their global warming potential. Gas mixtures with a low environmental impact include:

- SO₂;
- gas mixtures of N₂, CO₂ and/or SO₂;
- gas mixtures of argon and SO₂.

The use of SO₂ results in the formation of a protective layer composed of MgSO₄, MgS and MgO.

Technical description

According to Article 13 of Regulation (EU) No 517/2014 on fluorinated greenhouse gases, the use of sulphur hexafluoride in magnesium die-casting and in the recycling of magnesium die-casting alloys is prohibited. As regards installations using a quantity of sulphur hexafluoride below 850 kg per year, in respect of magnesium die-casting and in the recycling of magnesium die-casting alloys, this prohibition has been valid since 1 January 2018.

Gas mixtures containing HFC-134a (CF₃CH₂F) and Novec 612 (perfluoroketone, C₃F₇C(O)C₂F₅) have been successfully tested. Research is on-going on the applicability of both compounds. HFC-134a falls under the restrictions of the Kyoto protocol. Both compounds show a lower global warming potential than SF₆: SF₆ GWP = 23900; HFC-134a GWP = 1300; Novec 612 GWP = 1.

Information from industry states that German foundries have applied the following cover gases/mixtures: N₂ + R134a, N₂ + CO₂ + SO₂, N₂ + SO₂, SO₂, S/Ar.

The use of R134a (1,1,1,2-tetrafluoroethane) results in a MgF₂ protective layer. The use of SO₂ (sulphur dioxide) to form MgSO₄, MgS and MgO phases. However, different companies have introduced different 'philosophies'.

Until 2005, SO₂ was a viable alternative. Some magnesium foundries have long experience with this gas, and never turned to SF₆ when this gas was first introduced at the beginning of the 1970s. SO₂ reacts with liquid magnesium and builds a protective film on the surface. A mixing unit for blending a low concentration SO₂-air mixture is available. Furthermore, handling procedures for SO₂ have been established to reduce workers exposure and risk.

The protective gas is supplied through a manifold with several outlets. The positions of the outlets are chosen to give protection to all areas of the metal surface. Areas closer to hatches that will be opened frequently during operation need a higher flow of gas than areas where interaction with the surrounding atmosphere is small.

In order to optimise safety and minimise gas consumption, totally encapsulated melting and casting processes are applied.

Achieved environmental benefits

The replacement of SF₆ avoids using this greenhouse gas, which has a GWP of 22 200 over a 100-year time horizon.

Environmental performance and operational data

In an undisturbed melt, the use of SO₂ would be typically 0.7 % in air at a flow rate of 5 litre/minute to 10 litre/minute. In closed (but not airtight) furnaces, such as the melting and dosing furnaces of die-casting machines, pure SO₂ is applied. Small amounts of air entering through the lid are needed to provide the covering action. If a carrier gas is used, nitrogen is the preferred gas because of its inertness. The SO₂ is then mixed in concentrations of 1 – 2 %.

Mass balance data for the fluxless re-melting of magnesium scrap are given in Section 3.2.1.4.1.2.

Cross-media effects

SO₂ is a toxic gas and exposure limit values for workers should be taken into account. The occupational exposure limit in most countries is 2 ppm (5 mg/m³) over 8 hours. Sulphur- and oxygen-containing deposits may form on the furnace wall. Under unfavourable conditions these

deposits can be immersed into the molten metal where they cause reactions leading to metal eruptions from the surface. Frequent removal of scaling can prevent this from happening.

The technique results in emissions of small amounts of SO₂, the amount depending on the foundry capacity and the number of furnaces.

Technical considerations relevant to applicability

Generally applicable.

Economics

Conversion from SF₆ to another covering gas system entails an associated economic cost.

Driving force for implementation

Legal requirements related to the greenhouse gases.

Example plants

LM Leichtmetall Systemtechnik, Felbach (DE)

In the SF data collection, of the three plants that produce magnesium castings, data for one plant (DE033) indicate the use of SO₂ as oxidation control agent.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

DE033.

Reference literature

[81, Closset, B 2002], [89, Schubert et al. 2000], [90, IMA et al. 2000], [91, Gjestland et al. 1996], [92, UNEP IPCC 2002], [116, Harnisch et al. 2003], [134, CAEF 2020], [169, TWG 2021]

3.3 Techniques to consider in the determination of BAT for smitheries

3.3.1 Energy efficiency

3.3.1.1 General processing techniques

Description

Energy-efficient processes by applying general processing techniques.

Technical description

General processing techniques and several different measures are presented here, which can be applied to the smitheries processes individually or in combination:

- automation in heating furnace operation;
- computer-based control of energy consumption in critical points in the production process;
- energy-efficient lighting;
- energy management system;
- improvements in heating system, e.g replacement of burners, use of central recuperators for combustion air preheating, use of recuperative burners, use of burners with internal recuperation;
- management system for air compressors; [169, TWG 2021]
- minimisation/reduction of process steps, such as avoidance of reheating processes; [137, Herbertz et al., 2013]

Achieved environmental benefits

Increased energy efficiency.

Environmental performance and operational data

No information provided.

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable to smitheries.

Economics

No information provided.

Driving force for implementation

- Legal requirements.
- Local conditions.
- Saving costs by saving energy.
- Reduction of CO₂ emissions.

Example plants

In the SF data collection: DE002, DE003, DE006, DE007, ES008 and PL009

Reference literature

[137, Herbertz et al., 2013], [169, TWG 2021], [224, PL 2023]

3.3.1.2 Optimum furnace design

Description

This includes techniques such as the following:

- optimisation of key furnace characteristics (e.g. number and type of burners, air tightness and furnace insulation using suitable refractory materials);
- minimisation of heat losses from furnace door openings, e.g. by using several liftable segments instead of one in continuous reheating furnaces;
- minimisation of the number of feedstock supporting structures inside the furnace (e.g. beams, skids) and use of suitable insulation to reduce the heat losses from water cooling of the supporting structures in continuous reheating furnaces.

Technical description

Fuel-fired furnaces: The design of the furnace and the degree of insulation have a significant effect on thermal efficiency. The furnace together with the number and the capacity of the burners are carefully calculated starting from several realistic production scenarios. Different heating temperatures of the feedstock, and differences in production rhythm caused by changes in the dimensions of the feedstock are taken into account. [168, COM 2022]

From 2004 to the end of 2009, new impulse burners were developed for the smitheries industry. These impulse burners are in use and show an optimisation of the heating process, such as a better and optimised heat transfer to the steel parts in the furnace and a homogeneous temperature distribution in the furnace chamber is achieved. [146, Ade 2017]

Electrical furnaces: For induction furnaces, the energy efficiency can be increased using coils adjusted to the size of the raw material input (best-fitting coils). (EUROFORGE submission in [237, TWG 2023])

Achieved environmental benefits

- Reduced energy consumption.
- Reduction of NO_x and CO emissions in the case of fuel-fired furnaces.

Environmental performance and operational data

No information provided.

Cross-media effects

None.

Technical considerations relevant to applicability

Only applicable to new plants and major plant upgrades.

Economics

No information provided.

Driving force for implementation

- Reduction of costs.
- Natural resources savings by reduction of energy consumption.
- Legal requirements.
- Local conditions.

Example plants

In the SF data collection: DE001 reported for induction furnaces the 'adjustment of coils to raw material size'.

Reference literature

[137, Herbertz et al., 2013], [146, Ade 2017], [168, COM 2022], [169, TWG 2021], [177, COM 2009], (EUROFORGE submission in [237, TWG 2023])

3.3.1.3 Furnace automation and control**Description**

The heating process is optimised by using a computer system controlling key parameters such as furnace and feedstock temperature, the air to fuel ratio and the furnace pressure.

Technical description

Furnace automation controls the combustion parameters, the energy consumption, material handling, temperature control of the feedstock and process safety continuously. In addition, it enables adjustment of the air to fuel ratio for optimum combustion which in turn reduces NO_x emissions. [168, COM 2022]

With the help of a process computer, the heating process can be optimised (e.g. no unnecessary overheating of feedstock during interruptions, more accurate temperature control) in accordance with the material quality and dimensions. [168, COM 2022]

Achieved environmental benefits

- Reduced energy consumption.
- NO_x emissions reduction.

Environmental performance and operational data

No information provided.

Cross-media effects

No negative effects on other media are known.

Technical considerations relevant to applicability

Generally applicable.

Economics

No information provided.

Driving force for implementation

Reduced energy consumption – energy savings.
Improved product quality and reduced maintenance costs.

Example plants

In the SF data collection: DE002, DE003, DE006, ES008 and PL009

Reference literature

[137, Herbertz et al., 2013], [168, COM 2022], [169, TWG 2021]

3.3.1.4 Optimisation of feedstock heating/reheating**Description**

This includes techniques such as:

- techniques related to the entire process, e.g. ensure that feedstock heating/reheating target temperatures are consistently met;
- switching off equipment during idle periods;

- furnace operation optimisation, e.g. furnace capacity utilisation, correction of the air/fuel ratio, improvement of insulation.

Technical description

Gas furnaces, electric induction and conduction furnaces are available for heating the material, which ensure a precise process temperature.

Optimisation of furnace operation includes setting furnace temperatures at an optimal level to achieve a suitable temperature distribution with minimum energy use. One factor affecting feedstock heating/reheating and the efficiency of the furnace is the effective loading of the furnace and the furnace capacity utilisation. An improvement of insulation of the furnace helps to make furnaces more energy-efficient, compact, safe and sustainable.

Achieved environmental benefits

Reduction of energy consumption.

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

- Legal requirements.
- Local conditions.
- Reduction of costs.
- Natural resources savings by reduction of energy consumption.

Example plants

In the SF data collection: DE004 and DE006

Reference literature

[169, TWG 2021], [177, COM 2009]

3.3.1.5 Preheating of combustion air

Description

See Section 3.2.1.3.13.

Technical description

More information on this technique: see Section 3.2.1.3.13.

As reported, in some cases recuperative burners are applied (DE002, DE003), waste heat is directly used (PL009) or is reused via a central recuperator (DE004). The flue-gases are used to preheat the combustion air [169, TWG 2021]. PL009 reported the use of burners with internal recuperation: the gas and combustion air flow through the inner tube of the burner, while the flue-gases from the furnace are routed outside the burner (i.e. the furnace does not have a typical flue-gas outlet, but a chimney hole inside the furnace). The combustion air is preheated by the flue-gases. [224, PL 2023]

Technical considerations relevant to applicability

Applicability to existing plants may be restricted by a lack of space for the installation of regenerative burners.

Driving force for implementation

Reduction of energy consumption.

Example plants

In the SF data collection: DE002, DE003, DE004 and PL009.

Reference literature

[168, COM 2022], [169, TWG 2021], [177, COM 2009], [210, TWG 2022], [224, PL 2023]

3.3.2 Material efficiency**3.3.2.1 Process optimisation****Description**

Process optimisation includes techniques such as:

- computerised management of processes, e.g. heating/reheating cycles, hammering sequences;
- selection of an appropriate hammer according to raw material size;
- adjustment of raw material size, either in the forging line (fully automated) or in the organisational area of the material shearing (manual), in order to minimise the amount of modifications in the hammering process.

Technical description

Process optimisation leads to an efficient use of material and energy, and may result in targeted adjustment of various process parameters within the smitheries processes.

Computerised management of processes

The smitheries processes are operated in an optimised regime as much as possible, e.g. heating/reheating cycles, hammering sequences, hammer's impact loads.

Furthermore, by using computerised management of robots (for handling of forging pieces) and automation, precise and central insertion of forging billets is achieved, reducing the amount of faulty forgings. [210, TWG 2022]

Adjustment of raw material size

The size of raw material input (e.g. bars) is reduced to the actual minimum required for each forging piece to avoid excess material. Cutting the input material to size can be done with either of the following two reduction methods:

- fully automatic, centrally in the forging line;
- manually decentralised in the organisational area of the material shredding.

[169, TWG 2021]

Material-efficient equipment

The use of material-efficient equipment (new equipment for productivity, safety and consumption improvements, efficient motors, fans, compressors and control components, thin sawing blades) was reported. [169, TWG 2021]

Achieved environmental benefits

Efficient use of material and energy.

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

- Increase in material efficiency and reduced generation of residues.

Example plants

In the SF data collection the following was reported:

- computerised management system: DE003, DE004, DE006 and PL009;
- computerised management of robots and automation: DE001, DE002, DE006 and ES008;
- material-efficient equipment: DE002, DE006, ES008 and PL009.

Reference literature

[169, TWG 2021], [210, TWG 2022], (EUROFORGE submission in [237, TWG 2023])

3.3.2.2 Optimisation of raw material and auxiliary consumption

Description

This includes techniques such as:

- use of computer-aided design of products to optimise the amount of raw material used and the forging (die) geometry in order to reduce the forging test;
- selection of an appropriate type of coolant/lubricant in forging, e.g. synthetic lubricant for closed-die forging, water-based dispersions of graphite;
- centralised distribution system for coolants/lubricants for closed-die forging that reduce intermediate storage and consumption, and facilitates leak detection;
- systems for collecting and recirculating coolants/lubricants for closed-die forging.

Technical description

Techniques to improve raw material and auxiliary consumption includes computer-aided design (CAD) and forging process computer simulation.

Computer-aided design (CAD) systems result in optimisation of the forging tool geometry by CAD flow simulations within the tool design. Simulation of the forging processes reduces forging tests and the generation of residues (burrs). Furthermore, a reduction of energy input during tests is achieved. Theoretical process modelling through CAD is possible, as reported by DE006. Common CAD programs are generally applicable. [169, TWG 2021]

Simulation software is used for, e.g.:

- simulation of the forging process for optimisation (DE001);
- optimisation of raw materials input (ES008, DE004);
- reduction of numbers of trial forging;
- flash reduction and forging force reduction (DE002). [169, TWG 2021];

Selection of an appropriate type of lubricants/coolants

Lubricants are used in hot and warm forging and often include water-based dispersions of graphite. Graphite can support the metal-forming process and can resist high pressures applied perpendicularly to the planes, avoiding metal-to-metal contact between the workpiece and dies, thus minimising die wear. The disadvantage is the effect of galvanic corrosion, which is supported by the conductivity of graphite.

There is a clear trend to replace graphite-based die lubricants with synthetic lubricants. This is driven by the need for cleaner work environments, easier handling and to avoid graphite-induced galvanic corrosion of equipment. [165, Odink, G. J. 2021]

Centralised distribution system for coolants/lubricants

Use of centralised distribution systems with an automated dosing mechanism that controls in real time the coolant/lubricant quantities used in closed-die forging. By using centralised distribution systems, intermediate storage and consumption of coolants/lubricants is reduced and leak detection is facilitated.

The concentrations of lubricants are specific to the different forging geometries and could make a centralised distribution difficult.

Systems for collecting and recirculating coolants/lubricants

Used coolants/lubricants are collected using a collection system (e.g. a sump at the bottom of the working area) and recirculated in the work area (if necessary after filtration).

Closed cooling circuits can be installed, e.g. for turning machines and saws.

Achieved environmental benefits

- Efficient use of materials.
- Minimisation of residues through reducing the surplus of raw material input leading, for example, to burrs.
- Reduction of the consumption of coolants/lubricants, improvement of storage management and handling, facilitation of leak detection.

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

- Legal requirements.
- Local conditions.

Example plants

In the SF data collection the following was reported:

- computer-aided design: DE001, DE002, DE004, DE005 and DE006;
- computer simulation for forging processes: DE004, DE005 and DE006;
- collecting and recirculating coolants/lubricants: DE001 (closed cooling circuits for turning machines and saws), DE005, DE007, ES008 and PL009.

Reference literature

[137, Herbertz et al., 2013], [146, Ade 2017], [169, TWG 2021], [165, Odink, G. J. 2021], (EUROFORGE submission in [237, TWG 2023])

3.3.2.3 Recycling of process residues

Description

Process residues (e.g. metallic residues from the processes of preparation of raw materials, hammering and finishing; used shot blast media) are recycled and/or reused.

Technical description

In smitheries, process residues may occur, e.g. metallic residues and/or used/unusable shot blast media, which can be recycled and/or reused. Recycling might be carried out off site.

Achieved environmental benefits

Minimisation of residue generation.

Environmental performance and operational data

One plant (DE002) reported that metal scrap is sorted by size and quality, purity of type in order to facilitate its recycling.

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable.

Economics

No information provided.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

In the SF data collection: DE003, DE007, ES008 and PL009.

Reference literature

[169, TWG 2021], [210, TWG 2022], (EUROFORGE submission in [237, TWG 2023])

3.3.2.4 Automation of forging machines

Description

Automation of forging machines, such as in the processes of heating/reheating, hammering and feedstock manipulators/robots, supports the optimisation of material efficiency.

Technical description

Automation is related to both the individual operation steps and the different parts of forging machines. It includes, for example, the production process, the process economy of the machinery, the operation unit and the control unit in order to regulate for example the efficiency of the operation steps, including energy and material efficiency. The control of temperature, heating conditions, hammering power, temperature of the material can be automated and optimised. Automation can directly detect problems with the machinery and the process. Corrective measures are directly added by the automation procedure or can be carried out on demand.

Furthermore, robots are applied for special production steps or production processes. A very flexible grabbing principle is combined with almost any web guide system. As a result, geometrically complex components can also be grabbed and transported on almost any web guides within the area, including across the boundaries of a machine. This principle enables robots

to pick up the workpieces easily and securely. Usually, the robots have a limit to their cycle time. The cycle time limit can sometimes be bypassed by increasing the number of robots used and by sharing the work. [137, Herbertz et al., 2013]

Automated systems may limit the flexibility of production, for example with regard to the form and dimensions of products that can be forged.

Achieved environmental benefits

Optimisation of material efficiency.

Environmental performance and operational data

No information provided.

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable.

Economics

Investment and operating costs generally depend on both the type of automation and the parts of machinery that have to be automated. Labour expenses may be reduced.

To be economically viable, automation generally requires large batch sizes.
[137, Herbertz et al., 2013]

Driving force for implementation

- Reduction of labour expenses.
- Increase of productivity.

Example plants

In the SF data collection, ‘Computerised management of robots and automations’ was reported by DE001, DE002, DE006, and ES008.

Reference literature

[137, Herbertz et al., 2013], (EUROFORGE submission in [237, TWG 2023])

3.3.3 Vibrations

3.3.3.1 Reduction of vibrations

Description

Reduction of vibration occurring from the hammering process by using vibration-reducing and insulating techniques.

Vibration-reducing and insulating techniques for the hammering equipment include the installation of vibration-damping components, e.g. layered elastomeric isolators or viscous spring isolators below the anvil or spring casings below the hammer foundation.

Technical description

Forging hammers are types of shock-producing machines and generate powerful brief impact loads and powerful dynamic effects that are relatively short in duration and can be characterised as shock pulses. Only a part of the shock energy is utilised in the intended machine function and the rest is dissipated in the foundation, causing intense vibration. Heavy shocks imparted to the foundation can cause alignment problems (i.e. reduce operating life), neighbour complaints and prohibit proper operation of adjacent equipment. The main objectives are to reduce the vibration

amplitudes and the forces transmitted to the soil and/or to minimise any disturbance to the neighbourhood and surroundings. [164, Heidari et al. 2011], [235, Dynemtech 2023]

The extent to which vibrations affect third parties depends to a large extent on the soil properties. Particular local conditions may lead to vibrations being an issue, e.g. if sensitive receptors are affected. However, in other cases, where no sensitive receptors are in the vicinity or where the geological characteristics of the ground prevent or dampen the transmission of vibration, there may be no recipients outside the plant affected. (EUROFORGE submission in [237, TWG, 2023])

Measures to reduce vibrations include the installation of a suitable insulating/anti-vibration base [139, Probst 2006], [169, TWG 2021], [169, TWG 2021], e.g. increasing the base area or mass of foundation, interposing insulating media [235, Dynemtech 2023] vibration-damping components, e.g. elastomer below the anvil and spring casings below the foundation [162, Raju et al. 2017].

The use of anti-vibration bases was reported by Plants DE002, DE003, DE005 and DE007. Plant DE002 reported the use of two proven types of anti-shock elements, such as spring viscose dampers and shock-absorbing panels, each with specific advantages. Furthermore, Plant DE006 reported the decoupling of the machine foundation from the building structure. The machines are founded on solid concrete foundations in deep pits on bedrock. [210, TWG 2022]

The correct application of a well-designed isolation system will result in a significant reduction of the ram's impact shock [163, Veroeven 2010]. Shock is isolated by the motion of the isolator and internal viscous damping of the vibration isolators. The force transmitted to the base and the motion of the ground/foundation are both reduced considerably. [235, Dynemtech 2023].

Example of vibration reducing and insulating techniques (spring viscous isolators and spring damper systems) are shown in the figures below. [235, Dynemtech 2023], [236, GERB 2022]



Figure 3.68: Closed-die hammer (3.5 tonne) on spring viscous isolators

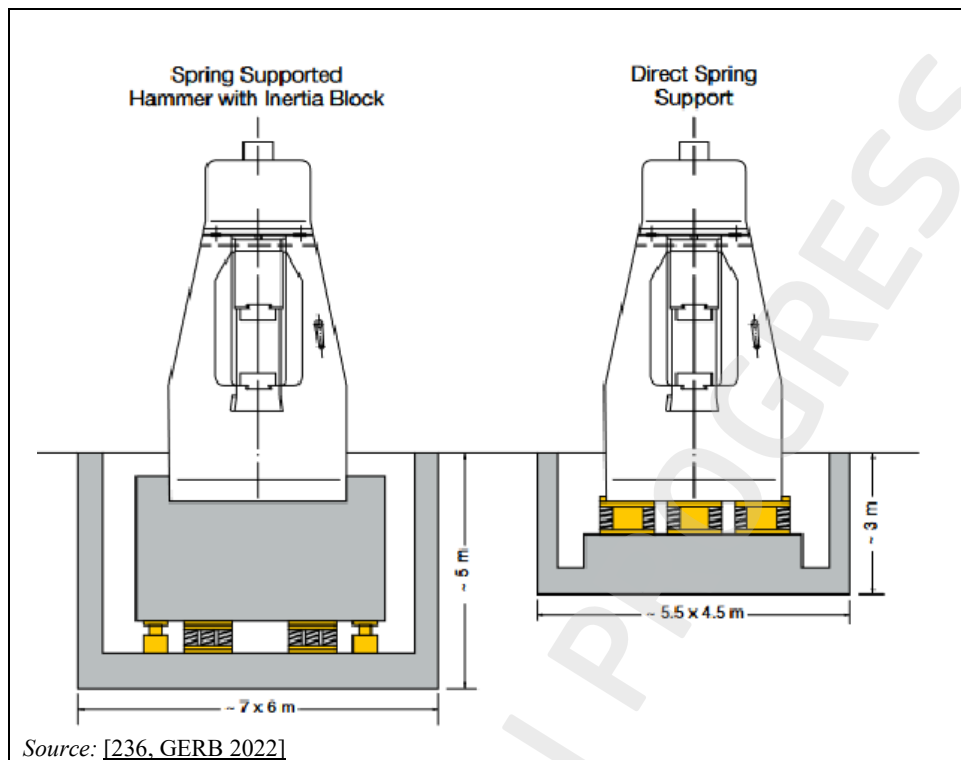


Figure 3.69: Examples of spring damper systems for forging hammers

Figure 3.70 shows as an example the basic foundation below the spring foundation of a large hammer of 6 tonnes at Plant DE002. On this foundation, the complete hammer in bridge construction was set up. This foundation is approximately 10 m deep and weighs about 2 000 tonnes of steel-reinforced concrete (EUROFORGE submission in [237, TWG 2023]).



Figure 3.70: Foundation of a 6-tonne hammer at Plant DE002

Achieved environmental benefits

Reduction of vibrations.

Environmental performance and operational data

Improving the vibration reduction and insulation for existing plants can be technically challenging, especially when considering to install these techniques under the hammering equipment. A dismantling of the forge (hammer, anvil), dismantling of existing concrete fundamentals or renewal of fundamentals may be needed. Layered elastomeric isolators may be considered a relatively easy to install solution but are mainly effective for smaller hammering equipment. For large hammers, the efficiency may be low, i.e. the vibrations are reduced, but not eliminated (EUROFORGE submission in [237, TWG 2023]).

Cross-media effects

None.

Technical considerations relevant to applicability

Generally applicable.

Economics

No information provided.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

In the SF data collection, the application of anti-vibration bases was reported by DE001, DE002, DE003, DE005, DE006 and DE007.

Reference literature

[139, Probst 2006], [162, Raju et al. 2017], [163, Veroeven 2010], [164, Heidari et al. 2011], [169, TWG 2021], [235, Dynemech 2023], [236, GERB 2022], (EUROFORGE submission in [237, TWG 2023])

3.3.4 Noise emissions

3.3.4.1 General considerations regarding noise

Noise emissions and vibrations occur in the several steps during the smitheries process. Noise emissions may occur throughout the whole smitheries process, such as preparing and processing raw materials, cutting, heating, forging/hammering, heat treatment, surface treatment, material transport and storage of products as well as from the dispatch and shipping of the final products. [139, Probst 2006], [169, TWG 2021]

The high level of noise is mainly caused by the production process itself. Metal requires large forces in the transformation process.

The heavy machinery and large fans used in various parts of the smitheries processes can give rise to noise emissions, particularly from:

- forging/hammering vibrations and any operations involving hammering;
- exhaust fans;
- blowers;
- duct vibration.

A reduction of sound emissions can often be achieved by directly applying measures at the source of the noise.

Plants are required to comply with noise impact standards according to national legislation, and noise surveys are conducted and evaluated. At the process/hammering hall, the windows and doors are closed during working periods. Natural noise barriers, such as office buildings, walls, trees or bushes, are used in the smitheries industry to reduce the impact of noise emissions.

Furthermore, sound-absorbing surfaces can be installed and construction measures can be applied. [139, Probst 2006]

In the machine shop, technical noise-absorbing devices and sound-absorbing surfaces can be applied, e.g. cement-bonded particleboards/wood fibre boards. Externally insulated trapezoidal sheet roofs in which the space-side plates are perforated and filled with mineral fibre wedges have also proved efficient as noise absorption roof structures. [139, Probst 2006]

Furthermore, low-noise machinery, equipment and tools can be applied, e.g. low-noise nozzles. For material transport, noise-reduced equipment is used.

In the event that the installation is located close to residential areas, the planning of new buildings at the site is connected with the necessity to reduce noise emissions and vibrations.

See also Section 3.1.5 for further techniques and measures which are applicable for reduction of noise emissions.

3.3.4.2 General measures

Description

Techniques and measures to reduce noise emissions.

Technical description

A reduction of noise emissions can often be achieved by directly applying techniques at the source of the noise. In addition, various techniques for noise abatement can be applied at smitheries in order to reduce the noise levels for neighbourhood protection, such as:

- installation of noise walls and utilisation/optimisation of the noise-absorbing effect of buildings: (DE001, DE002, DE006, DE007 and ES008):
 - 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;
- enclosure (full or partial) of the noisy equipment (DE003, DE006, ES008 and PL009);
- full enclosure of the smitheries building (DE007);
- decoupling of machine foundations from the building structure (DE006);
- noise management measures (e.g. improved inspection and maintenance of equipment, closing of doors and windows) (DE003 and DE007);
- noise reduction measures for fans (e.g. using silencers, slow rotating fans) (DE003, DE004 and ES008);
- avoidance of noisy activities (e.g. transport) at night (DE002, DE003, DE006 and DE007);
- encapsulation of material supply in the outside area (DE006);
- soundproofing the building fronts including arrangement of soundproofed ventilation elements (DE006).

[169, TWG 2021]

If the above-mentioned noise prevention/reduction techniques cannot be applied, secondary noise reduction techniques, e.g. construction of buildings or natural barriers, such as growing trees and

bushes between the protected area and the noisy activity, have to be carried out. Doors and windows of covered areas have to be kept closed during noisy operations.

The overall reduction of noise levels involves developing a noise reduction plan. Each source needs to be checked and evaluated. Alternative techniques with lower noise levels may be applied and/or point sources may be enclosed, as described above.

Achieved environmental benefits

Reduction of noise emissions.

Environmental performance and operational data

No information provided.

Cross-media effects

No issues.

Technical considerations relevant to applicability

Applicable to all new and existing installations.

Economics

Additional investment and maintenance costs can occur due to the noise protection techniques.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

In the SF data collection: DE001, DE002, DE003, DE004, DE005, DE006, DE007, ES008 and PL009.

Reference literature

[169, TWG 2021]

3.3.5 Monitoring

3.3.5.1 Overview

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:

- point sources' channelled, diffuse emissions to the atmosphere, water reservoirs or sewer;
- residues/wastes, particularly hazardous wastes, if applicable;
- contamination of land, water and air;
- use of water, energy (electrical, thermal);
- discharge of water, , noise, vibration;
- effects on specific parts of the environment and ecosystems;
- complaints from community residents.

Monitoring, however, is not restricted to analytical measuring. It also includes regular maintenance, as well as visual and safety checks.

In parallel to this document, the reader is referred to the Reference Report on Monitoring of Emissions to Air and Water from IED installations (ROM) for further information. [174, COM 2018]

Preferably, the monitoring records for emissions to air and water shall be made available in an electronic format.

3.3.5.2 Monitoring of channelled emissions to air

Description

Regular monitoring of emissions to air.

Technical description

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.

For heating/reheating and heat treatment processes, NO_x and CO emissions are usually monitored regularly (yearly or once every 3 years), as reported by the smitheries plants involved in data collection.

Achieved environmental benefits

Monitoring the off-gas characteristics and pollutant concentrations is important for the evaluation of the environmental impact from smitheries operation. In addition, it contributes to the process optimisation (e.g. combustion processes) and to detect accidental releases, helping to prevent any possible adverse environmental impact.

Environmental performance and operational data

For NO_x emissions, 5 plants reported data from 29 emission points. For CO emissions, 4 plants reported data for 19 emission points.

Yearly monitoring of NO_x is reported by plants DE006, ES008 and PL009 and monitoring of NO_x once every 3 years is reported by plants DE004, DE007 and ES008.

Yearly monitoring of CO is reported by plants DE006 and PL009 and monitoring of CO once every 3 years is reported by plants DE004 and ES008.

Cross-media effects

No cross-media-effects.

Technical considerations relevant to applicability

Generally applicable to all smitheries plants where there are channelled emissions to air.

Economics

The costs associated with monitoring the waste gas of a smithery relate to personnel and equipment used for sampling and measurement.

Driving force for implementation

Environmental legislation.

Example plants

In the SF data collection: DE004, DE006, DE007, ES008 and PL009.

Reference literature

[174, COM 2018], [169, TWG 2021]

3.3.6 Emissions to air

3.3.6.1 General considerations regarding diffuse emissions to air

Various process steps in smitheries operation have the potential to produce dust, fume and other pollutants, e.g. material storage, handling and processing.

Diffuse emissions occur when emissions from specific process sources and process steps are not collected. Potential sources include:

- raw materials and chemicals storage areas;
- the loading and unloading of transport containers;
- preparation of raw materials;
- moving of materials (basically caused mechanically by moving material around the premises);
- furnaces, heating/reheating, heat treatment (emissions from combustion if not channelled);
- hammering;
- cooling;
- cleaning/descaling;
- any accidental loss of containment from a plant or equipment failure, including leakages;
- spills.

[169, TWG 2021], [210, TWG 2022]

3.3.6.1.1 Operational and technical measures

Description

This includes techniques such as:

- use of closed bags or drums to handle materials with dispersible or water-soluble components, e.g. auxiliaries;
- minimisation of transport distances;
- efficient material handling;

Technical description

Diffuse dust emissions mainly arise from the storage, preparation and handling of materials, heating/reheating, heat treatment, hammering, cooling and/or finishing as well as from transport processes. Several techniques are available to prevent or minimise diffuse emissions, e.g. from material handling and preparation (e.g. enclosure/encapsulation of dusty operations and/or use of closed bags or drums to handle materials), heating/reheating, heat treatment, hammering, finishing. A simple and linear site layout is advisable to minimise possible sources of diffuse dust. Proper and complete maintenance of the installation always has the indirect result of reducing diffuse dust emissions by reducing air leakages and spillage points. The use of automatic devices and control systems also helps diffuse dust reduction. Reduction of fugitive emissions from material handling was reported by Plant DE006.

Minimisation of transport distances was reported by plant DE006 and includes the storage of input material close to the process and the sawing machine where the material is used.

Efficient and appropriate material handling includes the periodical cleaning (e.g. weekly) of outdoor areas, such as roads, paths and squares, especially in the dry season, as reported by Plant DE006. Diffuse emissions from raw materials and chemicals storage and handling are basically caused by moving material around the premises. [210, TWG 2022]

Enclosure of storage areas was reported by Plants DE003 and ES008. Enclosure of production equipment was reported by plant DE007.

For new and large open-die forging furnaces, waste gas is extracted. For smaller and older furnaces, diffuse emissions are collected by the use of ridge turrets on the roofs of the workshops. [210, TWG 2022]

Achieved environmental benefits

- Reduction of diffuse emissions (mainly dust).
- By enclosure of storage areas, noise emission reduction is also possible.

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

- Legal requirements.
- Local conditions.
- Health and safety requirements for the workplace.

Example plants

In the SF data collection: DE003, DE006, DE007 and ES008.

Reference literature

[169, TWG 2021], [210, TWG 2022]

3.3.6.1.2 Extraction of emissions from shot blasting

Description

Emissions from shot blasting are extracted using enclosures. Extracted off-gases are treated using techniques such as fabric filters.

Technical description

Finishing processes, such as shot blasting, sandblasting or grinding, are carried out in enclosures. Off-gases are extracted. Off-gas treatment may be applied, e.g. by using fabric filters. More information on fabric filters is given in Section 3.2.1.12.7. The use of a fabric filter requires the selection of a fabric suitable for the characteristics of the off-gas and the maximum operating temperature.

The following plants reported extraction and treatment:

- DE006: Collection of off-gases from cleaning after hand grinding processes and after sandblasting processes. Permanent emission monitoring. Off-gas treatment using a gate filter and bag filter. Shutdown of the plant when emission limit values are exceeded.
- ES008: Capture and treatment of emissions from finishing processes and mechanical processes, e.g. blasting. Application of mechanical filters for welding process.
- DE002: Capture and treatment of emissions from finishing processes (e.g. blasting) and dust concentration measurement after filtering.
- Furthermore, it was reported by Plant DE005 that dust emissions from blasting are avoided by filtering.

Achieved environmental benefits

Prevention or reduction of diffuse emissions.

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

- Legal requirements.
- Local conditions.
- Health and safety requirements for the workplace.

Example plants

In the SF data collection: DE002, DE005, DE006 and ES008.

Reference literature

[169, TWG 2021], [210, TWG 2022], (EUROFORGE submission in [237, TWG 2023])

3.3.6.1.3 Efficient storage and handling of raw materials

Description

Efficient storage and handling of raw materials and reduction of diffuse emissions to air. Structuring and management of covered storage areas.

Technical description

Different techniques and measures were reported for storage and handling of raw materials and prepared materials, which can be applied individually or in combination. By applying these techniques, raw materials are efficiently stored and handled. The materials are well sorted, remain in a dry area under the roof or in closed storage containers and can quickly be delivered to the heating furnace and the corresponding forging line. Furthermore, raw materials and auxiliaries are stored close to their location of use to reduce transport activities. The personnel is trained to manage, handle and distribute the material in an efficient way. The raw material preparation is made manually (decentralised) or automated [169, TWG 2021]:

The following techniques are applied:

- Careful choice of the storage location for the raw materials delivered taking into consideration the disposition of the forging line Raw and auxiliaries materials are classified and stored near the places where they will be used in covered and paved locations to minimise the distance of transport (Plants DE001, DE002, DE003, DE004, DE005, DE006, DE007 and ES008). Input material (blanks) is stored in a temperature-controlled hall (Plant DE002).
- Storage personnel training, information material and visible safety signs (Plants DE003, DE004, DE006, DE007, ES008 and PL009).

Achieved environmental benefits

- Efficient storage and handling of raw materials and reduced transportation distances.
- Reducing diffuse emissions to air due to minimised transport distances, and covered and paved floor and locations.

- Reducing noise emissions.

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

- Legal requirements.
- Local conditions.

Example plants

In the SF data collection: DE001, DE002, DE003, DE004, DE005, DE006, DE007, ES008 and PL009.

Reference literature

[169, TWG 2021]

3.3.6.2 Emissions to air from heating, reheating and heat treatment**3.3.6.2.1 Use of a fuel or a combination of fuels with low NO_x formation potential****More information on the technique**

See Section 3.2.1.7.4.

3.3.6.2.2 Combustion optimisation**Description**

Measures taken to maximise the efficiency of energy conversion in the furnace while minimising emissions (in particular of CO). This is achieved by a combination of techniques including good design of the furnace, optimisation of the temperature (e.g. efficient mixing of the fuel and combustion air) and residence time in the combustion zone, and use of furnace automation and control.

Technical description

Measures are taken to maximise the efficiency of energy conversion in the furnace while minimising emissions (in particular of CO). Elevated CO emissions mainly result from poor combustion and improper burning conditions in furnaces.

An improvement in the heating system through automation in the heating furnace operation was reported by Plant ES008. PL009 reported proper operation and maintenance of burners and the use of waste heat. Automation in heating furnace operation was reported by Plant DE006.

See the LCP BREF for more information. [178, COM 2017]

Achieved environmental benefits

Reduced CO emissions.

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

- Legal requirements.
- Local conditions.

Example plants

In the SF data collection: ES008; PL009 and DE006

Reference literature

[169, TWG 2021], [178, COM 2017]

3.3.6.2.3 Furnace automation and control

See also Section 3.3.1.3.

3.3.6.2.4 Flue-gas recirculation

Description

Recirculation (external) of part of the flue-gas to the combustion chamber to replace part of the fresh combustion air, with the dual effect of lowering the temperature and limiting the O₂ content for nitrogen oxidation, thus limiting the NO_x generation. It implies the supply of flue-gas from the furnace into the flame to reduce the oxygen content and therefore the temperature of the flame.

Technical description

Flue-gas recirculation is a technique for limiting peak flame temperatures. Recirculating flue-gases into the combustion air will reduce the oxygen and lower flame temperatures, hence limiting the formation of thermal NO_x. It implies the supply of flue-gas from the furnace into the flame to reduce the oxygen content and therefore the temperature of the flame.

More information is available in the FMP BREF. [168, COM 2022]

Achieved environmental benefits

Reduced NO_x emissions.

Environmental performance and operational data

No information provided.

Cross-media effects

None.

Technical considerations relevant to applicability

Applicability to existing plants may be restricted by a lack of space.

Economics

No information provided.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

In the SF data collection: none of the smitheries reported the application of this technique.

Reference literature

[168, COM 2022], [169, TWG 2021]

3.3.6.2.5 Low-NO_x burners**More information on the technique**

See Section 3.2.1.7.6.

Example plants

In the SF data collection: none of the smitheries reported the application of this technique.

3.3.6.2.6 Limiting the temperature of air preheating**Description**

Limiting the air preheating temperature leads to a decrease of the concentration of NO_x emissions. A balance has to be achieved between maximising heat recovery from the flue-gas and minimising NO_x emissions.

Technical description

Emission levels of NO_x increase with increasing preheating temperatures of combustion air. Thus limiting air preheating can be a measure to limit NO_x emissions.

On the other hand, the preheating of combustion air is a commonly applied measure to increase the energy efficiency of furnaces and to decrease fuel consumption. Limiting air preheating means that the unused energy content in the flue-gas is wasted and has to be compensated with higher fuel consumption.

Generally, plant operators are interested in reducing the fuel consumption as this implies a monetary benefit, but the reduction of fuel consumption can additionally reduce other air pollutants, such as CO₂ and particulates. Thus a balance may need to be achieved between energy efficiency and decreasing CO₂ emissions on one hand and increasing NO_x emissions on the other. When keeping air preheating temperatures high, the application of secondary NO_x reduction measures might be necessary.

More information is available in the FMP BREF. [168, COM 2022]

Achieved environmental benefits

Reducing NO_x emissions.

Environmental performance and operational data

No information provided.

Cross-media effects

Reduced energy efficiency.

Technical considerations relevant to applicability

Generally applicable.

Economics

No information provided.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

In the SF data collection: no plants reported the application of this technique.

Reference literature

[169, TWG 2021], [168, COM 2022]

3.3.6.2.7 Oxy-fuel combustion

More information on the technique: See Section 3.2.1.3.7.

More information is also available in the FMP BREF. [168, COM 2022]

Example plants

In the SF data collection: none of the smitheries reported the application of this technique.

3.3.6.2.8 Flameless combustion

Description

Flameless combustion is achieved by injecting fuel and combustion air separately into the combustion chamber of the furnace at high velocity, to suppress flame formation and reduce the formation of thermal NO_x while creating a more uniform heat distribution throughout the chamber. Flameless combustion can be used in combination with oxy-fuel combustion.

Technical description

Flameless combustion can be achieved using conventional air-fuelled furnaces equipped with a flameless burner or using oxy-fuel flameless burners.

Flameless combustion

Flameless combustion can be achieved with intense mixing of the fuel gas, the combustion air and the recirculated exhaust gases. Fuel gas and combustion air are injected separately into the combustion chamber at high velocity. Inside the combustion chamber, a very intensive internal flue-gas circulation mixes the combustion air, the fuel gas and the products of combustion. Under these conditions, flameless combustion occurs provided that the combustion temperature inside the furnace is above the auto-ignition temperature of the mixture (e.g. > 800 °C using natural gas and air) and the flue-gas recirculation ratio is higher than three. [168, COM 2022]

With flameless combustion, the temperature peak of the flame front does not exist, reducing to a large extent the formation of NO_x in comparison with conventional burners. Another additional benefit provided by flameless combustion is that the fuel oxidises throughout the entire volume of the combustion chamber, providing a very homogeneous furnace temperature. With the uniform distribution, it is possible to maintain a higher average combustion chamber temperature, resulting in reduced heating time, and lower CO emissions since complete combustion is achieved. Finally, flameless combustion results in lower noise emissions and reduced thermal stress for the burner. [168, COM 2022]

Flameless combustion in combination with oxy-fuel

Flameless technology can be used in combination with the oxy-fuel technique. This technique involves the replacement of the combustion air with oxygen (> 90 % purity) which means less nitrogen to be heated and a reduction of the total exhaust gas volume, leading to increased energy efficiency.

Flameless oxy-fuel combustion is achieved by separately injecting the fuel and oxygen at high velocities into the furnace. [168, COM 2022]

Achieved environmental benefits

- Reduced NO_x emissions.
- Reduced CO emissions.
- Reduced noise emissions

Environmental performance and operational data

No information provided.

Cross-media effects

None.

Technical considerations relevant to applicability

Applicability to existing plants may be restricted by furnace design (i.e. furnace volume, space for burners, distance between burners) and the need for a change of the furnace refractory lining. This technique is not applicable to furnaces operating at a temperature lower than the auto-ignition temperature required for flameless combustion.

Economics

Application of oxy-fuel burners requires the additional purchase or on-site production of oxygen. Accordingly, the flameless oxy-fuel technique is often only economically viable at plants where oxygen is available at a low price. [168, COM 2022]

Driving force for implementation

- Increased productivity.
- Energy savings.
- Legal requirements.
- Local conditions.

Example plants

In the SF data collection, none of the smitheries reported the application of this technique.

Reference literature

[168, COM 2022], [169, TWG 2021]

3.3.7 Water consumption and waste water generation**3.3.7.1 Segregation of water streams****Description**

Water streams (e.g. surface run-off water, process 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 from waste water streams that require treatment.

Technical description

Plant DE006 reported the use of surface water as cooling water for cooling compressors, furnaces and presses. After use in the cooling circuit, it is cleaned via a sludge trap and oil separator and

directly discharged into a surface water body. Rainwater is also pretreated in the same way on site. Sanitary waste water is routed separately, discharged indirectly and fed into the municipal sewage treatment plant. Plant DE002 reported separation of different types of waste water, e.g. oil-containing and oil-free water.

Segregation of different types of waste water was reported by Plants DE002, DE003, DE006 and ES008.

A further detailed technical description of a waste water collection and segregation system can be found in the CWW BREF [\[179, COM 2016\]](#).

Achieved environmental benefits

Reduced emissions to water.

Environmental performance and operational data

No information provided.

Cross-media effects

None.

Technical considerations relevant to applicability

Applicability to existing plants may be restricted by the layout of the water collection system.

Only applicable when waste water generation is identified as relevant based on the inventory of inputs and outputs mentioned in Section 3.1.1.2.

Economics

No information provided.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

In the SF data collection: DE002, DE003, DE006 and ES008.

Reference literature

[\[169, TWG 2021\]](#), [\[179, COM 2016\]](#)

3.3.7.2 Water reuse and/or recycling

Description

Water streams (e.g. process water, cooling water) are reused and/or recycled in closed or semi-closed circuits, if necessary after treatment.

Technical description

Techniques and measures were reported for efficient use of water, waste water prevention/minimisation and waste water treatment to reduce emissions to water, which can be applied individually or in combination, such as minimisation of waste water generation in cooling by using a closed cooling circuit [\[148, Euroforge 2021\]](#).

Achieved environmental benefits

- Efficient water consumption.
- Reduction of emissions to water.

Environmental performance and operational data

No information provided.

Cross-media effects

None.

Technical considerations relevant to applicability

The degree of water reuse and/or recycling is limited by the water balance of the plant, the content of impurities and/or the characteristics of the water streams. It applies when waste water generation is identified as relevant.

Only applicable when waste water generation is identified as relevant based on the inventory of inputs and outputs mentioned in Section 3.1.1.2.

Economics

No information provided.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

In the SF data collection: DE007, ES008 and PL009.

Reference literature

[169, TWG 2021]

3.3.7.3 Water management plan and audits

Information on this technique can be found in Section 3.2.1.16.1.

3.3.8 Emissions to water

3.3.8.1 Techniques for waste water treatment

Description

Techniques are described in Section 3.2.1.17. The objective is to reduce the volume of waste water generated as well as to improve water recyclability.

Technical description

Techniques and measures were reported for waste water prevention/minimisation and waste water treatment to reduce emissions to water, which can be applied individually or in combination, such as:

- pH and oils/fats monitoring at the outflow of waste water (DE003, DE006 and ES008);
- industrial waste water treatment (ES008).

[169, TWG 2021]

Regular monitoring of pH and oils/fats at the outflow of waste water and sampling and analysis of directly discharged waste water carried out by the operator are reported by DE006.

As reported by Plant ES008, rainwater is collected through gutters, downpipes and sewers and is directed to the plant's water collection system, and is then directly sent to the municipal waste water treatment plant. Sanitary water converges with both the effluent leaving the internal sewage treatment plant and with the rainwater and is then directly discharged to the municipal sanitation network. Industrial waste water, rainwater from two waste silos and the cleaning water is treated

in the plant's waste water treatment facility and is finally discharged to the municipal waste water treatment plant. The plant's waste water treatment facility is composed of a pretreatment, a homogenisation tank, and a physico-chemical treatment (coagulation, flocculation in a mixing flocculator and subsequent flotation (dissolved air flotation – DAF). [221, ES 2018]

Separation of different types of waste water was reported (DE002, DE003, DE006 and ES008), e.g. separation of oil-containing water and oil-free water (DE002).

DE006 reported the use of surface water as cooling water for cooling compressors and furnaces. After use in cooling equipment, it is cleaned via a sludge trap and an oil separator and then it is directly discharged into a surface water body. Rainwater is also pretreated in this way on the plant premises. Sanitary waste water is routed separately, discharged indirectly and fed into the municipal sewage treatment plant.

As reported by Plants DE002, DE005, DE007, ES008 and PL009, for cooling, a closed cooling circuit/system is applied in order to avoid waste water generation. Furthermore, also the once-through cooling system is applied (DE006). The cooling system is operated in continuous flow.

DE005, ES008 and PL009 reported the collection and reuse of cooling lubricants. [169, TWG 2021]

Achieved environmental benefits

Reduced emissions to water.

Environmental performance and operational data

No information provided.

Cross-media effects

None.

Technical considerations relevant to applicability

Only applicable when waste water generation is identified in the inventory of inputs and outputs mentioned in Section 3.1.1.2.

Economics

No information provided.

Driving force for implementation

- Legal requirements.
- Local conditions.

Example plants

In the SF data collection: DE002, DE003, DE005, DE006, DE007, ES008 and PL009.

Reference literature

[169, TWG 2021], [221, ES 2018]

4 BEST AVAILABLE TECHNIQUES (BAT CONCLUSIONS FOR THE SMITHERIES AND FOUNDRIES INDUSTRY)

Scope

These BAT conclusions concern the following activities specified in Annex I to Directive 2010/75/EU:

- 2.3. Processing of ferrous metals:
 - (b) operation of smitheries with hammers the energy of which exceeds 50 kilojoules per hammer, where the calorific power used exceeds 20 MW.
- 2.4. Operation of ferrous metal foundries with a production capacity exceeding 20 tonnes per day.
- 2.5. Processing of non-ferrous metals:
 - (b) melting, including the alloyage, of non-ferrous metals, including recovered products, and operation of non-ferrous metal foundries, with a melting capacity exceeding 4 tonnes per day for lead and cadmium or 20 tonnes per day for all other metals.
- 6.11 Independently operated treatment of waste water not covered by Directive 91/271/EEC⁵, provided that the main pollutant load originates from the activities covered by these BAT conclusions.

These BAT conclusions also cover the following:

- Ferrous metal foundries employing continuous casting processes for the production of grey or nodular iron castings at or near their final shape.
- Non-ferrous metal foundries using alloyed ingots, scrap, recovered products or liquid metal for the production of castings at or near their final shape.
- 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/EEC⁵.
- The coating of moulds and cores in ferrous and non-ferrous metal foundries.
- The storage, transfer and handling of materials, including the storage and handling of scrap and sand in foundries.
- Combustion processes directly associated with the activities covered by these BAT conclusions provided that the gaseous products of combustion are put into direct contact with material (such as direct feedstock heating or direct feedstock drying).

These BAT conclusions do not cover the following:

- The continuous casting of iron and/or steel (i.e. to produce thin slabs, thin strips, and sheets). This is covered by the BAT conclusions for Iron and Steel Production (IS).
- The production of semi-finished non-ferrous metal products requiring further forming. This is covered by the BAT conclusions for the Non-Ferrous Metals Industries (NFM).
- Cadmium, titanium and precious metal foundries, as well as bell and art casting.
- The coating of castings. This may be covered by the BAT conclusions for the Surface Treatment Using Organic Solvents including Wood and Wood Products Preservation with Chemicals.
- Forging presses.
- Waste water from indirect cooling systems. This may be covered by the BAT conclusions for Industrial Cooling Systems (ICS).

⁵ Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment (OJ L 135, 30.5.1991, p. 40).

- Rolling mills. This is covered by the BAT conclusions for the Ferrous Metals Processing Industry (FMP).
- 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) 2015/2193 of the European Parliament and of the Council⁶.

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

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

These BAT conclusions apply without prejudice to other relevant legislation, e.g. on the registration, evaluation, authorisation and restriction of chemicals (REACH), on classification, labelling and packaging of substances and mixtures (CLP).

⁶ 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).

Definitions

For the purposes of these BAT conclusions, the following definitions apply:

General terms	
Term used	Definition
Casting	A metal workpiece, produced using a casting process, which is ejected or released out of a mould.
Casting process	Pouring molten metal into the cavity of a mould. The molten metal is subsequently allowed to solidify.
Centrifugal casting	Molten metal is poured into a preheated rotating mould, placed either vertically or horizontally depending on the product shape. After pouring, the mould rotates around its central axis creating a centrifugal force which displaces the molten metal towards the periphery, forcing it to deposit on the walls of the mould.
Channelled emissions	Emissions of pollutants into the environment through any kind of duct, pipe, stack, etc.
Clean scrap	Scrap metal which meets at least all of the following characteristics: <ul style="list-style-type: none"> • free of non-metallic impurities; • free of galvanised, primed or painted scrap parts; • free of oil and grease; • free of explosive can material; • free of tool steels, stainless steels or chrome-alloyed steels, except for steel foundries; • for iron and steel foundries, free of non-ferrous metal scrap parts. Free means that residual impurities are present at such a low level that they do not adversely affect the environmental performance (e.g. increased TVOC, PCDD/F and/or heavy metal emissions) and the operation/safety of the plant.
Cold-setting processes	Curing processes for moulds and cores where the sand binder hardens at ambient temperature. Curing begins immediately after the last component of the sand binder formulation is introduced in the mix.
Continuous casting	Molten metal is poured into a water-cooled die that is open at the bottom or at the side. Through intensive cooling, the outside of the metal product solidifies while it is slowly pulled out of the mould. Subsequently, the product (e.g. bars, tubes, profiles) is cut to the desired product length.
Continuous measurement	Measurement using an automated measuring system permanently installed on site.
Core-making	Production of cores which can be solid or hollow. Cores are inserted into the mould to provide the internal cavities or part of the external shape of the casting before the mould halves are joined.
Diffuse emissions	Non-channelled emissions to air. Diffuse emissions include both fugitive and non-fugitive emissions.
Direct discharge	Discharge to a receiving water body without further downstream waste water treatment.
Dross	Solid substances formed during the melting or holding of metal at the surface of the molten metal, e.g. by oxidation with air.
Existing plant	A plant that is not a new plant.
Feedstock	Any metal input in the smitheries production process.
Finishing	In foundries, this includes a number of mechanical operations carried out after the casting process including deburring, abrasive cutting, chiselling, needling, fettling, slide grinding, shot blasting and welding. In smitheries, this includes fettling, deburring, machining, cutting and chipping.
Flue-gas	The exhaust gas exiting a combustion unit.
Forging	A deformation and metal-shaping process using heating and hammers (e.g. pneumatic, steam-driven, mechanical, electrical, hydraulic).
Full mould process	Moulding technique using a foam pattern made of expanded polymers (e.g. expanded polystyrene) incorporated in chemically bonded sand. The foam pattern is lost upon pouring. This process is generally used for large castings.

General terms	
Term used	Definition
Gas-hardening processes	Curing processes for cores where a catalyst or hardener is injected in a gaseous form into the core box.
Gravity die-casting	Molten metal is poured directly from a ladle into a die under gravity. After solidification, the die is opened and the metal workpiece is released.
Green sand	Mixture of sand, clay (e.g. bentonite) and additives (e.g. coal dust, cereal binders) used for mould making.
Hazardous substances	Hazardous substances as defined in point 18 of Article 3 of Directive 2010/75/EU.
Heat treatment	A thermal process where castings (in foundries) or workpieces (in smitheries) are heated below their melting point to improve their physical properties.
High-pressure die-casting	Molten metal is forced under pressure into a sealed mould cavity. It is held in place by a powerful compressive power until the metal solidifies. After solidification, the die is opened and the metal workpiece is released.
Hot-curing processes	Curing processes for cores or moulds where the sand binder hardens into a heated core box or a heated pattern, both made of metal or wood.
Indirect discharge	A discharge that is not a direct discharge.
Internal scrap	Internal scrap consists of gates, risers, defective castings, and other metal pieces generated within the installation.
Ladle preheating	Ladles used to transfer molten metal from a melting furnace to the casting process are preheated to a controlled temperature in order to dry the ladle after preparation, to minimise thermal shock and refractory wear during pouring and to reduce temperature losses of the molten metal.
Liquid metal output	The amount of liquid metal produced in the melting furnaces.
Lost foam casting	Foam patterns of the parts to be cast, made of expanded polymers (e.g. expanded polystyrene), are produced using automated moulding machines and assembled together into clusters. The clusters are subsequently incorporated in unbonded sand. Upon pouring, the molten metal causes the pyrolysis of the expanded polystyrene and fills the emptied space.
Low-pressure die-casting	Molten metal is transferred from an airtight furnace through a rising tube into a metal die. The molten metal is pushed upwards into the die under low gas pressure. After solidification, the gas pressure is released allowing the rising tube to fall back into the furnace, the die is opened and the casting is released.
Major plant upgrade	A major change in the design or technology of a plant with major adjustments or replacements of the process and/or abatement technique(s) and associated equipment.
Mass flow	The mass of a given substance or parameter which is emitted over a defined period of time.
Metal melting	The production of ferrous or non-ferrous molten metal using furnaces. This also includes melting of, for example, scrap generated on site and heat conservation of molten metal in holding furnaces.
Moulding	Making of a mould into which the molten metal will be poured. This also includes the making of patterns.
Natural sand	Mixture composed of silica sand (e.g. 85 %), clay (e.g. 15 %) and water. Generally, no other additives are added to the mixture.
New plant	A plant first permitted at the site of the installation following the publication of these BAT conclusions or a complete replacement of a plant following the publication of these BAT conclusions.
Nodular iron	Cast iron with carbon in a nodular/spheroidal shape, commonly referred to as ductile iron.
Nodularisation	Treatment of molten cast iron with magnesium or with a rare-earth element to change the carbon particles into a nodular/spheroidal shape.
Periodic measurement	Measurement at specified time intervals using manual or automated methods.
Heating/reheating	A succession of thermal process steps used to raise the temperature of the feedstock before hammering.
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.
Refining of steel	Steel treatment process to remove carbon (decarburisation) from pig iron (primary refining) followed by removal of impurities.

General terms	
Term used	Definition
Residue	Substance or object generated by the activities covered by the scope of these BAT conclusions as waste or by-product.
Sand reuse	The process of reusing sand in a foundry after sand reconditioning or reclamation.
Sand reconditioning	Any mechanical operation carried out at the installation to reuse green and/or natural sand. This includes screening, removing tramp metal, separating and removing fines and oversized agglomerates. The sand is then cooled and sent for storage/reuse.
Sand reclamation	Any mechanical and/or thermal operation carried out at the installation to reuse chemically bonded sand or mixed sand. This includes an initial mechanical step (e.g. crushing, screening) followed by mechanical (e.g. grinding wheel, impact drum) and/or thermal (e.g. fluidised bed, rotary furnaces) processes in order to remove the residual binders.
Sensitive receptors	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).
Slag	Liquid substances that do not dissolve in liquid metal but separate easily from them and form a separate layer on the liquid metal because of their lower density. Slag is formed by the oxidation of non-metallic elements that are present in the metal charge.
Substances of very high concern	Substances meeting the criteria mentioned in Article 57 and included in the Candidate List of Substances of Very High Concern, according to the REACH Regulation ((EC) No. 1907/2006 ⁷).
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.
Treatment of molten metal	Refining operations in aluminium melting processes which include degassing, grain refining, and fluxing. Degassing (i.e. removal of dissolved hydrogen using nitrogen) is often combined with cleaning (i.e. removal of alkali or alkaline earth metal such as Ca) using Cl ₂ gas.
Valid hourly (or half-hourly) average	An hourly (or half-hourly) average is considered valid when there is no maintenance or malfunction of the automated measuring system.

⁷ 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).

Pollutants and parameters	
Term used	Definition
Amines	Collective term for derivatives of ammonia in which one or more of the hydrogen atoms has been replaced by an alkyl or aryl group.
AOX	Adsorbable organically bound halogens, expressed as Cl, include adsorbable organically bound chlorine, bromine and iodine.
As	The sum of arsenic and its compounds, dissolved or bound to particles, expressed as As.
B[a]P	Benzo[a]pyrene.
BOD ₅	Biochemical oxygen demand. Amount of oxygen needed for the biochemical oxidation of organic and/or inorganic matter in 5 (BOD ₅) days.
Cd	The sum of cadmium and its compounds, dissolved or bound to particles, expressed as Cd.
Cl ₂	Elemental chlorine.
CO	Carbon monoxide.
COD	Chemical oxygen demand. Amount of oxygen needed for the total chemical oxidation of the organic matter to carbon dioxide using dichromate. COD is an indicator for the mass concentration of organic compounds.
Cr	The sum of chromium and its compounds, dissolved or bound to particles, expressed as Cr.
Cu	The sum of copper and its compounds, dissolved or bound to particles, expressed as Cu.
Dust	Total particulate matter (in air).
Fe	The sum of iron and its compounds, dissolved or bound to particles, expressed as Fe.
HCl	Hydrogen chloride.
HF	Hydrogen fluoride.
Hg	The sum of mercury and its compounds, dissolved or bound to particles, expressed as Hg.
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).
Mg	Magnesium.
MgO	Magnesium oxide.
MgS	Magnesium sulphide.
MgSO ₄	Magnesium sulphate.
Ni	The sum of nickel and its compounds, dissolved or bound to particles, expressed as Ni.
NO _x	The sum of nitrogen monoxide (NO) and nitrogen dioxide (NO ₂), expressed as NO ₂ .
PCDD/F	Polychlorinated dibenzo-p-dioxins/furans.
Phenol index	The sum of phenolic compounds, expressed as phenol concentration and measured according to EN ISO 14402.
Pb	The sum of lead and its compounds, dissolved or bound to particles, expressed as Pb (in water). The sum of lead and its compounds, expressed as Pb (in air).
SO ₂	Sulphur dioxide.
TOC	Total organic carbon, expressed as C (in water), includes all organic compounds.
TSS	Total suspended solids. Mass concentration of all suspended solids (in water), measured via filtration through glass fibre filters and gravimetry.
Total nitrogen (TN)	Total nitrogen, expressed as N, includes free ammonia and ammonium nitrogen (NH ₄ -N), nitrite nitrogen (NO ₂ -N), nitrate nitrogen (NO ₃ -N) and organically bound nitrogen.
TVOC	Total volatile organic carbon, expressed as C (in air).
VOC	Volatile organic compound as defined in Article 3(45) of Directive 2010/75/EU.
Zn	The sum of zinc and its compounds, dissolved or bound to particles, expressed as Zn.

Acronyms

For the purposes of these BAT conclusions, the following acronyms apply.

Acronym	Definition
CBC	Cold blast cupola
CMS	Chemicals management system
CMR	Carcinogenic, mutagenic or toxic for reproduction.
CMR 1A	CMR substance of category 1A as defined in Regulation (EC) No 1272/2008 as amended, i.e. carrying the hazard statements H340, H350, H360.
CMR 1B	CMR substance of category 1B as defined in Regulation (EC) No 1272/2008 as amended, i.e. carrying the hazard statements H340, H350, H360.
CMR 2	CMR 2 CMR substance of category 2 as defined in Regulation (EC) No 1272/2008 as amended, i.e. carrying the hazard statements H341, H351, H361.
DMEA	N,N-Dimethylethylamine
EAF	Electric arc furnace
EMS	Environmental management system
ESP	Electrostatic precipitator
HBC	Hot blast cupola
HPDC	High-pressure die-casting
NFM	Non-ferrous metal
OME	Operational material efficiency
OTNOC	Other than normal operating conditions
TEA	Triethylamine

General considerations

Best Available Techniques

The techniques listed and described in these BAT conclusions are neither prescriptive nor exhaustive. Other techniques may be used that ensure at least an equivalent level of environmental protection.

Unless otherwise stated, the BAT conclusions are generally applicable.

Emission levels associated with the best available techniques (BAT-AELs) and indicative emission levels for emissions to air

In foundries, the BAT-AELs and indicative emission levels for emissions to air given in these BAT conclusions refer to concentrations (mass of emitted substances per volume of waste gas) under the following standard conditions: dry gas at a temperature of 273.15 K and a pressure of 101.3 kPa, without correction to a reference oxygen level, and expressed in the unit mg/Nm³ or ng WHO-TEQ/Nm³.

In smitheries, the BAT-AEL and indicative emission level for emissions to air given in these BAT conclusions refer to concentrations (mass of emitted substances per volume of waste gas) under the following standard conditions: dry gas at a temperature of 273.15 K and a pressure of 101.3 kPa, corrected at a reference oxygen level of 3 dry vol-% and expressed in the unit mg/Nm³.

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 in vol-%;
 E_M : measured emission concentration;
 O_M : measured oxygen level in vol-%.

For averaging periods of BAT-AELs and indicative emission levels for channelled emissions to air, the following definitions apply:

Type of measurement	Averaging period	Definition
Continuous	Daily average	Average over a period of 1 day based on valid hourly or half-hourly averages.
Periodic	Average over the sampling period	Average value of three consecutive samplings/measurements of at least 30 minutes each ⁽¹⁾ .
⁽¹⁾ For any parameter where, due to sampling or analytical limitations and/or due to operational conditions (e.g. batch processes), a 30-minute sampling/measurement and/or an average of three consecutive samplings/measurements is inappropriate, a more representative sampling/measurement procedure may be employed. For PCDD/F, one sampling period of 6 to 8 hours is used.		

When the waste gases of two or more sources (e.g. furnaces) are discharged through a common stack, the BAT-AELs apply to the combined discharge from the stack.

For the purpose of calculating the mass flows in relation to BAT 12, where waste gases with similar characteristics, e.g. containing the same (type of) substances/parameters, and discharged

through two or more separate stacks could, in the judgement of the competent authority, be discharged through a common stack, these stacks shall be considered as a single stack.

Emission levels associated with the best available techniques (BAT-AELs) for emissions to water

The BAT-AELs for emissions to water given in these BAT conclusions refer to concentrations (mass of emitted substances per volume of water), expressed in mg/l.

Averaging periods associated with the BAT-AELs refer to either of the following two cases:

- In the case of continuous discharge, daily average values, i.e. 24-hour flow-proportional composite samples.
- In the case of batch discharge, average values over the release duration taken as flow-proportional composite samples, or, provided that the effluent is appropriately mixed and homogeneous, a spot sample taken before discharge.

Time-proportional composite samples can be used provided that sufficient flow stability is demonstrated. Alternatively, spot samples may be taken, provided that the effluent is appropriately mixed and homogeneous.

The BAT-AELs apply at the point where the emission leaves the installation.

Other environmental performance levels associated with the best available techniques (BAT-AEPLs) and indicative levels

BAT-AEPLs for specific energy consumption (foundries)

The BAT-AEPLs for specific energy consumption refer to yearly averages calculated using the following equation:

$$\text{specific energy consumption} = \frac{\text{energy consumption rate}}{\text{activity rate}}$$

where:

energy consumption rate: total amount of heat (generated from primary energy sources) and electricity consumed by the relevant process(es) (melting and holding, ladle preheating) in foundries, expressed in kWh/year; and

activity rate: total amount of liquid metal output, expressed in t/year.

The energy consumption rate corresponds to the total amount of heat (generated from primary energy sources) and electricity consumed by all furnaces in the relevant process(es): melting and holding, ladle preheating.

Indicative levels for specific energy consumption (smitheries)

The indicative levels for specific energy consumption refer to yearly averages calculated using the following equation:

$$\text{specific energy consumption} = \frac{\text{energy consumption rate}}{\text{activity rate}}$$

where:

energy consumption rate: total amount of heat (generated from primary energy sources) and electricity consumed by the plant in smitheries, expressed in kWh/year; and

activity rate: total amount of feedstock, expressed in t/year.

BAT-AEPLs for specific water consumption (foundries)

The BAT-AEPLs for specific water consumption refer to yearly averages calculated using the following equation:

$$\text{specific water consumption} = \frac{\text{water consumption rate}}{\text{activity rate}}$$

where:

water consumption rate: total amount of water consumed by the plant excluding:

- recycled and reused water, and
- cooling water used in once-through cooling systems, and
- water for domestic-type usage, expressed in m³/year; and,

activity rate: total amount of liquid metal output, expressed in t/year.

BAT-AEPLs for specific amount of waste sent for disposal (foundries)

The BAT-AEPLs for specific amount of waste sent for disposal refer to yearly averages calculated using the following equation:

$$\text{specific amount of waste sent for disposal} = \frac{\text{waste disposal rate}}{\text{activity rate}}$$

where:

waste disposal rate: total amount of waste sent for disposal, expressed in kg/year; and

activity rate: total amount of liquid metal output, expressed in t/year.

Indicative levels for operational material efficiency (OME) (foundries)

The indicative levels for OME refer to yearly averages expressed as a percentage and calculated using the following equation:

$$\text{operational material efficiency (OME)} = \frac{\text{good casting rate}}{\text{activity rate}} \times 100$$

where:

- good casting rate: total amount of final castings produced at the installation without defects, expressed in t/year; and
- activity rate: total amount of liquid metal output, expressed in t/year.

BAT-AEPLs for sand reuse (foundries)

The BAT-AEPLs for sand reuse refer to yearly averages expressed as a percentage and calculated using the following equation:

$$\text{sand reuse ratio} = \frac{\text{amount of reused sand}}{\text{total amount of sand used}} \times 100$$

where:

- amount of reused sand: total amount of reused sand, originating from reconditioning or reclamation, expressed in t/year; and
- total amount of sand used: total amount of sand used, expressed in t/year.

4.1 General BAT conclusions

4.1.1 Overall environmental performance

BAT 1. In order to improve the overall environmental performance, BAT is to elaborate and implement an environmental management system (EMS) that incorporates all of the following features:

- i. commitment, leadership, and accountability of the management, including senior management, for the implementation of an effective EMS;
- ii. an analysis that includes the determination of the organisation's context, the identification of the needs and expectations of interested parties, the identification of characteristics of the installation that are associated with possible risks for the environment as well as of the applicable legal requirements relating to the environment and human health;
- 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 smitheries and foundries industry, BAT is also to incorporate the following features in the EMS:

- xxi. an inventory of inputs and outputs (see BAT 2);
- xxii. a chemicals management system (see BAT 3);
- xxiii. a plan for the prevention and control of leaks and spillages (see BAT 4 (a));
- xxiv. an OTNOC management plan (see BAT 5);
- xxv. an energy efficiency plan and audits (see BAT 7 (a));
- xxvi. a water management plan and audits (see BAT 35 (a));
- xxvii. a noise and/or vibration management plan (see BAT 8);
- xxviii. a residues management plan (see BAT 10);
- xxix. an odour management plan for foundries (see BAT 32).

Note

Regulation (EC) No 1221/2009 establishes the European Union eco-management and audit scheme (EMAS), which is an example of an EMS consistent with this BAT.

Applicability

The level of detail and the degree of formalisation of the EMS will generally be related to the nature, scale and complexity of the installation, and the range of environmental impacts it may have.

BAT 2. In order to improve the overall environmental performance, BAT is to establish, maintain and regularly review (including when a significant change occurs) an inventory of inputs and outputs, as part of the EMS (see BAT 1), that incorporates all of the following features:

- (i) information about the production processes, including:
 - (a) simplified process flow sheets that show the origin of the emissions to air, water and soil;
 - (b) descriptions of process-integrated techniques and waste water/waste gas treatment techniques to prevent or reduce emissions, including their performance (e.g. abatement efficiency);
- (ii) information about the quantity and characteristics of raw materials (e.g. scrap, feedstock, sand) and fuels (e.g. coke) used;
- (iii) information about water consumption and usage (e.g. flow diagrams and water mass balances);
- (iv) information about energy consumption and usage;
- (v) information about the characteristics of the waste water streams, such as:
 - (a) average values and variability of flow, pH, temperature and conductivity;
 - (b) average concentration and mass flow values of relevant substances/parameters (e.g. total suspended solids, TOC or COD, hydrocarbon oil index, metals) and their variability;
- (vi) information about the quantity and characteristics of the process chemicals used:
 - (a) the identity and the characteristics of process chemicals, 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 (e.g. dust, NO_x, SO₂, CO, metals) and their variability;
 - (c) presence of other substances that may affect the waste gas treatment system (e.g. oxygen, nitrogen, water vapour) or installation safety;
 - (d) presence of substances classified as CMR 1A, CMR 1B or CMR 2; the presence of such substances may for example be assessed according to the criteria of Regulation (EC) No 1272/2008 on classification, labelling and packaging (CLP);
- (viii) information about the quantity and characteristics of residues generated.

Applicability

The level of detail and the degree of formalisation of the inventory will generally be related to the nature, scale and complexity of the plant, and the range of environmental impacts it may have.

BAT 3. In order to improve the overall environmental performance, BAT is to elaborate and implement a chemicals management system (CMS), as part of the EMS (see BAT 1), that incorporates all of the following features:

- (i) A policy to reduce the consumption 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:
- the comparative analysis of their bioeliminability/biodegradability, ecotoxicity and potential to be released into the environment in order to reduce emissions to the environment;
 - 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;
 - the potential for recovery and reuse (see BAT 17 (f));
 - 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 BAT 11 for foundries);
 - 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 BAT 2 (vi.)) 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 (e.g. see BAT 4).

Applicability

The level of detail and degree of formalisation of the CMS will generally be related to the nature, scale and complexity of the plant.

BAT 4. In order to prevent or reduce emissions to soil and groundwater, BAT is to use all of the techniques given below.

Technique		Description	Applicability
a	Set-up and implementation of a plan for the prevention and control of leaks and spillages	<p>A plan for the prevention and control of leaks and spillages is part of the EMS (see BAT 1) and includes, but is not limited to:</p> <ul style="list-style-type: none"> 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; 	The level of detail of the plan will generally be related to the nature, scale and complexity of

Technique		Description	Applicability
		<ul style="list-style-type: none"> • 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 (at least on an annual basis) inspections of storage and handling areas, testing and calibration of leak detection equipment and prompt repair of leaks from valves, glands, flanges, etc. 	the plant, as well as to the type and quantity of liquids used.
b	Structuring and management of process areas and raw material storage areas	<p>This includes techniques such as:</p> <ul style="list-style-type: none"> • impermeable (for example, cemented) floor for process areas and for scrap/feedstock yards; • separate storage for various types of raw materials, close to the production lines; this can be achieved using, for example, compartments or boxes in the storage areas, bunkers. 	Generally applicable.
c	Prevention of the contamination of surface run-off water	<p>Production areas and/or areas where process chemicals, residues or waste are stored or handled are protected against surface run-off water. This is achieved by using at least the following techniques:</p> <ul style="list-style-type: none"> • drainage channels and/or an outer kerb bund around the plant; • roofing with roof guttering of process and/or storage areas. 	Generally applicable.
d	Collection of potentially contaminated surface run-off water	Surface run-off water from areas that are potentially contaminated is collected separately and only discharged after appropriate measures are taken, e.g. monitoring, treatment, reuse.	Generally applicable.
e	Safe handling and storage of process chemicals	<p>This includes the following:</p> <ul style="list-style-type: none"> • 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; • loading/unloading areas for process chemicals, lubricants and coatings, etc. are designed and constructed in such a way that potential leaks and spillages are contained and sent to on-site treatment (see BAT 36) or off-site treatment. • highly flammable liquids (e.g. methyl formate, TEA, DMEA, mould coatings containing alcohol) are stored separately from incompatible substances (e.g. oxidisers) in enclosed and well-ventilated storage areas. 	Generally applicable.
f	Good housekeeping	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 any spillages).	Generally applicable.

BAT 5. In order to reduce the frequency of the occurrence of OTNOC and to reduce emissions during OTNOC, BAT is to set up and implement a risk-based OTNOC management plan as part of the EMS (see BAT 1) that includes all of the following elements:

- i. identification of potential OTNOC (e.g. failure of equipment critical to the protection of the environment ('critical equipment')), of their root causes and of their potential consequences;
- ii. appropriate design of critical equipment (e.g. off-gas treatment, waste water treatment);
- iii. set-up and implementation of an inspection plan and preventive maintenance programme for critical equipment (see BAT 1 (xii.));
- iv. monitoring (i.e. estimating or, where possible, measuring) and recording of emissions during OTNOC and of associated circumstances;
- v. periodic assessment of the emissions occurring during OTNOC (e.g. frequency of events, duration, amount of pollutants emitted) and implementation of corrective actions if necessary;
- vi. regular review and update of the list of identified OTNOC under point i. following the periodic assessment of point v.;
- vii. regular testing of backup systems.

Applicability

The level of detail and degree of formalisation of the OTNOC management plan will generally be related to the nature, scale and complexity of the plant, and the range of environmental impacts it may have.

4.1.2 Monitoring

BAT 6. BAT is to monitor at least once every year:

- **the consumption of water, energy and materials used, including process chemicals, 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.**

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.

4.1.3 Energy efficiency

BAT 7. In order to increase the overall energy efficiency of the plant, BAT is to use all of the techniques given below.

Technique	Description	Applicability
Management techniques		
a.	<p>Energy efficiency plan and audits</p> <p>An energy efficiency plan is part of the EMS (see BAT 1) and entails defining and monitoring the specific energy consumption of the activity/processes (e.g. kWh/t liquid metal), setting objectives in terms of energy efficiency and implementing actions to achieve these objectives. Audits (also part of the EMS, see BAT 1) are carried out at least once every year to ensure that the objectives of the energy efficiency plan are met and the audits recommendations are followed up and implemented. The energy efficiency plan may be integrated in the overall energy efficiency plan of a larger installation (e.g. surface treatment activities).</p>	<p>The level of detail of the energy efficiency plan, of the audits and of the balance record will generally be related to the nature, scale and complexity of the plant and the types of energy sources used.</p>
b.	<p>Energy balance record</p> <p>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:</p> <ul style="list-style-type: none"> • energy consumption: electricity, natural gas, renewable energy, imported heat and/or cooling; • energy generation: electricity and/or steam. <p>This includes:</p> <ul style="list-style-type: none"> • 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. 	
Process and equipment selection and optimisation		
c.	<p>Use of general energy-saving techniques</p> <p>This includes techniques such as:</p> <ul style="list-style-type: none"> • burner maintenance and control; • energy-efficient motors; • energy-efficient lighting; • optimising steam and compressed air distribution systems; • regular inspection and maintenance of the steam distribution systems to prevent or reduce steam leaks; • process control systems; • variable speed drives; • optimising air conditioning and building heating. 	<p>Generally applicable.</p>

Further sector-specific techniques to increase energy efficiency are given in Sections 4.2.1.3, 4.2.2.1, 4.2.4.1 and 4.3.1 of these BAT conclusions.

4.1.4 Noise and vibrations

BAT 8. In order to prevent or, where that is not practicable, to reduce emissions of noise and vibrations, BAT is to set up, implement and regularly review a noise and/or vibration management plan, as part of the EMS (see BAT 1), that includes all of the following elements:

- a protocol containing appropriate actions and timelines;
- a protocol for monitoring emissions of noise and/or vibrations;
- a protocol for responding to identified noise and vibration events, e.g. managing complaints and/or taking corrective actions;
- a noise and/or vibration reduction programme designed to identify the source(s), to measure/estimate noise and/or vibration exposure, to characterise the contributions of the sources and to implement prevention and/or reduction measures.

Applicability

The applicability is restricted to cases where a noise and/or vibration nuisance at sensitive receptors is expected and/or has been substantiated.

BAT 9. In order to prevent or, where that is not practicable, to reduce noise emissions, BAT is to use one or a combination of the techniques given below.

Technique		Description	Applicability
a.	Appropriate location of equipment and buildings	Increasing the distance between the emitter and the receiver, by using buildings as noise screens and by relocating equipment and/or building openings.	For existing plants, the relocation of equipment and openings of the buildings may not be applicable due to a lack of space and/or excessive costs.
b.	Operational measures	These include at least the following: <ul style="list-style-type: none"> • 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, during production and maintenance activities, transport and handling of feedstock and materials, e.g. reducing the number of material transfer operations, reducing the height from which pieces fall on to hard surfaces. 	Generally applicable.
c.	Low-noise equipment	This includes direct drive motors; low-noise compressors, pumps and fans; low-noise transportation equipment.	
d.	Noise control equipment	This includes techniques such as: <ul style="list-style-type: none"> • use of noise reducers; • use of acoustic insulation of equipment; • enclosure of noisy equipment and processes (e.g. unloading of raw materials, hammering, compressors, fans, shake-out, finishing); • use of building materials with high sound insulation properties (e.g. for walls, roofs, windows, doors). 	Applicability to existing plants may be restricted by a lack of space.

Technique		Description	Applicability
e.	Noise abatement	Inserting obstacles between emitters and receivers (e.g. protection walls, embankments).	Only applicable to existing plants, as the design of new plants should make this technique unnecessary. For existing plants, the insertion of obstacles may not be applicable due to a lack of space.

4.1.5 Residues

BAT 10. In order to increase material efficiency and reduce the amount of waste sent for disposal, BAT is to set up, implement and regularly review a residues management plan.

Description

A residues management plan is part of the EMS (see BAT 1) and comprises a set of measures aiming to:

- I. minimise the generation of residues;
- II. optimise the reuse, recycling and/or recovery of residues, and
- III. ensure the proper disposal of waste.

The residues management plan may be integrated in the overall residues management plan of a larger installation (e.g. surface treatment activities).

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 plant.

4.2 BAT conclusions for foundries

4.2.1 General BAT conclusions for foundries

The BAT conclusions in this section apply in addition to the general BAT conclusions given in Section 4.1.

4.2.1.1 Hazardous substances and substances of very high concern

BAT 11. In order to prevent or reduce the use of hazardous substances and substances of very high concern in moulding and core-making with chemically bonded sand, BAT is to use alternative substances which are non- or less hazardous.

Description

Hazardous substances and substances of very high concern used in moulding and core-making are substituted by non-hazardous substances or – when this is not feasible – by less hazardous substances, by using for example:

- **aliphatic organic (instead of aromatic) binders in moulding and core-making (see BAT 25 (d), (e) and (f));**
- **non-aromatic solvents for cold-box core-making (see BAT 25 (j));**
- **inorganic binders in moulding and core-making (see BAT 25 (d), (e) and (f));**
- **water-based coatings in moulding and core-making (see BAT 25 (l)).**

4.2.1.2 Monitoring of emissions

4.2.1.2.1 Monitoring of emissions to air

BAT 12. BAT is to monitor channelled emissions to air with at least the frequency given below, and in accordance with EN standards. If EN standards are not available, BAT is to use ISO, national or other international standards that ensure the provision of data of an equivalent scientific quality.

Substance/ Parameter	Process(es) /source(s)	Foundry/furnace type	Standard(s)	Minimum monitoring frequency ⁽¹⁾	Monitoring associated with
Amines	Moulding using lost moulds and core-making ⁽²⁾	All	No EN standard available	Once every year	BAT 26
Benzene	Moulding using lost moulds and core-making ⁽³⁾	All	No EN standard available		BAT 26
	Casting, cooling and shake-out using lost moulds including full mould process ⁽³⁾				BAT 27
B[a]P	Metal melting ⁽⁴⁾	Cast iron	No EN standard available	Once every year	-
Carbon monoxide (CO)	Heat treatment ⁽⁵⁾	All	EN 15058	Once every year	BAT 24

Substance/ Parameter		Process(es) /source(s)	Foundry/furnace type	Standard(s)	Minimum monitoring frequency ⁽¹⁾	Monitoring associated with
		Metal melting	Cast iron: CBC, HBC and rotary furnaces			BAT 38
			NFM ⁽⁵⁾			BAT 43
Dust		Heat treatment ⁽⁴⁾	All	EN 13284-1 ⁽⁷⁾ ⁽⁸⁾	Once every year	BAT 24
		Metal melting				Once every year ⁽⁶⁾
		Nodularisation ⁽⁹⁾	Cast iron		Once every year	BAT 39
		Refining	Steel			BAT 41
		Moulding using lost moulds and core-making	All		BAT 26	
		Casting, cooling and shake-out using lost moulds including full mould process	All		BAT 27	
		Finishing	All		BAT 30	
		Lost foam casting	Cast iron and NFM		BAT 28	
		Casting in permanent moulds	All		BAT 29	
Sand reuse	All	BAT 31				
Formaldehyde ⁽⁴⁾		Moulding using lost moulds and core-making	All	EN standard under development	Once every year	BAT 26
		Casting, cooling and shake-out using lost moulds including full mould process				Once every year
Gaseous chlorides		Metal melting	Cast iron: CBC, HBC and rotary furnaces ⁽⁴⁾	EN 1911	Once every year	BAT 38
			Aluminium ⁽⁴⁾			BAT 43
Gaseous fluorides		Metal melting	Cast iron: CBC, HBC and rotary furnaces ⁽⁴⁾	EN standard under development	Once every year	BAT 38
			Aluminium			BAT 43
Metals	Cadmium and its compounds	Casting, cooling and shake-out using lost moulds including full mould process ⁽⁴⁾	All	EN 14385	Once every year	-
		Metal melting	All			Once every year

Substance/ Parameter	Process(es) /source(s)	Foundry/furnace type	Standard(s)	Minimum monitoring frequency (1)	Monitoring associated with	
Chromium and its compounds	Finishing (4)	All	EN 14792	Once every year	-	
	Casting, cooling and shake-out using lost moulds including full mould process(4)	All		Once every year	-	
		Metal melting (4)		All	Once every year	-
		Finishing (4)		All	Once every year	-
	Nickel and its compounds	Casting, cooling and shake-out using lost moulds including full mould process(4)		All	Once every year	-
		Metal melting (4)		All	Once every year	-
		Finishing (4)		All	Once every year	-
	Lead and its compounds	Casting, cooling and shake-out using lost moulds including full mould process (4)		All	Once every year	-
		Metal melting		<u>Cast iron</u> : CBC and HBC (4)	Once every year	BAT 38
				NFM (10)	Once every year	BAT 43
		Casting in permanent moulds		Lead	Once every year	BAT 29
		Finishing (4)		All	Once every year	-
	Zinc and its compounds	Metal melting (4)		All	Once every year	-
	Nitrogen oxides (NO _x)	Heat treatment (5)		All	EN 14792	Once every year
Thermal sand regeneration, except for sand originating from the cold-box process (5)		All	Once every year	BAT 31		
				Thermal regeneration of sand originating from the cold- box process		
Metal melting		<u>Cast iron</u> : CBC, HBC and rotary furnaces NFM (5)	Once every year	BAT 43		

Substance/ Parameter	Process(es) /source(s)	Foundry/furnace type	Standard(s)	Minimum monitoring frequency ⁽¹⁾	Monitoring associated with		
PCDD/F	Metal melting	Cast iron: CBC, HBC and rotary furnaces	EN 1948-1, EN 1948-2, EN 1948-3		BAT 38		
		Cast iron: Induction ⁽⁴⁾			BAT 38		
		Steel and NFM ⁽⁴⁾			BAT 40 BAT 43		
Phenol	Moulding using lost moulds and core-making ⁽¹¹⁾	All	No EN standard available	Once every year	BAT 26		
	Casting, cooling and shake-out using lost moulds including full mould process ⁽¹¹⁾				BAT 27		
Sulphur dioxide (SO ₂)	Thermal regeneration of sand in which sulphonic acid catalysts have been used	All	EN 14791		BAT 31		
	Metal melting	Cast iron: CBC, HBC and rotary furnaces			BAT 38		
		NFM ⁽⁵⁾ ⁽¹²⁾			BAT 43		
Total volatile organic carbon (TVOC)	Moulding using lost moulds and core-making	All	EN 12619	Once every year	BAT 26		
	Lost foam, casting				BAT 28		
	Casting, cooling and shake-out using lost moulds including full mould process				BAT 27		
	Sand reuse				BAT 31		
	Metal melting				Cast iron	BAT 38	
					Steel and NFM ⁽⁴⁾	-	
	Casting in permanent moulds ⁽¹³⁾				All ⁽⁴⁾		BAT 29

Substance/ Parameter	Process(es) /source(s)	Foundry/furnace type	Standard(s)	Minimum monitoring frequency ⁽¹⁾	Monitoring associated with
⁽¹⁾ To the extent possible, the measurements are carried out at the highest expected emission state under normal operating conditions. ⁽²⁾ The monitoring only applies in the cold-box process when amines are used. ⁽³⁾ The monitoring only applies when aromatic binders/chemicals are used or when the full mould process is used. ⁽⁴⁾ The monitoring only applies when the substance/parameter concerned is identified as relevant in the waste gas stream based on the inventory of inputs and outputs mentioned in BAT 2. ⁽⁵⁾ The monitoring does not apply when only electricity is used. ⁽⁶⁾ For any stack associated with a cupola furnace and with a dust mass flow > 0.5 kg/h, continuous monitoring applies. ⁽⁷⁾ If measurements are continuous, the following generic EN standards apply instead: EN 15267-1, EN 15267-2, EN 15267-3, and EN 14181. ⁽⁸⁾ If measurements are continuous, EN 13284-2 also applies. ⁽⁹⁾ The monitoring does not apply when BAT 39 (a) is used. ⁽¹⁰⁾ The monitoring only applies to lead foundries or to other NFM foundries using lead as an alloying element. ⁽¹¹⁾ The monitoring only applies when phenolic-based binder systems are used. ⁽¹²⁾ The monitoring does not apply when only natural gas is used. ⁽¹³⁾ The monitoring only applies when cores with chemically bonded sand are used.					

4.2.1.2.2 Monitoring of emissions to water

BAT 13. BAT is to monitor emissions to water with at least the frequency given below, and in accordance with EN standards. If EN standards are not available, BAT is to use ISO, national or other international standards that ensure the provision of data of an equivalent scientific quality.

Substance/parameter	Process	Standard(s)	Minimum monitoring frequency ⁽¹⁾	Monitoring associated with	
Adsorbable organically bound halogens (AOX) ⁽²⁾	Waste water from wet scrubbing of cupola off-gases	EN ISO 9562	Once every 3 months ⁽³⁾	BAT 36	
Biochemical oxygen demand (BOD ₅) ⁽³⁾	Die-casting, off-gas treatment (e.g. wet scrubbing), finishing, heat treatment, contaminated surface run-off water, direct cooling, wet sand regeneration and cupola furnace slag granulation.	Various EN standards available (e.g. EN 1899-1, EN ISO 5815)			
Chemical oxygen demand (COD) ⁽³⁾ ⁽⁴⁾		No EN standard available			
Hydrocarbon oil index (HOI) ⁽²⁾		EN ISO 9377-2			
Metals/ metalloids		Arsenic (As) ⁽²⁾			Various EN standards available (e.g. EN ISO 11885, EN ISO 15586, EN ISO 17294-2)
		Cadmium (Cd) ⁽²⁾			
		Chromium (Cr) ⁽²⁾			
		Copper (Cu) ⁽²⁾			
		Iron (Fe) ⁽²⁾			
		Lead (Pb) ⁽²⁾			
Nickel (Ni) ⁽²⁾		Various EN standards available (e.g. EN ISO 12846, EN ISO 17852)			
Zinc (Zn) ⁽²⁾					
Mercury (Hg) ⁽²⁾	Various EN standards available (e.g. EN ISO 12846, EN ISO 17852)				
Phenol index ⁽⁵⁾	EN ISO 14402				
Total nitrogen (TN) ⁽³⁾	Various EN standards available (e.g. EN				

Substance/parameter	Process	Standard(s)	Minimum monitoring frequency ⁽¹⁾	Monitoring associated with
		12260, EN ISO 11905-1)		
Total organic carbon (TOC) ⁽³⁾ ⁽⁴⁾		EN 1484		
Total suspended solids (TSS) ⁽³⁾		EN 872		

(¹) In the case of batch discharge less frequent than the minimum monitoring frequency, monitoring is carried out once per batch.
(²) The monitoring only applies when the substance/parameter is identified as relevant in the waste water stream based on the inventory of inputs and outputs mentioned in BAT 2.
(³) In the case of an indirect discharge, the minimum monitoring frequency may be reduced to once every 6 months if the downstream waste water treatment plant is designed and equipped appropriately to abate the pollutants concerned.
(⁴) Either COD or TOC is monitored. TOC monitoring is the preferred option because it does not rely on the use of very toxic compounds.
(⁵) The monitoring only applies when phenolic binding systems are used.

4.2.1.3 Energy efficiency

BAT 14. In order to increase energy efficiency, BAT is to use all of the techniques (a) to (f), and an appropriate combination of the techniques (g) to (n) given below.

Technique	Description	Applicability
Design and operation		
a.	Selection of an energy-efficient type of furnace See Section 4.4.1.	Only applicable to new plants and/or major plant upgrades.
b.	Techniques for maximising the thermal efficiency of furnaces See Section 4.4.1.	Generally applicable.
c.	Furnace automation and control See Section 4.4.1.	Generally applicable.
d.	Use of clean scrap See Section 4.4.1.	Generally applicable.
e.	Improving casting yield and decreasing scrap generation See Section 4.4.1.	Generally applicable.
f.	Reducing energy losses/improving ladle preheating practices This includes all of the following elements: <ul style="list-style-type: none"> • use of clean preheated ladles; • keeping closed lids on ladles to preserve heat; • use of energy-efficient techniques for preheating ladles (e.g. flameless microporous burners or oxy-fuel burners); • use of large (as practically possible) ladles fitted with heat-retaining covers; • minimising the molten metal transfer from one ladle to another; • transferring the molten metal as quickly as possible. 	Applicability may be restricted in the case of big ladles (e.g. > 2 t) and bottom pouring ladles due to design constraints.
g.	Oxy-fuel combustion See Section 4.4.1.	Applicability to existing plants may be restricted by furnace design and the need for a minimum waste gas flow.
h.	Use of medium-frequency power in induction furnaces Use of medium-frequency (250 Hz) induction furnaces instead of mains frequency (50 Hz) furnaces.	Generally applicable.

Technique		Description	Applicability
i.	Compressed air system optimisation	This includes all of the following measures: <ul style="list-style-type: none"> • applying an 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. 	Generally applicable.
j.	Microwave drying of cores for water-based coatings	Use of microwave drying ovens (e.g. with a frequency of 2 450 Hz) for drying cores coated with water-based coatings (see BAT 21 (e)), resulting in rapid and homogeneous drying of the entire core surface.	May not be applicable to continuous casting processes or to the production of large castings, or when cores are made of reclaimed sand containing traces of carbon.
Heat recovery techniques			
k.	Scrap preheating using recovered heat	Scrap is preheated by recovering the heat from hot flue-gases which are redirected to come into contact with the charge.	Only applicable to shaft furnaces in non-ferrous metal foundries and to EAFs in steel foundries.
l.	Heat recovery from off-gases generated in furnaces	Waste heat from hot off-gases is recovered (e.g. through heat exchangers) and reused on site or off site (e.g. in thermal oil/hot water/heating circuits, for steam generation or for preheating of combustion air (see technique (m))). This may include the following: <ul style="list-style-type: none"> • Excess heat from cupola hot off-gases is used for example for steam production, thermal oil heating, water heating. • Excess heat from the furnace cooling system is used for example for drying of raw material, space heating, water heating. • In fuel-fired furnaces in aluminium foundries, excess heat is used for example for heating the premises and/or the water for the casting cleaning facility. • Low-grade heat is converted into electricity using high-molecular-weight fluids by using the Organic Rankine Cycle (ORC). 	Applicability may be restricted by the lack of a suitable heat demand.
m.	Preheating of combustion air	See Section 4.4.1.	Generally applicable.
n.	Waste heat utilisation in induction furnaces	Waste heat from the induction furnace cooling system is recovered using heat exchangers for drying raw materials (e.g. scrap), space heating or hot water supply.	Generally applicable.

Further sector-specific techniques to increase energy efficiency are given in Sections 4.2.2.1 and 4.2.4.1 of these BAT conclusions.

Table 4.1: BAT-associated environmental performance levels (BAT-AEPLs) for specific energy consumption in cast iron foundries

Process – Furnace type	Unit	BAT-AEPL (Yearly average)
Melting and holding – Cold blast cupola	kWh/t of liquid metal	900 – 1 750
Melting and holding – Hot blast cupola		900 – 1 500
Melting and holding – Induction		600 – 1 200
Melting and holding – Rotary		800 – 950
Ladle preheating		50 – 150 ⁽¹⁾
⁽¹⁾ For foundries producing large castings, the upper end of the BAT-AEPL range may be higher and up to 200 kWh/t of liquid metal.		

Table 4.2: BAT-associated environmental performance levels (BAT-AEPLs) for specific energy consumption in steel foundries

Process – Furnace type	Unit	BAT-AEPL (Yearly average)
Melting – (EAF/induction)	kWh/t of liquid metal	600 – 1 200
Ladle preheating		100 – 300

Table 4.3: BAT-associated environmental performance levels (BAT-AEPLs) for specific energy consumption in aluminium foundries

Process	Unit	BAT-AEPL (Yearly average)
Melting and holding	kWh/t of liquid metal	600 – 2 000

The associated monitoring is given in BAT 6.

4.2.1.4 Material efficiency

4.2.1.4.1 Storage and handling of residues, packaging and unused process chemicals

BAT 15. In order to prevent or reduce the environmental risk associated with the storage and handling of residues, packaging and unused process chemicals and to facilitate their reuse and/or recycling, BAT is to use all of the techniques given below.

Technique	Description
a. Appropriate storage of various residue types	This includes the following: <ul style="list-style-type: none"> Fabric filter dust is stored on impermeable surfaces, in enclosed areas and in closed containers/bags. Other residue types (e.g. slag, dross, spent furnace refractory linings) are stored separately from each other on impermeable surfaces in covered areas protected from surface run-off water.
b. Reuse of internal scrap	Reuse of internal scrap directly or after treatment. The degree of reuse of internal scrap depends on its content of impurities.
c. Reuse/recycling of packaging	Process chemicals packaging is selected to facilitate its complete emptying (e.g. considering the size of the packaging aperture or the nature of the packaging material). After emptying, the packaging is reused, returned to the supplier or sent for material recycling. Preferably, process chemicals are stored in large containers.

d.	Return of unused process chemicals	Unused process chemicals (i.e. which remain in their original containers) are returned to their suppliers.
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4.2.1.4.2 Operational material efficiency in the casting process

BAT 16. In order to increase material efficiency in the casting process, BAT is to use either technique (a) or technique (a) in combination with one or both of the techniques (b) and (c) given below.

Technique		Description
a.	Improving casting yield and decreasing scrap generation	See Section 4.4.2
b.	Use of computer-aided simulation for casting, pouring and solidification	A computer simulation system is used to optimise the casting, pouring and solidification process, to minimise the number of defective castings and increase foundry productivity.
c.	Production of light-weight castings using topology optimisation	Use of topology optimisation (i.e. casting simulation by means of algorithms and computer programs) to reduce the product mass while meeting the product performance requirements.

Table 4.4: Indicative levels for operational material efficiency

Foundry type	Unit	Indicative levels (Yearly average)
Cast iron foundries	%	50 – 97 ⁽¹⁾ ⁽²⁾
Steel foundries		50 – 100 ⁽¹⁾ ⁽²⁾
NFM foundries (all types except HPDC) – Pb		50 – 97.5 ⁽¹⁾
NFM foundries (all types except HPDC) – metals other than Pb		50 – 98 ⁽¹⁾
NFM foundries (HPDC)		60 – 97 ⁽¹⁾
⁽¹⁾ The lower end of the range is typically associated with the production of complex casting shapes due, for example, to the high number of cores and/or risers/feeders used.		
⁽²⁾ The upper end of the range is typically associated with centrifugal casting.		

The associated monitoring is given in BAT 6.

4.2.1.4.3 Reduction of material consumption

BAT 17. In order to reduce material (e.g. chemicals, binders) consumption, BAT is to use an appropriate combination of the techniques given below.

Technique	Description	Applicability
Techniques for aluminium high-pressure die-casting		
a.	Separate spraying of release agent and water	See Section 4.4.2.
b.	Minimisation of release agent and water consumption	Measures to minimise the consumption of release agent and water include: <ul style="list-style-type: none"> • use of an automated spraying system; • optimisation of the release agent's dilution factor; • application of in-die cooling; • closed-mould application of release agent;
		Generally applicable.

Technique		Description	Applicability
		<ul style="list-style-type: none"> measuring the consumption of release agents; measuring the die surface temperature to indicate hotspots in the die. 	
Techniques for processes using chemically bonded sand and core-making			
c.	Optimisation of binder and resin consumption	See Section 4.4.2.	Generally applicable.
d.	Minimisation of mould and core sand losses	Production parameters of the various product types are stored in an electronic database that allows easy changeover to new products with minimised losses in time and materials.	Generally applicable.
e.	Use of best practices for cold-setting processes	See Section 4.4.2.	Generally applicable.
f.	Recovery of amines from acid scrubbing water	When acid washing is used (e.g. using sulphuric acid) to treat the cold-box off-gases, amine sulphate is formed. The amines are recovered from the treatment of amine sulphate using sodium hydroxide. This may take place on site or off site.	Applicability may be restricted due to safety considerations (explosion hazard).
g.	Use of best practices for gas-hardening processes	See Section 4.4.2.	Generally applicable.
h.	Applying alternative moulding/core-making processes	<p>Alternative moulding/core-making processes using no or a reduced amount of binders include:</p> <ul style="list-style-type: none"> lost foam casting process; vacuum moulding. 	<p>Applicability of the lost foam casting process to existing plants may be restricted due to the required infrastructure modifications.</p> <p>Applicability of vacuum moulding may be restricted in the case of large moulding boxes (e.g. above 1.5 m x 1.5 m).</p>

4.2.1.4.4 Sand reuse

BAT 18. In order to reduce the consumption of new sand and the generation of spent sand from sand reuse in the lost mould casting process, BAT is to use one or an appropriate combination of the techniques given below.

Technique		Description	Applicability
a.	Optimised reconditioning of green sand	The green sand reconditioning process is controlled by a computer system to optimise raw material consumption and green sand reuse, e.g. cooling (evaporative or fluidised bed), addition of binders and additives, moistening, mixing, quality control.	Generally applicable.
b.	Low-waste green sand reconditioning	Green sand reconditioning in aluminium foundries is carried out using a scanner for identifying impurities in green sand based on brightness/colour. These impurities are separated from green sand using an air blast pulse.	Generally applicable.
c.	Preparation of clay-bonded sand by vacuum mixing and cooling	See BAT 25 (b).	Generally applicable.

Technique		Description	Applicability
d.	Mechanical reclamation of cold-setting sand	Mechanical techniques (e.g. breaking of lumps, segregation of sand fractions) using crushers or mills are used to reclaim cold-setting sand.	May not be applicable to silicate-bonded sand.
e.	Cold mechanical reclamation of clay-bonded or chemically bonded sand using a grinding wheel	Use of a rotating grinding wheel to remove clay layers and chemical binders from used sand grains.	Generally applicable.
f.	Cold mechanical reclamation of sand using an impact drum	Use of an impact drum with a spinning internal axis, equipped with small blades, for abrasive cleaning of sand grains. When applied on a mixture of bentonite and chemically bonded sand, a preliminary magnetic separation is carried out to remove parts with magnetic properties from the green sand.	Generally applicable.
g.	Cold reclamation of sand using a pneumatic system	Removal of binders from the sand grains using abrasion and impact. The kinetic energy is provided by a compressed air stream.	Generally applicable.
h.	Thermal reclamation of sand	Use of heat to burn binders and contaminants contained in chemically bonded and mixed sand. This is combined with an initial mechanical pretreatment to bring the sand to the correct grain size and remove any metallic contaminant. In the case of mixed sand, the share of chemically bonded sand should be high enough.	May not be applicable in the case of used sand containing residues from inorganic binders.
i.	Combined reclamation (mechanical-thermal-mechanical) for mixed organic-bentonite sands	After pretreatment (sieving, magnetic separation) and drying, sand is mechanically or pneumatically cleaned to remove part of the binder. In the thermal step, organic constituents are burned and inorganic constituents are transferred to the dust or burned onto the grains. In a final mechanical treatment, these grain layers are removed mechanically or pneumatically and discarded as dust.	May not be applicable for core sands containing acidic binders (because it may alter bentonite characteristics) or in the case of water glass (because it may alter green sand characteristics).
j.	Combined sand reclamation and heat treatment of aluminium castings	After pouring and solidification, moulds/casting units are loaded into the furnace. When the units reach a temperature > 420 °C, the binders are burnt, the cores/moulds disintegrate, and the castings undergo heat treatment. The sand falls to the bottom of the furnace for final cleaning in a heated fluidised bed. After cooling, the sand is reused in the core sand mixer without further treatment.	Generally applicable.
k.	Wet reclamation for green sand, silicate- or CO ₂ -bonded sands	Sand is mixed with water to produce a sludge. The removal of grain-bound binder residues is performed through intensive inter-particle rubbing of the sand grains. The binders are released into the wash water. The washed sand is dried, screened and finally cooled.	Generally applicable.
l.	Reclamation of sodium silicate sand (water glass) using a pneumatic system	Sand is heated to make the silicate layer brittle before the use of a pneumatic system (see technique (g)). The reclaimed sand is cooled before reuse.	Generally applicable.
m.	Internal reuse of core sand (cold-box or furan-acid binders)	Sand resulting from broken/faulty cores, and excess sand from the core-making machines (after hardening in a specific unit), are fed to a breaking unit. The resulting sand is mixed with new sand for the production of new cores.	Generally applicable.

Technique		Description	Applicability
n.	Reuse of dust from the green sand circuit in mould making	Dust is collected through the exhaust filtration from the shake-out installation and from the dosing and handling stations for dry green sand. The collected dust (containing active binder compounds) can be recycled into the green sand circuit.	Generally applicable.

Table 4.5: BAT-associated environmental performance levels (BAT-AEPLs) for sand reuse

Foundry type	Unit	BAT-AEPL ⁽¹⁾ (Yearly average)
Cast iron foundries	%	> 90
Steel foundries	%	> 80
NFM foundries ⁽²⁾	%	> 90

⁽¹⁾ The BAT-AEPLs may not apply when the quantity of used sand is lower than 10 000 t/year.
⁽²⁾ The BAT-AEPL may not apply in aluminium die casting foundries when water glass is used.

The associated monitoring is given in BAT 6.

4.2.1.4.5 Reduction of generated residues and of waste sent for disposal

BAT 19. In order to reduce the amount of residues generated in metal melting and to reduce the amount of waste sent for disposal, BAT is to use all of the techniques given below.

Technique		Description
Techniques for all furnace types		
a.	Minimisation of slag forming	Slag forming can be minimised by in-process measures, such as: <ul style="list-style-type: none"> • using clean scrap; • using a lower metal temperature (as close as possible to the theoretical melting point); • avoiding high temperature peaks; • preventing extended holding of molten metal in the melting furnace or using a separate holding furnace; • making adequate use of fluxes; • making adequate choice of the furnace refractory lining; • applying water cooling of the furnace walls to avoid the wear of the furnace refractory lining; • liquid aluminium skimming.
b.	Mechanical pretreatment of slag / dross / filter dust / spent refractory linings to facilitate recycling	See Section 4.4.2. This may also take place off site.
Techniques for cupola furnaces		
c.	Adjustment of the slag acidity/basicity	See Section 4.4.2.
d.	Collection and recycling of coke breeze	Coke breeze generated during handling, transport and charging of coke is collected (e.g. by using collection systems below conveyor belts and/or charging points) and recycled in the process (injected into the cupola furnace or used for recarburisation).
e.	Recycling of filter dust in cupola furnaces using zinc-containing scraps	Cupola filter dust is partially re-injected into the cupola furnace in order to increase the zinc content in the dust, up to a level that allows Zn recovery (> 18 %).
Techniques for EAFs		
f.	Recycling of filter dust in the EAF	Collected dry filter dust, usually after pretreatment (e.g. by pelletising or briquetting), is recycled in the furnace to enable the recovery of the

Technique	Description
	metallic content of the dust. The inorganic content is transferred to the slag.

BAT 20. In order to reduce the amount of waste sent for disposal, BAT is to prioritise off-site recycling and/or other recovery over disposal for spent sand, undersize sand, slags, refractory linings and collected filter dust (e.g. fabric filter dust).

Description

Off-site recycling and/or other recovery have priority over disposal for spent sand, undersize sand, slags, refractory linings and filter dust. Spent sand, undersize sand, slags and refractory linings can be:

- recycled, e.g. in road construction, building materials (such as cement, bricks, tiles);
- recovered, e.g. filling of mining cavities, landfill construction (such as roads on landfills and permanent covers).

Filter dust can be externally recycled, e.g. in metallurgy, sand fabrication, the construction sector.

Applicability

Recycling and/or other recovery may be restricted by the physico-chemical properties of the residue (e.g. organic/metal content, granulometry).

It may not be applicable in the case of absence of a suitable third-party demand for recycling and/or recovery.

Table 4.6: BAT-associated environmental performance levels (BAT-AEPLs) for waste sent for disposal

Waste type	Unit	BAT-AEPL ⁽¹⁾ (Yearly average)		
		NFM foundries	Cast iron foundries	Steel foundries
Slag	kg/t of liquid metal	0 – 50	0 – 50 ⁽²⁾	0 – 50 ⁽²⁾
Dross		0 – 30	0 – 30	0 – 30
Filter dust	kg/t of liquid metal	0 – 5	0 – 60	0 – 10
Spent furnace refractory linings		0 – 5	0 – 20 ⁽³⁾	0 – 20

⁽¹⁾ The BAT-AEPL may not apply in the absence of a suitable third-party demand for recycling and/or recovery.

⁽²⁾ For steel or cast iron foundries operating EAFs, the upper end of the BAT-AEPL range may be higher and up to 100 kg/t of liquid metal due to increased slag formation during the metallurgical treatment.

⁽³⁾ For cast iron foundries operating CBC, the upper end of the BAT-AEPL range may be higher and up to 100 kg/t of liquid metal.

The associated monitoring is given in BAT 6.

4.2.1.5 Diffuse emissions to air

BAT 21. In order to prevent or, where that is not practicable, to reduce diffuse emissions to air, BAT is to use all of the techniques given below.

Technique		Description	Applicability
a.	Covering the delivery equipment (containers) and the cargo space of transport vehicles	Cargo space of transport vehicles and delivery equipment (containers) are covered (e.g. with tarpaulins).	Generally applicable.
b.	Cleaning roads and transport vehicle wheels	Roads as well as the wheels of transport vehicles are regularly cleaned, e.g. by using mobile vacuum systems, water lagoons.	Generally applicable.
c.	Using closed conveyors	Materials are transferred using conveyor systems, e.g. closed conveyors, pneumatic conveying. Material drops are minimised.	Generally applicable.
d.	Vacuum cleaning of moulding and casting process areas	The moulding and casting process areas in sand moulding foundries are regularly vacuum-cleaned.	May not be applicable in areas where the sand has a technical or safety-related function.
e.	Substitution of alcohol-based coatings with water-based coatings	See Section 4.4.3.	Applicability may be restricted in the case of large or complex casting shapes because of difficulties for circulation of the drying air. Not applicable to water-glass-bonded sands, the magnesium casting process, vacuum moulding or the production of manganese steel castings with MgO coating.
f.	Control of emissions from quenching baths	This includes the following: <ul style="list-style-type: none"> • Minimising the generation of emissions from quenching baths by using water-based polymer solutions (e.g. containing polyvinylpyrrolidone or polyalkylene glycol). • Collecting emissions from quenching baths (especially from oil quenching baths) as close as possible to the emission source, using roof ventilation, extraction domes or edge extractors. Extracted off-gases may be treated, e.g. by using an ESP (see Section 4.4.3). • Use of tempered water as quenching media. 	Generally applicable.
g.	Control of emission from transfer operations in metal melting	This includes the following: <ul style="list-style-type: none"> • Extraction as close as possible to the source of diffuse emissions (e.g. dust, fumes) from transfer processes such as furnace charging/tapping using hoods for example. The extracted off-gases are treated using for example fabric filter, wet scrubbing. • Minimisation of diffuse emissions from liquid metal transfer through launders using covers for example. 	Generally applicable.

Further process-specific techniques to prevent or reduce diffuse emissions are given in BAT 24, BAT 26, BAT 27, BAT 28, BAT 29, BAT 30, BAT 31, BAT 38, BAT 39, BAT 40, BAT 41 and BAT 43.

4.2.1.6 Channelled emissions to air

BAT 22. In order to facilitate the recovery of materials and the reduction of channelled emissions to air, as well as to increase energy efficiency, BAT is to combine waste gas streams with similar characteristics, thus minimising the number of emission points.

Description

The combined treatment of waste gases with similar characteristics ensures more effective and efficient treatment compared to the separate treatment of individual waste gas streams. The combination of waste gases is carried out considering plant safety (e.g. avoiding concentrations close to the lower/upper explosive limit), technical (e.g. compatibility of the individual waste gas streams, concentration of the substances concerned), environmental (e.g. maximising recovery of materials or pollutant abatement) and economic factors (e.g. distance between different production units). Care is taken that the combination of waste gases does not lead to the dilution of emissions.

4.2.1.7 Emissions to air from thermal processes

BAT 23. In order to prevent or reduce emissions to air from metal melting, BAT is to use either electricity generated from fossil-free energy sources in combination with techniques (a) to (e), or techniques (a) to (e) and an appropriate combination of the techniques (f) to (i) given below.

	Technique	Description	Applicability
General techniques			
a.	Selection of an appropriate furnace type and maximisation of the thermal efficiency of furnaces	See Section 4.4.1	The selection of an appropriate furnace type is only applicable to new plants and major plant upgrades.
b.	Use of clean scrap	See Section 4.4.1	Generally applicable.
Primary control measures to minimise PCDD/F emissions			
c.	Maximisation of the off-gases' residence time and optimisation of the temperature in the post-combustion chamber in cupola furnaces	In cupola furnaces, the temperature of the post-combustion chamber is optimised ($T > 850\text{ }^{\circ}\text{C}$) and continuously monitored while the off-gases' residence time is maximised ($> 2\text{ s}$).	Generally applicable.
d.	Rapid off-gas cooling	The off-gas is cooled rapidly from temperatures above $400\text{ }^{\circ}\text{C}$ to below $250\text{ }^{\circ}\text{C}$ before dust abatement to prevent the de novo synthesis of PCDD/F. This is achieved by appropriate design of the furnace and/or the use of a quench system.	
e.	Minimising dust build-up in heat exchangers	The build-up of dust along the cooling trajectory of the off-gases is minimised, especially in the heat exchangers, e.g. by using vertical exchanger tubes, efficient internal cleaning of the exchanger tubes, high-temperature de-dusting.	
Techniques for reducing the generation of NO_x and SO_2 emissions			
f.	Use of a fuel or a combination of fuels	Fuels with a low NO_x formation potential include natural gas and liquefied petroleum gas.	Applicable within the constraints associated with the

	Technique	Description	Applicability
	with low NO _x formation potential		availability of different types of fuel, which may be impacted by the energy policy of the Member State.
g.	Use of a fuel or a combination of fuels with low sulphur content	Fuels with low sulphur content include natural gas and liquefied petroleum gas.	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.
h.	Low-NO _x burners	See Section 4.4.3.	Applicability to existing plants may be restricted by furnace design and/or operational constraints.
i.	Oxy-fuel combustion	See Section 4.4.3.	Applicability to existing plants may be restricted by furnace design and the need for a minimum waste gas flow.

The BAT-AELs for metal melting are given:

- in Table 4.18 for cast iron foundries;
- in Table 4.20 for steel foundries;
- in Table 4.21 for NFM foundries.

BAT 24. In order to prevent or reduce emissions to air from heat treatment, BAT is to use either electricity generated from fossil-free energy sources in combination with techniques (a) and (d), or all of the techniques given below.

	Technique	Description	Applicability
General techniques			
a.	Selection of an appropriate furnace type and maximisation of the thermal efficiency of furnaces	See Section 4.4.3	Only applicable to new plants and major plant upgrades.
Techniques for reducing the generation of NO_x emissions			
b.	Use of a fuel or a combination of fuels with low NO _x formation potential	Fuels with a low NO _x formation potential include natural gas and liquefied petroleum gas.	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.
c.	Low-NO _x burners	See Section 4.4.3.	Applicability to existing plants may be restricted by furnace design and/or operational constraints.
Collection of emissions			

	Technique	Description	Applicability
d.	Off-gas extraction as close as possible to the emission source	Off-gases from heat treatment furnaces (e.g. annealing, ageing, normalising, austempering) are extracted using hoods or cover extraction. The collected emissions may be treated using techniques such as fabric filters.	Generally applicable.

Table 4.7: BAT-associated emission levels (BAT-AELs) for channelled emissions to air of dust and NO_x and indicative emission level for channelled emissions to air of CO from heat treatment

Substance/ Parameter	Unit	BAT-AEL (Daily average or average over the sampling period)	Indicative emission level (Daily average or average over the sampling period)
Dust	mg/Nm ³	1 – 5 ⁽¹⁾	No indicative level
NO _x		20 – 120 ⁽²⁾ ⁽³⁾	No indicative level
CO		No BAT-AEL	10 – 100 ⁽³⁾

⁽¹⁾ The BAT-AEL only applies when the substance/parameter concerned is identified as relevant in the waste gas streams based on the inventory of inputs and outputs mentioned in BAT 2.
⁽²⁾ In the case of heat treatment over 1 000 °C (e.g. for the production of malleable iron), the upper end of the BAT-AEL range may be higher and up to 300 mg/Nm³.
⁽³⁾ The BAT-AEL and indicative emission level do not apply in the case of furnaces using only electric energy (e.g. resistance).

The associated monitoring is given in BAT 12.

[This BAT conclusion is based on information given in BREF Section 3.2.1.8]

4.2.1.8 Emissions to air from moulding using lost moulds and core-making

BAT 25. In order to prevent or reduce emissions to air from moulding using lost moulds and core-making, BAT is to:

- use an appropriate combination of the techniques (a) to (c) given below in the case of moulding with clay-bonded sand;
- use either technique (d), (e) or (f) and an appropriate combination of the techniques (g) to (k) given below, in the case of moulding and core-making with chemically bonded sand;
- use technique (l) given below for selecting the coatings applied to moulds and cores.

	Technique	Description	Applicability
Techniques for moulding with clay-bonded sand (green sand)			
a.	Use of best practices for green sand moulding	This includes techniques such as: <ul style="list-style-type: none"> • precise addition of the required quantity of key components (e.g. clay, water, coal dust or other additives) to restore the chemical properties of the returned green sand; • regular testing (e.g. daily) of the green sand properties (e.g. moisture, green strength, compactability, permeability, loss on ignition, volatile content). 	Generally applicable.
b.	Preparation of clay-bonded sand	Mixing and cooling processes are combined into a single process step by operating the sand mixer under reduced	Generally applicable.

	Technique	Description	Applicability
	by vacuum mixing and cooling	pressure, which results in cooling by the controlled vaporisation of the water.	
c.	Substitution of coal dust	Coal dust is replaced by additives such as graphite, coke flour and zeolites, resulting in significantly lower diffuse emissions during the casting process.	Applicability may be restricted by operational constraints (e.g. less efficient shake-out or occurrence of casting defects).
Techniques for prevention of emissions in moulding and core-making with chemically bonded sand			
d.	Selection of a low-emission cold-setting binder system	<p>A cold-setting binder system generating low emissions of formaldehyde, phenol, furfuryl alcohol, isocyanates, etc. is selected. This includes the use of:</p> <ul style="list-style-type: none"> • no-bake furan resins with low furfuryl alcohol content (e.g. less than 40 wt-%) for production of iron castings for example; • no-bake phenol/furan systems with a low-sulphur acid catalyst for production of steel castings for example; • aliphatic organic binders based for example on aliphatic polyalcohols (instead of aromatic organic binders) for production of iron, steel, aluminium or magnesium castings, etc.; • inorganic geopolymers based on polysialates (for production of grey iron, aluminium and steel castings, etc.); • ester silicate (for production of medium and large steel castings, etc.); • alkyd oil (e.g. for single castings or small batch production in steel foundries); • resol-ester (e.g. for lighter alloys in small or medium production); • cement (for production of very large castings for example). 	Applicability may be restricted due to product specifications.
e.	Selection of a low-emission gas curing binder system	<p>A gas curing binder system generating low emissions of amines, benzene, formaldehyde, phenol, isocyanates, etc. is selected. This includes the use of:</p> <ul style="list-style-type: none"> • inorganic binders, e.g. sodium silicate (water glass), hardened using CO₂ or organic esters, for example in aluminium die-casting; • inorganic geopolymers based on polysialates cured with CO₂ (for production of grey iron, aluminium, steel castings, etc.); • aliphatic organic binders based for example on aliphatic polyalcohols (instead of aromatic organic binders) for production of iron, steel, aluminium or magnesium castings, etc.; • phenolic urethane binders with very low free phenol and formaldehyde content (for production of iron and steel castings, etc.); • phenolic urethane binders with reduced amounts of solvents (for production of iron and steel castings, etc.). 	Applicability may be restricted due to product specifications.
f.	Selection of a low-emission hot-curing binder system	<p>A hot-curing binder system generating low emissions of formaldehyde, phenol, furfuryl alcohol, benzene, isocyanates, etc. is selected. This includes the use of:</p> <ul style="list-style-type: none"> • inorganic binders such as geopolymers based on polysialates; 	Applicability may be restricted due to product specifications.

	Technique	Description	Applicability
		<ul style="list-style-type: none"> inorganic binders cured using a warm-box process without phenol, formaldehyde and isocyanates (for preparing aluminium castings with complex shapes for example); aliphatic polyurethane warm box binders (used as an alternative to the cold box process). 	
General techniques for moulding and core-making with chemically bonded sand			
g.	Optimisation of binder and resin consumption	See Section 4.4.3.	Generally applicable.
h.	Use of best practices for cold-setting processes	See Section 4.4.3.	Generally applicable.
i.	Use of best practices for gas-hardening processes	See Section 4.4.3.	Generally applicable.
j.	Use of non-aromatic solvents for cold-box core production	Non-aromatic solvents are used that are based either on protein or animal fat (e.g. fatty acid methyl esters of vegetable oil) or on silicate esters in order to reduce emissions of VOCs (e.g. benzene, toluene).	Generally applicable.
k.	Use of best practices for hot-curing processes	<p>Several hot-curing processes may be used and a series of measures are in place to optimise each process including for the following:</p> <p>Hot-box process:</p> <ul style="list-style-type: none"> Curing is carried out within the optimum temperature range (e.g. 220 °C to 300 °C). Cores are usually precoated using water-based coatings to prevent burns at the core surface which may result in brittleness during pouring. Core blowers and the area around them are well ventilated and exhausted to capture the formaldehyde liberated during curing efficiently. <p>Warm-box process:</p> <ul style="list-style-type: none"> Curing is carried out at a lower optimum temperature range than the hot-box process (e.g. 150 °C to 190 °C), resulting in lower emissions and energy consumption than the hot-box process. <p>Shell (Croning):</p> <ul style="list-style-type: none"> Precoated sands with a phenol-formaldehyde resin are bound using hexamethylenetetramine that decomposes at 160 °C, releasing formaldehyde, necessary for cross-linking the resin, and ammonia. <p>The curing and/or core blower area is well ventilated and exhausted to capture the ammonia and formaldehyde liberated during curing efficiently.</p>	Generally applicable.
Techniques related to the coatings applied to moulds and cores			
l.	Substitution of alcohol-based coatings with water-based coatings	See Section 4.4.3.	Applicability may be restricted in the case of large or complex casting shapes because of difficulties for circulation of the drying air.

	Technique	Description	Applicability
			Not applicable to water glass-bonded sands, the magnesium casting process, vacuum moulding or the production of manganese steel castings with MgO coating.

BAT 26. In order to reduce emissions to air from moulding using lost moulds and core-making, BAT is to:

- use an appropriate combination of the techniques given in BAT 25;
- collect the emissions using technique (a);
- treat the off-gases using one or a combination of the techniques (b) to (f) given below

	Technique	Description	Applicability
Collection of emissions			
a.	Extraction of emissions generated from moulding and/or core-making as close as possible to the emission source	See Section 4.4.3.	Applicability may be restricted in the case of moulding in cast iron and steel foundries producing large castings.
Off-gas treatment			
b.	Fabric filter	See Section 4.4.3.	Generally applicable.
c.	Wet scrubbing	See Section 4.4.3.	Generally applicable.
d.	Adsorption	See Section 4.4.3.	Generally applicable.
e.	Thermal oxidation	See Section 4.4.3.	Applicability may be restricted where the energy demand is excessive due to the low concentration of the compound(s) concerned in the process off-gases. Applicability of recuperative and regenerative thermal oxidation to existing plants may be restricted by design and/or operational constraints.
f.	Catalytic oxidation	See Section 4.4.3.	Applicability may be restricted by the presence of catalyst poisons in the waste gases or where the energy demand is excessive due to the low concentration of the compound(s) concerned in the process off-gases.

Table 4.8: BAT-associated emission levels (BAT-AELs) for channelled emissions to air of dust, amines, benzene, formaldehyde, phenol and TVOC from moulding using lost moulds and core-making

Substance/ Parameter	Unit	BAT-AEL (Daily average or average over the sampling period)
Dust	mg/Nm ³	1 – 5
Amines		< 0.5 – 2.5 ⁽¹⁾
Benzene		< 1 – 2 ⁽²⁾
Formaldehyde		< 1 – 2 ⁽³⁾
Phenol		< 1 – 2 ⁽⁴⁾
TVOC	mg C/Nm ³	15 – 50 ⁽⁵⁾

(¹) The BAT-AEL only applies in the cold-box process when amines are used.
(²) The BAT-AEL only applies when aromatic binders/chemicals are used.
(³) The BAT-AEL only applies when the substance concerned is identified as relevant in the waste gas streams based on the inventory of inputs and outputs mentioned in BAT 2.
(⁴) The BAT-AEL only applies when phenolic-based binder systems are used.
(⁵) In the case of core-making, the upper end of the BAT-AEL range may be higher and up to 100 mg C/Nm³ if both of the following conditions (a) and (b) are met:
(a) organic binder systems generating low or no emissions of substances classified as CMR 1A, CMR 1B or CMR 2 (see techniques (d), (e) and/or (f) in BAT 25) are used in core-making;
(b) one or both of the following conditions are met:
- thermal or catalytic oxidation is not applicable,
- substitution with water-based coatings is not applicable.

The associated monitoring is given in BAT 12.

4.2.1.9 Emissions to air from casting, cooling and shake-out processes in foundries using lost moulds including the full mould process

BAT 27. In order to reduce emissions to air from casting, cooling and shake-out processes in foundries using lost moulds including the full mould process, BAT is to:

- collect the emissions by using technique (a);
- treat the off-gases using one or a combination of the techniques (b) to (h) given below.

Technique	Description	Applicability
Collection of emissions		
a.	<p>Emissions generated during the casting (especially emissions from pouring), cooling and shake-out processes are appropriately extracted.</p> <p>For the casting and cooling processes, this includes:</p> <ul style="list-style-type: none"> • restricting the pouring process to a fixed area or position to facilitate the capture of emissions using ventilators and enclosure (e.g. in serial pouring); • enclosure of pouring and cooling lines. <p>For the shake-out process, this includes:</p> <ul style="list-style-type: none"> • use of ventilator panels situated on both sides and at the rear of the shaker; • use of enclosed units equipped with roof openings or removable covers (e.g. doghouse); • installation of an extraction point situated underneath the shaker in the sand collection box. 	<p>Applicability may be restricted in the case of cast iron and steel foundries producing large castings.</p>
Off-gas treatment		

Technique		Description	Applicability
b.	Cyclone	See Section 4.4.3.	Generally applicable.
c.	Fabric filter	See Section 4.4.3.	Generally applicable.
d.	Wet scrubbing	See Section 4.4.3.	Generally applicable.
e.	Adsorption	See Section 4.4.3.	Generally applicable.
f.	Biofilter	The off-gas stream is passed through a bed of organic material (such as peat, heather, compost, root, tree bark, softwood and different combinations) or some inert material (such as clay, activated carbon, and polyurethane), where it is biologically oxidised by naturally occurring microorganisms into carbon dioxide, water, inorganic salts and biomass. The biofilter is sensitive to dust, high temperatures and high variations in the off-gas composition. Supplementary nutrient feeding may be needed.	Only applicable to the treatment of biodegradable compounds.
g.	Thermal oxidation	See Section 4.4.3.	Applicability of recuperative and regenerative thermal oxidation to existing plants may be restricted by design and/or operational constraints. Applicability may be restricted where the energy demand is excessive due to the low concentration of the compound(s) concerned in the process off-gases
h.	Catalytic oxidation	See Section 4.4.3.	Applicability may be restricted by the presence of catalyst poisons in the waste gases or where the energy demand is excessive due to the low concentration of the compound(s) concerned in the process off-gases.

Table 4.9: BAT-associated emission levels (BAT-AELs) for channelled emissions to air of dust, benzene, formaldehyde, phenol and TVOC from casting, cooling and shake-out processes in foundries using lost moulds including the full mould process

Substance/Parameter	Unit	BAT-AEL (Daily average or average over the sampling period)
Dust	mg/Nm ³	1 – 5
Benzene		< 1 – 2 ⁽¹⁾
Formaldehyde		< 1 – 2 ⁽²⁾
Phenol		< 1 – 2 ⁽³⁾
TVOC	mg C/Nm ³	15 – 50 ⁽⁴⁾
<p>⁽¹⁾ The BAT-AEL only applies when aromatic binders/chemicals are used or when the full mould process is used.</p> <p>⁽²⁾ The BAT-AEL only applies when the substance concerned is identified as relevant in the waste gas streams based on the inventory of inputs and outputs mentioned in BAT 2.</p> <p>⁽³⁾ The BAT-AEL only applies when phenolic-based binder systems are used in moulding and/or core-making.</p> <p>⁽⁴⁾ The upper end of the BAT-AEL range may be higher and up to 100 mg C/Nm³ when organic binder systems generating low or no emissions of substances classified as CMR 1A, CMR 1B or CMR 2 (see techniques (d), (e) and/or (f) in BAT 25) are used in core-making.</p>		

The associated monitoring is given in BAT 12.

4.2.1.10 Emissions to air from lost foam casting

BAT 28. In order to reduce dust and TVOC emissions to air from lost foam casting, BAT is to collect the emissions using technique (a) and to treat the off-gases by using an appropriate combination of the techniques (b) to (d) given below.

Technique	Description	Applicability
Collection of emissions		
a.	Extraction of emissions generated from lost foam casting as close as possible to the emission source In the lost foam casting processes, emissions from the pyrolysis of the expanded polymer during pouring and shake-out are extracted using, for example an enclosure or a hood.	Generally applicable.
Off-gas treatment		
b.	Fabric filter	See Section 4.4.3.
c.	Wet scrubbing	See Section 4.4.3.
d.	Thermal oxidation	See Section 4.4.3.
		Applicability of recuperative and regenerative thermal oxidation to existing plants may be restricted by design and/or operational constraints. Applicability may be restricted where the energy demand is excessive due to the low concentration of the compound(s)

Technique	Description	Applicability
		concerned in the process off-gases.

Table 4.10: BAT-associated emission levels (BAT-AELs) for channelled emissions to air of dust and TVOC from lost foam casting

Parameter	Unit	BAT-AEL (Daily average or average over the sampling period)
Dust	mg/Nm ³	1 – 5
TVOC	mg C/Nm ³	< 15 – 50 ⁽¹⁾
⁽¹⁾ The upper end of the BAT-AEL range may be higher and up to 100 mg C/Nm ³ if the TVOC abatement efficiency of the waste gas treatment system is > 95 %.		

The associated monitoring is given in BAT 12.

4.2.1.11 Emissions to air from the casting process in foundries using permanent moulds

BAT 29 In order to prevent or reduce emissions to air from the casting process in foundries using permanent moulds, BAT is to:

- prevent the generation of emissions by using one or a combination of the techniques (a) to (e);
- collect the emissions by using technique (f);
- treat the off-gases by using one or a combination of the techniques (g) to (j) given below.

Technique	Description	Applicability
Prevention of emissions		
a.	General techniques for gravity and low-pressure die-casting This includes techniques such as <ul style="list-style-type: none"> • selection of an appropriate lubricant to prevent castings surface defects; • optimised lubricant preparation and application to avoid excessive use. 	Generally applicable.
b.	General techniques for high-pressure die-casting This includes techniques such as: <ul style="list-style-type: none"> • proper lubrication of the die and plungers using water-based emulsions of silicone oils, ester oils, synthetic waxes for example; • minimisation of the release agent and water consumption by optimising the spraying process, e.g. use of micro-spraying for application of release agents (see also BAT 29 (b)). 	
c.	Optimisation of process parameters for centrifugal and continuous casting In centrifugal casting, important process parameters such as mould rotation, pouring temperature and mould preheating temperature are optimised (e.g. using flow simulation) to reduce the number of defects and minimise emissions. In continuous casting, the casting rate, casting temperature and cooling rate are optimised to minimise emissions and reduce the amount of water consumed for cooling while reaching the required product specification.	
d.	Separate spraying of release agent and water in high- See Section 4.4.2.	

Technique		Description	Applicability
	pressure die-casting		
e.	Use of water-free release agents in high-pressure die-casting	Water-free release agents (e.g. in a powdered form) are applied to the die using electrostatic deposition.	
Collection of emissions			
f.	Extraction of emissions generated from the casting process as close as possible to the emission source	Emissions generated from the casting process including high-pressure/low-pressure/gravity die-casting, centrifugal and continuous casting are extracted using enclosures or extraction hoods.	Generally applicable.
Off-gas treatment			
g.	Fabric filter	See Section 4.4.3.	
h.	Wet scrubbing	See Section 4.4.3.	Generally applicable.
i.	Electrostatic precipitator	See Section 4.4.3.	
j.	Thermal oxidation	See Section 4.4.3.	Applicability of recuperative and regenerative thermal oxidation to existing plants may be restricted by design and/or operational constraints. Applicability may be restricted where the energy demand is excessive due to the low concentration of the compound(s) concerned in the process off-gases.

Table 4.11: BAT-associated emission levels (BAT-AELs) for channelled emissions to air of dust, TVOC and lead from the casting process in foundries using permanent moulds

Substance/Parameter	Unit	BAT-AELs (Daily average or average over the sampling period)
Dust	mg/Nm ³	1 – 5
Pb		0.05 – 0.1 ⁽¹⁾
TVOC	mg C/Nm ³	2 – 30 ⁽²⁾ ⁽³⁾

⁽¹⁾ The BAT-AEL only applies to lead foundries.
⁽²⁾ The BAT-AEL only applies when TVOC is identified as relevant in the waste gas streams based on the inventory of inputs and outputs mentioned in BAT 2.
⁽³⁾ The BAT-AEL only applies when cores with chemically bonded sand are used.

The associated monitoring is given in BAT 12.

4.2.1.12 Emissions to air from finishing

BAT 30. In order to reduce dust emissions to air from finishing, BAT is to collect the emissions using technique (a) and to treat the off-gases by using one or a combination of the techniques (b) to (d) given below.

Technique		Description
Collection of emissions		
a.	Extraction of emissions generated from finishing as close as possible to the emission source	Emissions generated from finishing operations, such as deburring, abrasive cutting, fettling, slide grinding, shot blasting, welding, chiselling, needling, are appropriately extracted using, e.g.: <ul style="list-style-type: none"> • enclosure of the finishing process area; • roof ventilation or dome-shaped roofs; • rigid or adjustable extraction hoods; • extraction arms.
Off-gas treatment		
b.	Cyclone	See Section 4.4.3.
c.	Fabric filter	See Section 4.4.3.
d.	Wet scrubbing	See Section 4.4.3.

Table 4.12: BAT-associated emission level (BAT-AEL) for channelled emissions to air of dust from finishing

Parameter	Unit	BAT-AEL (Daily average or average over the sampling period)
Dust	mg/Nm ³	1 – 5

The associated monitoring is given in BAT 12.

4.2.1.13 Emissions to air from sand reuse

BAT 31. In order to reduce emissions to air from sand reuse, BAT is to:

- in the case of thermal sand regeneration, use either electricity generated from fossil-free energy sources or both of the techniques (a) and (b);
- collect the emissions using technique (c);
- treat the off-gases by using one or an appropriate combination of the techniques (d) to (g) given below.

Technique		Description	Applicability
Techniques for reducing the generation of emissions			
a.	Use of a fuel or a combination of fuels with low NO _x formation potential	Fuels with a low NO _x formation potential include natural gas and liquefied petroleum gas.	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.
b.	Use of a fuel or a combination of fuels with low sulphur content	Fuels with low sulphur content include natural gas and liquefied petroleum gas.	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.
Collection of emissions			
c.	Extraction of emissions	Emissions generated from sand reclamation are extracted using an	Generally applicable.

Technique	Description	Applicability
generated from sand reuse as close as possible to the emission source	enclosure or a hood for example. This includes extraction of the flue-gases generated from fluidised bed furnaces, rotary kilns or hearth furnaces, etc. used in thermal sand regeneration.	
Off-gas treatment		
d. Cyclone	See Section 4.4.3.	Generally applicable.
e. Fabric filter	See Section 4.4.3.	
f. Wet scrubbing	See Section 4.4.3.	
g. Thermal oxidation	See Section 4.4.3.	Applicability of recuperative and regenerative thermal oxidation to existing plants may be restricted by design and/or operational constraints. Applicability may be restricted where the energy demand is excessive due to the low concentration of the compound(s) concerned in the process off-gases.

Table 4.13: BAT-associated emission levels (BAT-AELs) for channelled emissions to air of dust and TVOC from sand reuse

Substance/Parameter	Unit	BAT-AEL (Daily average or average over the sampling period)
Dust	mg/Nm ³	1 – 5
TVOC	mg C/Nm ³	5 – 20 ⁽¹⁾

⁽¹⁾ The upper end of the BAT-AEL range may be higher and up to 50 mg C/Nm³ with a high share of core sand in sand reuse.

Table 4.14: BAT-associated emission levels (BAT-AELs) for channelled emissions to air of NO_x and SO₂ from sand reuse

Substance/Parameter	Process	Unit	BAT-AEL (Daily average or average over the sampling period)
NO _x	Thermal regeneration of sand originating from the cold-box process	mg/Nm ³	50 – 140
SO ₂	Thermal regeneration of sand in which sulphonic acid catalysts have been used		10 – 100

The associated monitoring is given in BAT 12.

4.2.1.14 Odour

BAT 32. In order to prevent or, where that is not practicable, to reduce odour emissions, BAT is to set up, implement and regularly review an odour management plan, as part of the environmental management system (see BAT 1), that includes all of the following elements:

- A protocol containing appropriate actions and timelines.

- A protocol for conducting odour monitoring as set out in BAT 33. The protocol may be complemented by measurement/estimation of odour exposure or estimation of odour impact.
- A protocol for response to identified odour incidents, e.g. managing complaints and/or taking corrective actions.
- 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.

Applicability

The applicability is restricted to cases where an odour nuisance at sensitive receptors is expected and/or has been substantiated.

BAT 33. BAT is to periodically perform odour monitoring.

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 (see BAT 32).

Applicability

The applicability is restricted to cases where an odour nuisance at sensitive receptors is expected and/or has been substantiated.

BAT 34. In order to prevent or, where that is not practicable, to reduce odour emissions, BAT is to use all of the techniques given below.

Technique		Description	Applicability
a.	Substitution of chemicals containing alcohol-based or aromatic solvents	This includes techniques such as: <ul style="list-style-type: none"> • the use of water-based coatings (see BAT 25 (l)); • the use of alternative solvents in cold-box core-making (see BAT 25 (h)). 	Applicability of water-based coatings may be restricted due to the type of raw material or product specifications (e.g. big moulds/cores, water glass bonded sands, Mg castings, production of manganese steel with MgO coating).
b.	Collection and treatment of amine emissions from the cold-box core-making process	Off-gases containing amines, generated from the gassing of cold-box cores are extracted and treated using for example wet scrubbing, a biofilter, thermal or catalytic oxidation (see BAT 26).	Generally applicable.
c.	Collection and treatment of VOC emissions from chemically bonded sand preparation, pouring, cooling and shake-out	Off-gases containing VOCs, generated from the preparation of chemically bonded sand, pouring, cooling and shake-out are extracted and treated using for example wet scrubbing, a biofilter, thermal or catalytic oxidation (see BAT 26).	

4.2.1.15 Water consumption and waste water generation

BAT 35. In order to optimise water consumption and to reduce the volume of waste water generated as well as to improve water recyclability, BAT is to use both techniques (a) and (b), and an appropriate combination of the techniques (c) to (g) given below.

Technique		Description	Applicability
a.	Water management plan and audits	<p>A water management plan and audits are part of the EMS (see BAT 1) and include:</p> <ul style="list-style-type: none"> – flow diagrams and water mass balances of the plant as part of the inventory of inputs and outputs mentioned in BAT 2; – establishment of water efficiency objectives; – implementation of water optimisation techniques (e.g. control of water usage, reuse/recycling, detection and repair of leaks). <p>Audits 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.</p>	The level of detail of the water management plan and audits will generally be related to the nature, scale and complexity of the plant.
b.	Segregation of water streams	See Section 4.4.4.	Applicability to existing plants may be restricted by the layout of the water collection system.
c.	Water reuse and/or recycling	Water streams (e.g. process water, effluents from wet scrubbing, cooling water) are reused and/or recycled in closed or semi-closed circuits, if necessary after treatment (see BAT 36).	The degree of water reuse and/or recycling is limited by the water balance of the plant, the content of impurities and/or the characteristics of the water streams.
d.	Prevention of waste water generation from process and storage areas	See BAT 4 (b).	Generally applicable.
e.	Use of dry dedusting systems	This includes techniques such as fabric filters and dry ESPs (see Section 4.4.3).	Generally applicable.
f.	Separate spraying of release agent and water in high-pressure die-casting	See Section 4.4.2.	Generally applicable.
g.	Use of waste heat for the evaporation of waste water	When waste heat is available on a continuous basis, it can be used to evaporate waste water.	Applicability may be restricted by the physico-chemical properties of the pollutants present in the waste water that can be emitted into the air.

Table 4.15: BAT-associated environmental performance levels (BAT-AEPLs) for specific water consumption

Foundry type	Unit	BAT-AEPL (Yearly average)
Cast iron foundries	m ³ /t of liquid metal	0.5 – 4
Steel foundries		
Non-ferrous metal foundries (all types except HPDC)		0.5 – 7
Non-ferrous metal HPDC foundries		

The associated monitoring is given in BAT 6.

4.2.1.16 Emissions to water

BAT 36. In order to reduce emissions to water, BAT is to treat waste water using an appropriate combination of the techniques given below.

Technique ⁽¹⁾	Typical pollutants targeted
Preliminary, primary and general treatment, e.g.	
a. Equalisation	All pollutants
b. Neutralisation	Acids, alkalis
c. Physical separation through for example screens, sieves, grit separators, grease separators, hydrocyclones, oil-water separators or primary settlement tanks	Gross solids, suspended solids, oil/grease
Physico-chemical treatment, e.g.	
d. Adsorption	Adsorbable dissolved non-biodegradable or inhibitory pollutants, e.g. hydrocarbons, mercury, AOX
e. Chemical precipitation	Precipitable dissolved non-biodegradable or inhibitory pollutants, e.g. metals, fluoride
f. Evaporation	Soluble contaminants, e.g. salts
Biological treatment, e.g.	
g. Activated sludge process	Biodegradable organic compounds
h. Membrane bioreactor	
Solids removal, e.g.	
i. Coagulation and flocculation	Suspended solids and particulate-bound metals
j. Sedimentation	Suspended solids and particulate-bound metals or non-biodegradable or inhibitory pollutants
k. Filtration, e.g. sand filtration, microfiltration, ultrafiltration, reverse osmosis	Suspended solids and particulate-bound metals
l. Flotation	
⁽¹⁾ The descriptions of the techniques are given in Section 4.4.4	

Table 4.16: BAT-associated emission levels (BAT-AELs) for direct discharges

Substance/Parameter		Unit	BAT-AEL (¹)	Origin of waste water stream(s)
Adsorbable organically bound halogens (AOX) (²)		mg/l	0.1 – 1	Wet scrubbing of cupola off-gases
Chemical oxygen demand (COD) (³)			25 – 120	Die-casting, off-gas treatment (e.g. wet scrubbing), finishing, heat treatment, contaminated surface run-off water, direct cooling, wet sand regeneration and cupola furnace slag granulation.
Total organic carbon (TOC) (³)			8 – 40	
Total suspended solids (TSS)			5 – 25	
Hydrocarbon oil index (HOI) (²)			0.1 – 5	
Metals	Copper (Cu) (²)		0.1 – 0.4	
	Chromium (Cr) (²)	0.1 – 0.2		
	Lead (Pb) (²)	0.1 – 0.3		
	Nickel (Ni) (²)	0.1 – 0.5		
	Zinc (Zn) (²)	0.5 – 2		
Phenol index		mg/l	0.05 – 0.5(⁴)	
Total nitrogen (TN) (²)			1 – 20	

(¹) The averaging periods are defined in the General considerations.
(²) The BAT-AELs only apply when the substance/parameter concerned is identified as relevant in the waste water stream based on the inventory of inputs and outputs mentioned in BAT 2.
(³) Either the BAT-AEL for COD or the BAT-AEL for TOC applies. The BAT-AEL for TOC is the preferred option because TOC monitoring does not rely on the use of very toxic compounds.
(⁴) The BAT-AEL only applies when phenolic binding systems are used.

The associated monitoring is given in BAT 13.

Table 4.17: BAT-associated emission levels (BAT-AELs) for indirect discharges

Substance/Parameter		Unit	BAT-AEL (¹) (²)	Origin of waste water stream(s)	
Adsorbable organically bound halogens (AOX) (³)		mg/l	0.1 – 1	Wet scrubbing of cupola off-gases	
Hydrocarbon oil index (HOI) (³)			0.1 – 5	Die-casting, off-gas treatment (e.g. wet scrubbing), finishing, heat treatment, contaminated surface run-off water, direct cooling, wet sand regeneration and cupola furnace slag granulation.	
Metals	Copper (Cu) (³)		0.05 – 0.2		
	Chromium (Cr) (³)		0.1 – 0.4		
	Lead (Pb) (³)		0.1 – 0.2		
	Nickel (Ni) (³)		0.1 – 0.3		
	Zinc (Zn) (³)	0.1 – 0.5			
Phenol index		mg/l	0.5 – 2		
			0.05 – 0.5 (⁴)		

(¹) The averaging periods are defined in the General considerations.
(²) The BAT-AELs may not apply if the downstream waste water treatment plant is designed and equipped appropriately to abate the pollutants concerned, provided this does not lead to a higher level of pollution in the environment.
(³) The BAT-AELs only apply when the substance/parameter concerned is identified as relevant in the waste water stream based on the inventory of inputs and outputs mentioned in BAT 2.
(⁴) The BAT-AEL only applies when phenolic binding systems are used.

The associated monitoring is given in BAT 13.

4.2.2 BAT conclusions for cast iron foundries

The BAT conclusions in this section apply in addition to the general BAT conclusions given in Sections 4.1 and 4.2.1.

4.2.2.1 Energy efficiency

BAT 37. In order to increase energy efficiency in metal melting, BAT is to use an appropriate combination of the techniques given below.

Technique		Description	Applicability
a.	Increase of shaft height in CBC furnaces	See Section 4.4.1.	Only applicable to new plants and major plant upgrades. Applicability to existing plants may be restricted by building and other structural constraints.
b.	Oxygen enrichment of the combustion air	See Section 4.4.1.	Generally applicable.
c.	Minimal blast shut-off periods for HBC furnaces	See Section 4.4.1.	Generally applicable.
d.	Long-campaign cupola	See Section 4.4.1.	Generally applicable.
e.	Post-combustion of off-gases	See Section 4.4.1.	Generally applicable.

The BAT-AEPLs for specific energy consumption are given in BAT 14.

4.2.2.2 Emissions to air from thermal processes

4.2.2.2.1 Emissions to air from metal melting

BAT 38. In order to prevent or reduce emissions to air from metal melting, BAT is to:

- use an appropriate combination of process-integrated techniques (a) to (e) in the case of cupola furnaces;
- collect the emissions using technique (f);
- treat the extracted off-gases using one or an appropriate combination of the techniques (g) to (l) given below.

Technique		Description	Applicability
Process-integrated techniques for cupola furnaces			
a.	Control of coke quality	Coke is purchased based on important quality specifications (e.g. fixed carbon, ash, volatile matter, sulphur and moisture content, mean size diameter) which are systematically controlled before use.	Generally applicable.
b.	Adjustment of the slag acidity/basicity	See Section 4.4.3.	
c.	Increase of shaft height in CBC furnaces	See Section 4.4.1.	Only applicable to new plants and

Technique		Description	Applicability
			major plant upgrades. Applicability to existing plants may be restricted by building and other structural constraints.
d.	Oxygen enrichment of the combustion air	See Section 4.4.3.	Generally applicable.
e.	Long-campaign cupola	See Section 4.4.3.	Generally applicable.
Collection of emissions			
f.	Off-gas extraction as close as possible to the emission source	<p>In cupola furnaces, the off-gases are extracted either:</p> <ul style="list-style-type: none"> • above the charge-hole offtake at the end of the cupola stack using ductwork and a downstream fan; or • below the charge-hole offtake using an annular ring. <p>After extraction, the off-gases are cooled for example using:</p> <ul style="list-style-type: none"> • long ducts to decrease the temperature by natural convection; • air/gas or oil/gas heat exchangers; • water quenching. <p>For induction furnaces, off-gases are extracted, for example using:</p> <ul style="list-style-type: none"> • hood extraction (e.g. canopy or side-draught hoods); • lip extraction; • cover extraction. <p>For rotary furnaces, off-gases are extracted, for example using hood extraction.</p> <p>For EAFs, off-gases are extracted, for example using:</p> <ul style="list-style-type: none"> • roof-mounted hood extraction; • canopy or side-draught hoods; • partial furnace enclosures (mobile or fixed) mounted around the furnace and tapping area; • total furnace enclosure using a complete room enclosure around the furnace and tapping area equipped with a moveable roof for charging/tapping operations. 	Generally applicable.
Off-gas treatment			
g.	Post-combustion of off-gases	See Section 4.4.3.	Generally applicable.
h.	Cyclone	See Section 4.4.3.	Generally applicable.
i.	Adsorption	See Section 4.4.3.	Generally applicable.
j.	Dry scrubbing	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) to form a solid which is removed by filtration (e.g. fabric filter).	Generally applicable.

Technique		Description	Applicability
k.	Fabric filter	See Section 4.4.3.	Generally applicable.
l.	Wet scrubbing	See Section 4.4.3.	Generally applicable.

Table 4.18: BAT-associated emission levels (BAT-AELs) for channelled emissions to air of dust, HCl, HF, NO_x, PCDD/F, SO₂, TVOC, lead, and indicative emission level for channelled emissions to air of CO from metal melting

Substance/ Parameter	Unit	Furnace type	BAT-AEL (Daily average or average over the sampling period)	Indicative emission level (Daily average or average over the sampling period)
Dust	mg/Nm ³	Induction, rotary, EAF	1 – 5	No indicative emission level
		CBC, HBC	1 – 7 ⁽¹⁾	
HCl		CBC, HBC	10 – 30 ⁽²⁾	
HF		CBC, HBC, rotary furnaces	1 – 3 ⁽²⁾	
CO		Rotary furnaces	No BAT-AEL	10 – 30
		CBC, HBC	No BAT-AEL	20 – 220
NO _x		HBC	20 – 160	No indicative emission level
		CBC	20 – 70	
		Rotary furnaces	20 – 100	
PCDD/F		ng WHO- TEQ/Nm ³	CBC, HBC, rotary furnaces	
	Induction		< 0.01 – 0.08 ⁽³⁾	
SO ₂	mg/Nm ³	HBC	30 – 100	
		Rotary furnaces	10 – 50	
		CBC	50 – 150	
TVOC	mg C/Nm ³	All furnace types	5 – 30	
Pb	mg/Nm ³	CBC, HBC	0.02 – 0.1 ⁽³⁾	

(¹) For existing HBC plants using wet scrubbing, the upper end of the BAT-AEL range may be higher and up to 12 mg/Nm³ until the next major upgrade of the cupola.
(²) The lower end of the BAT-AEL range can be achieved by using dry lime injection.
(³) The BAT-AEL only applies when the substance/parameter concerned is identified as relevant in the waste gas stream based on the inventory of inputs and outputs mentioned in BAT 2.

The associated monitoring is given in BAT 12.

4.2.2.2 Emissions to air from the nodularisation of cast iron

BAT 39. In order to prevent or reduce dust emissions to air from the nodularisation of cast iron, BAT is to use technique (a) or both of the techniques (b) and (c) given below.

Technique		Description
a.	Nodularisation with no magnesium oxide emissions	Use of the in-mould process whereby the magnesium alloy is added as a tablet, directly into the mould cavity, and the nodularisation reaction takes place during pouring.
b.	Off-gas extraction as close as possible to the emission source	When magnesium oxide emissions are generated from the nodularisation technique used (e.g. sandwich, ductilator), off-gases are extracted as close as possible to the emission source using a fixed or movable extraction hood.

Technique		Description
c.	Fabric filter	See Section 4.4.3. The magnesium oxide collected may be reused for the production of pigments or refractory materials.

Table 4.19: BAT-associated emission levels (BAT-AELs) for channelled emissions to air of dust from the nodularisation of cast iron

Parameter	Unit	BAT-AEL ⁽¹⁾ (Daily average or average over the sampling period)
Dust	mg/Nm ³	1 – 5
⁽¹⁾ The BAT-AEL does not apply when technique (a) is used.		

The associated monitoring is given in BAT 12.

4.2.3 BAT conclusions for steel foundries

The BAT conclusions in this section apply in addition to the general BAT conclusions given in Sections 4.1 and 4.2.1.

4.2.3.1 Emissions to air from thermal processes

4.2.3.1.1 Emissions to air from metal melting

BAT 40. In order to prevent or reduce emissions to air from metal melting, BAT is to use both of the techniques given below.

Technique		Description
Collection of emissions		
a.	Off-gas extraction as close as possible to the emission source	<p>The off-gases from induction furnaces are extracted, for example using:</p> <ul style="list-style-type: none"> • hood extraction (e.g. canopy or side-draught hoods); • lip extraction; • cover extraction. <p>The off-gases from EAFs are extracted, for example using:</p> <ul style="list-style-type: none"> • partial furnace enclosures (mobile or fixed) mounted around the furnace and tapping area; • total furnace enclosure using a complete room enclosure around the furnace and tapping area equipped with a moveable roof for charging/tapping operations; • hood extraction (e.g. roof-mounted, canopy or side-draught hoods); • direct extraction through the fourth hole in the furnace roof.
Off-gas treatment		
b.	Fabric filter	See Section 4.4.3.

Table 4.20: BAT-associated emission levels (BAT-AELs) for channelled emissions to air of dust and PCDD/F

Parameter	Unit	BAT-AEL (Daily average or average over the sampling period)
Dust	mg/Nm ³	1 – 5
PCDD/F	ng WHO-TEQ / Nm ³	< 0.01 – 0.08 ⁽¹⁾
⁽¹⁾ The BAT-AEL only applies when PCDD/F are identified as relevant in the waste gas stream based on the inventory of inputs and outputs mentioned in BAT 2.		

The associated monitoring is given in BAT 12.

4.2.3.1.2 Emissions to air from steel refining

BAT 41. In order to reduce emissions to air from steel refining, BAT is to use both of the techniques given below.

Technique		Description
Collection of emissions		
a.	Off-gas extraction as close as possible to the emission source	Off-gases from steel refining (e.g. from Argon Oxygen Decarburisation (AOD) or Vacuum Oxygen Decarburisation (VOD) converters) are extracted using for example a direct extraction hood or a roof canopy combined with an accelerator stack. Extracted off-gases are treated using technique (b).
Off-gas treatment		
b.	Fabric filter	See Section 4.4.3.

Table 4.21: BAT-associated emission level (BAT-AEL) for channelled emissions to air of dust from steel refining

Parameter	Unit	BAT-AEL (Daily average or average over the sampling period)
Dust	mg/Nm ³	1 – 5

The associated monitoring is given in BAT 12.

4.2.4 BAT conclusions for non-ferrous metal foundries

The BAT conclusions in this section apply in addition to the general BAT conclusions given in Sections 4.1 and 4.2.1.

4.2.4.1 Energy efficiency

BAT 42. In order to increase energy efficiency in metal melting, BAT is to use one of the techniques given below.

Technique		Description
a.	Molten metal circulation in reverberatory furnaces	A pump is installed on reverberatory furnaces to force the circulation of molten metal and minimise the temperature gradient throughout the molten bath (from top to bottom).
b.	Minimisation of energy losses by radiation in crucible furnaces	Crucible furnaces are covered using a lid and/or equipped with radiant panel linings to minimise energy losses by radiation.

The BAT-AEPLs for specific energy consumption are given in BAT 14.

4.2.4.2 Emissions to air from thermal processes

4.2.4.2.1 Emissions to air from metal melting

BAT 43. In order to reduce emissions to air from metal melting, BAT is to collect the emissions using technique (a) and to treat the off-gases using one or a combination of the techniques (b) to (e) given below.

Technique	Description
Collection of emissions	
a.	Off-gases from shaft, crucible, resistance, reverberatory (hearth-type) and radiant roof furnaces are extracted using hood extraction (e.g. canopy hoods). The extraction equipment is fitted in such a way that it enables the capture of emissions during pouring. Off-gases from induction furnaces are extracted, for example using: <ul style="list-style-type: none"> • hood extraction (e.g. canopy or side-draught hoods); • lip extraction; • cover extraction. Off-gases from rotary furnaces are extracted, for example using hood extraction.
Off-gas treatment	
b.	Cyclone See Section 4.4.3.
c.	Dry scrubbing See Section 4.4.3
d.	Fabric filter See Section 4.4.3
e.	Wet scrubbing See Section 4.4.3

Table 4.22: BAT-associated emission levels (BAT-AELs) for channelled emissions to air of dust, HCl, HF, NO_x, PCDD/Fs, TVOC, SO₂, Pb, and indicative emission level for channelled emissions to air of CO, from metal melting

Substance/Parameter	Unit	BAT-AEL (Daily average or average over the sampling period)	Indicative emission level (Daily average or average over the sampling period)
Dust	mg/Nm ³	1 – 5	No indicative emission level
HCl		1 – 3 ⁽¹⁾	
HF		< 1 ⁽¹⁾	
CO		No BAT-AEL	5 – 30 ⁽²⁾ ⁽³⁾
NO _x		20 – 50 ⁽⁴⁾ ⁽⁵⁾	
PCDD/F	ng WHO-TEQ/Nm ³	< 0.01 – 0.08 ⁽⁶⁾	No indicative emission level
SO ₂	mg/Nm ³	< 10 ⁽⁴⁾ ⁽⁷⁾	
Pb		< 0.02 – 0.1 ⁽⁸⁾	

(1) The BAT-AEL only applies to aluminium foundries.
(2) The upper end of the indicative emission level may be higher and up to 70 mg/Nm³ in the case of shaft furnaces.
(3) The indicative emission level does not apply in the case of furnaces using only electric energy (e.g. resistance).
(4) The BAT-AEL does not apply in the case of furnaces using only electric energy (e.g. resistance).
(5) The upper end of the BAT-AEL range may be higher and up to 100 mg/Nm³ in the case of shaft furnaces.
(6) The BAT-AEL only applies when the substance/parameter concerned is identified as relevant in the waste gas stream based on the inventory of inputs and outputs mentioned in BAT 2.
(7) The BAT-AEL does not apply when only natural gas is used.
(8) The BAT-AEL only applies to lead foundries or to other NFM foundries using lead as an alloying element.

The associated monitoring is given in BAT 12.

4.2.4.3 Emissions to air from the treatment and protection of molten metal

BAT 44. It is not BAT to use chlorine gas for molten aluminium treatment (degassing/cleaning).

BAT 45. In order to prevent emissions of substances with a high global warming potential from the protection of molten metal in magnesium melting, BAT is to use oxidation control agents with a low global warming potential.

Description

Suitable oxidation control agents (covering gases) with a low global warming potential include:

- SO₂;
- gas mixtures of N₂, CO₂ and/or SO₂;
- gas mixtures of argon and SO₂.

The use of SO₂ results in the formation of a protective layer composed of MgSO₄, MgS and MgO.

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4.3 BAT conclusions for smitheries

The BAT conclusions in this section apply in addition to the general BAT conclusions given in Section 4.1.

4.3.1 Energy efficiency

BAT 46. In order to increase energy efficiency in heating/reheating and heat treatment, BAT is to use all the techniques given below.

Technique	Description	Applicability
a. Optimisation of furnace design	This includes techniques such as: <ul style="list-style-type: none"> • optimisation of key furnace characteristics (e.g. number and type of burners, airtightness, furnace insulation using suitable refractory materials); • minimisation of heat losses from furnace door openings, e.g. by using several liftable segments instead of one in continuous reheating furnaces; • minimisation of the number of feedstock-supporting structures inside the furnace (e.g. beams, skids) and use of suitable insulation to reduce the heat losses from water cooling of the supporting structures in continuous reheating furnaces. 	Only applicable to new plants and major plant upgrades.
b. Furnace automation and control	See Section 4.4.1.	Generally applicable.
c. Optimisation of feedstock heating/reheating	This includes techniques such as: <ul style="list-style-type: none"> • ensuring that feedstock heating/reheating target temperatures are consistently met; • switching off equipment during idle periods; • furnace operation optimisation, e.g. furnace capacity utilisation, correction of the air/fuel ratio, improvement of insulation. 	Generally applicable.
d. Preheating of combustion air	See Section 4.4.1.	Applicability to existing plants may be restricted by a lack of space for the installation of regenerative burners.

Table 4.23: Indicative level for specific energy consumption at plant level

Sector	Unit	Indicative level (Yearly average)
Smitheries	kWh/t of feedstock	1 700 – 6 500

The associated monitoring is given in BAT 6.

4.3.2 Material efficiency

BAT 47. In order to increase the material efficiency and to reduce the quantity of waste sent for disposal, BAT is to use all of the techniques given below.

Technique		Description
a.	Process optimisation	This includes techniques such as: <ul style="list-style-type: none"> • computerised management of processes, e.g. heating/reheating cycles, hammering sequences; • selection of an appropriate hammer according to raw material size; • adjustment of raw material size, either in the forging line (fully automated) or in the organisational area of the material shearing (manual), in order to minimise the amount of residues and the number of process operations.
b.	Optimisation of raw and auxiliary material consumption	This includes techniques such as: <ul style="list-style-type: none"> • use of computer-aided design of products to optimise the amount of raw material used and the forging (die) geometry in order to reduce the forging tests; • selection of an appropriate type of coolant/lubricant for forging, e.g. synthetic lubricant for closed-die forging, water-based dispersions of graphite; • centralised distribution system for coolants/lubricants in closed-die forging that reduces intermediate storage and consumption, and facilitates leak detection; • systems for collecting and recirculating coolants/lubricants in closed-die forging.
c.	Recycling of process residues	Process residues (e.g. metallic residues from the processes of preparation of raw materials, hammering and finishing; used shot blast media) are recycled and/or reused.

4.3.3 Vibrations

BAT 48. In order to reduce vibrations occurring from the hammering process, BAT is to use vibration-reducing and insulating techniques.

Description

Vibration-reducing and insulating techniques for hammering equipment include the installation of vibration-damping components, e.g. layered elastomeric isolators or viscous spring isolators below the anvil, spring casings below the hammer foundation.

4.3.4 Monitoring of emissions to air

BAT 49. BAT is to monitor channelled emissions to air with at least the frequency given below, and in accordance with EN standards. If EN standards are not available, BAT is to use ISO, national or other international standards that ensure the provision of data of an equivalent scientific quality.

Substance/Parameter	Specific process	Standard(s)	Minimum monitoring frequency ⁽¹⁾	Monitoring associated with
Nitrogen oxides (NO _x)	Heating/reheating, heat treatment	EN 14792	Once every year	BAT50
Carbon monoxide (CO)	Heating/reheating, heat treatment	EN 15058		
⁽¹⁾ To the extent possible, the measurements are carried out at the highest expected emission state under normal operating conditions.				

4.3.5 Emissions to air

4.3.5.1 Diffuse emissions to air

BAT 50. In order to prevent or reduce diffuse emissions to air, BAT is to use both of the techniques given below.

Technique		Description
a.	Operational and technical measures	This includes techniques such as: <ul style="list-style-type: none"> • use of closed bags or drums to handle materials with dispersible or water-soluble components, e.g. auxiliaries; • minimising transport distances; • efficient material handling.
b.	Extraction of emissions from shot blasting	Emissions from shot blasting. Extracted off-gases are treated using techniques such as fabric filters.

4.3.5.2 Emissions to air from heating/reheating and heat treatment

BAT 51. In order to prevent or reduce NO_x emissions to air from heating, reheating and heat treatment while limiting CO emissions, BAT is to use either electricity generated from fossil-free energy sources or an appropriate combination of the techniques given below.

Technique		Description	Applicability
a.	Use of a fuel or a combination of fuels with low NO _x formation potential	Fuels with a low NO _x formation potential include natural gas and ion liquefied petroleum gas.	Generally applicable.
b.	Combustion optimisation	Measures taken to maximise the efficiency of energy conversion in the furnace while minimising emissions (in particular of CO). This is achieved by a combination of techniques including good design of the furnace, optimisation of the temperature (e.g. efficient mixing of the fuel and combustion air) and residence time in the combustion zone, and use of furnace automation and control.	
c.	Furnace automation and control	See Section 4.4.1.	
d.	Flue-gas recirculation	Recirculation (external) of part of the flue-gas to the combustion chamber to replace part of the fresh combustion air, with the dual effect of lowering the temperature and limiting the O ₂ content for nitrogen oxidation, thus limiting the NO _x generation. It implies the supply of flue-gas from the furnace into the flame to reduce the oxygen content and therefore the temperature of the flame.	Applicability to existing plants may be restricted by a lack of space.
e.	Low-NO _x burners	See Section 4.4.3.	Applicability to existing plants may be restricted by design and/or operational constraints.
f.	Limiting the temperature of air preheating	Limiting the air preheating temperature leads to a decrease of the concentration of NO _x emissions. A balance has to be achieved between maximising heat	Generally applicable.

Technique		Description	Applicability
		recovery from the flue-gas and minimising NO _x emissions.	
g.	Oxy-fuel combustion	See Section 4.4.3.	Applicability to existing plants may be restricted by furnace design and the need for a minimum waste gas flow.
h.	Flameless combustion	See Section 4.4.3.	Applicability to existing plants may be restricted by furnace design (i.e. furnace volume, space for burners, distance between burners) and the need for a change of the furnace refractory lining. Not applicable to furnaces operating at a temperature lower than the auto-ignition temperature required for flameless combustion.

Table 4.24: BAT-associated emission level (BAT-AEL) for channelled emissions to air of NO_x and indicative emission level for channelled emissions to air of CO

Parameter	Unit	Process(es)	BAT-AEL (Daily average or average over the sampling period)	Indicative emission level (Daily average or average over the sampling period)
NO _x	mg/Nm ³	Heating / reheating / heat treatment	100 – 250 ⁽¹⁾	No indicative level
CO	mg/Nm ³	Heating / reheating / heat treatment	No BAT-AEL	10 – 100

⁽¹⁾ The upper end of the BAT-AEL range may be higher and up to 350 mg/Nm³ when recuperative/regenerative burners are used.

The associated monitoring is given in BAT 48.

4.3.6 Water consumption and waste water generation

BAT 52. In order to optimise water consumption and to reduce the volume of waste water generated, BAT is to use both of the techniques (a) and (b) given below:

Technique		Description	Applicability
a.	Segregation of water streams	See Section 4.4.4.	Applicability to existing plants may be restricted by the layout of the water collection system.
b.	Water reuse and/or recycling	Water streams (e.g. process water, cooling water) are reused and/or recycled in closed or semi-closed circuits, if necessary after treatment.	The degree of water reuse and/or recycling is limited by the water balance of the plant, the content of impurities and/or the characteristics of the water streams.

Note: BAT 51 only applies when waste water generation is identified as relevant based on the inventory of inputs and outputs mentioned in BAT 2.

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4.4 Descriptions of techniques

4.4.1 Techniques to increase energy efficiency

Technique	Description
Furnace automation and control	The heating process is optimised by using a computer system controlling key parameters such as furnace and feedstock temperature, the air to fuel ratio and the furnace pressure.
Improving casting yield and decreasing scrap generation	Measures are taken to maximise the efficiency of the casting process and to decrease the generation of scrap, e.g.: <ul style="list-style-type: none"> • optimising melting and pouring operations to reduce, for example, melting losses, excessive pigging, scrap generation rates; • optimising moulding and core-making to reduce scrap generation resulting from deficiencies in moulds and cores; • optimising gating and rising systems; • using insulated exothermic feeders.
Increase of shaft height in CBC furnaces	Increasing the shaft height in cold blast cupola furnaces enables combustion gases to remain in contact with the charge for longer, resulting in a higher heat transfer.
Long-campaign cupola	The cupola furnace is set up for long campaign operation to minimise maintenance and process changes. This may be achieved by using more resistant furnace refractory linings in the shaft, bottom and hearth, by using water cooling of the furnace wall and with water-cooled blasting pipes penetrating deeper into the furnace shaft.
Minimal blast shut-off periods for HBC furnaces	Minimisation of blast shut-off periods by programming the schedules of the moulding and casting processes to ensure a reasonably constant demand for metal.
Oxy-fuel combustion	Combustion air is replaced fully or partially with pure oxygen. Oxy-fuel combustion can be used in combination with flameless combustion.
Oxygen enrichment of the combustion air	Oxygen enrichment of the combustion air is realised either directly at the blast supply or through injection of oxygen into the coke bed, or via the tuyères.
Post-combustion of off-gases	See Section 4.4.3.
Preheating of combustion air	Reuse of part of the heat recovered from the combustion flue-gas to preheat the air used in combustion. This may be achieved for example by using regenerative or recuperative burners (see below). A balance has to be achieved between maximising heat recovery from the flue-gas and minimising NO _x emissions.
Recuperative burner	Recuperative burners employ different types of recuperators (e.g. heat exchangers with radiation, convection, compact or radiant tube designs) to directly recover heat from the flue-gases, which are then used to preheat the combustion air.
Regenerative burner	Regenerative burners consist of two burners which are operated alternately and which contain beds of refractory or ceramic materials. While one burner is in operation, the heat of the flue-gas is absorbed by the refractory or ceramic materials of the other burner and then used to preheat the combustion air.
Selection of an energy-efficient type of furnace	Furnace energy efficiency is taken into consideration for the furnace selection, e.g. furnaces that allow the preheating and drying of incoming charge prior to the melting zone.
Techniques for maximising the thermal efficiency of furnaces	Measures taken to maximise the efficiency of energy conversion in melting and heat treatment furnaces while minimising emissions (in particular of dust and CO). This is achieved by applying a series of process optimisation measures according to the furnace type including optimisation of the temperature (e.g. efficient mixing of the fuel and combustion air) and residence time in the combustion zone, and use of furnace automation and control (see above). Measures for some specific furnaces include the following: <p>For cupola furnaces:</p> <ul style="list-style-type: none"> • optimisation of operational regime; • avoidance of excess temperature; • uniform charging;

Technique	Description
	<ul style="list-style-type: none"> • minimisation of air losses; • good lining practice. <p>For induction furnaces:</p> <ul style="list-style-type: none"> • feedstock conditions (e.g. optimum size and density for input materials and scrap); • closure of furnace lid; • minimum holding time; • keeping a liquid heel in the furnace; • addition of carburisers at the beginning of the melting cycle; • operation at maximum power input level; • temperature control to prevent overheating; • prevention of excessive slag build-up by optimising melting temperatures; • minimisation and control of the wear of furnace refractory lining; • when several induction furnaces are in operation, the energy use is optimised through peak load management. <p>For rotary furnaces:</p> <ul style="list-style-type: none"> • use of anthracite and silicon for melt protection; • adjustment of the continuous or discontinuous speed rotation of the furnace to achieve maximum heat transfer; • adjustment of the power and angle of the burner to achieve maximum heat transfer. <p>For EAFs:</p> <ul style="list-style-type: none"> • shorter metal melting and/or treatment times using advanced control methods for example for the composition and the weight of the charged materials, the temperature of the melt, as well as by efficient sampling and deslagging methods. <p>For shaft furnaces:</p> <ul style="list-style-type: none"> • choice of the furnace size according to continuous melt demand, to achieve a continuous melting process; • keeping the shaft filled with charging material to have optimum heat recovery; • adapting the shaft design to the designated charging material for an optimum charging material distribution in the shaft; • regularly cleaning the furnace; • independent control of the fuel/air ratio for each gas-fired burner; • continuous CO or hydrogen monitoring for each row of burners; • addition of oxygen above the melting zone to provide afterburning in the upper level of the shaft; • preheating of the charge using waste heat recovered from the flue-gases. <p>For reverberatory furnaces:</p> <ul style="list-style-type: none"> • preheating of the charge in the case of dry hearth or side-well reverberatory furnaces; • use of burners with automatic temperature control. <p>For crucible furnaces:</p> <ul style="list-style-type: none"> • preheating of the crucible prior to charging; • use of crucibles with high thermal conductivity and thermal shock resistance (e.g. graphite); • cleaning of crucible walls immediately after emptying to remove slag or dross.
Use of clean scrap	Melting clean scrap prevents the risk of non-metal compounds being taken up by the slag and/or degrading the furnace or ladle refractory linings.

4.4.2 Techniques to increase material efficiency

Technique	Description
Adjustment of the slag acidity/basicity	Use of an appropriate flux (e.g. limestone for acidic and calcium fluoride for basic cupola operations) to render the slag fluid enough to separate from the iron.
Improving casting yield and decreasing scrap generation	See Section 4.4.1.
Mechanical pretreatment of slag / dross / filter dust / spent refractory linings to facilitate recycling	Generated slag / dross / filter dust / spent refractory linings are pretreated on site, by using techniques such as crushing, segregation, granulation, magnetic separation.
Optimisation of binder and resin consumption	Measures to optimise binder and resin consumption include: <ul style="list-style-type: none"> • use of a sand quality which is consistent with the binder system; • good management of sand storage and sand testing (purity, grain size, shape, moisture); • temperature control; • mixer maintenance and cleaning; • checking mould quality (to prevent and if necessary repair moulding defects); • optimising binder addition process; • optimising mixer operation.
Separate spraying of release agent and water in high-pressure die-casting	Water and release agents are applied separately to the mould using an additional row of nozzles mounted on the spray head. Water is sprayed first, leading to a significant cooling of the mould before the application of the release agent, which results in reduced emissions and consumption of release agents and water.
Use of best practices for cold-setting processes	Practices include the following (according to the binding system used): <ul style="list-style-type: none"> • Temperature control: the temperature of the sand is kept as constant as possible and low enough to prevent emissions caused by evaporation. For phenolic- and furan-acid-catalysed, polyurethane and ester silicate systems, the optimum temperature range is between 15 °C and 25 °C. For resol-ester systems, the optimum temperature range is between 15 °C and 35 °C; • for furan-acid-catalysed systems: <ul style="list-style-type: none"> ○ the content of free (monomer) furfuryl alcohol in the resin is minimised (e.g. less than 40 wt-%); and ○ the sulphur content of the acid catalyst is reduced by substituting a portion of the sulphonic acid with a strong sulphur-free organic acid.
Use of best practices for gas-hardening processes	Practices include the following (according to the hardening process used): <p>For phenolic urethane resins (cold-box process):</p> <ul style="list-style-type: none"> • the consumption of amines is minimised by optimising the diffusion process within the core, typically through computer simulation for optimisation of the gas flow; • the sand temperature is maintained as constant as possible, between 20 °C and 25 °C, to minimise gassing time and amine consumption; • the moisture of the sand is maintained below 0.1 % and the gassing and purging air is dried; • core boxes are well sealed to allow the amine catalyst gas to be extracted and the cores are thoroughly purged to prevent amine releases during the storage of cores. <p>For resol-ester resins:</p> <ul style="list-style-type: none"> • the sand temperature is maintained as constant as possible, between 15 °C and 30 °C; • curing of the alkaline phenolic resin is achieved using methyl formate that is gasified by air typically heated up to 80 °C;

Technique	Description
	<ul style="list-style-type: none"> core boxes and gassing heads are sealed correctly and the venting of the core box designed to give a slight backpressure so that the curing vapour is held long enough for the reaction to take place. <p>For CO₂-hardened resins (e.g. alkaline phenolic, silicate):</p> <ul style="list-style-type: none"> the exact volume of CO₂ gas necessary for curing the resins is used by employing a flow controller and a timer to achieve the best strength and storage time; for silicate resins, liquid breakdown agents are employed (e.g. soluble carbohydrates) to increase gassing speed. <p>For SO₂-hardened resins (e.g. phenolic, epoxy/acrylic):</p> <ul style="list-style-type: none"> the gassing period is followed by purging with either the same inert gas (e.g. nitrogen) used for curing or air, to remove the unreacted excess sulphuric dioxide from the sand; core boxes are well sealed and the cores are thoroughly purged to prevent gas releases during the storage of cores.
Use of clean scrap	See Section 4.4.1.

4.4.3 Techniques to reduce emissions to air

Technique	Description
Adjustment of the slag acidity/basicity	See Section 4.4.2.
Adsorption	The removal of pollutants from a process off-gas or waste gas stream by retention on a solid surface (activated carbon is typically used as the adsorbent). Adsorption may be regenerative or non-regenerative.
Catalytic oxidation	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.
Cyclone	Equipment for the removal of dust from an off-gas stream based on imparting centrifugal forces, usually within a conical chamber. Cyclones are mainly used as a pretreatment before further dust abatement or abatement of organic compounds. Multicyclones may also be used.
Dry scrubbing	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) to form a solid, which is removed by filtration (e.g. fabric filter).
Electrostatic precipitator	Electrostatic precipitators (ESPs) operate such that particles are charged and separated under the influence of an electrical field. Electrostatic precipitators are capable of operating under a wide range of conditions. Abatement efficiency may depend on the number of fields, residence time (size), and upstream particle removal devices. They generally include between two and five fields, but may contain up to seven fields for the most advanced ESPs. Electrostatic precipitators 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.
Extraction of emissions generated from moulding and/or core-making as close as possible to the emission source	<p>Emissions generated from moulding (including the making of patterns) and/or core-making are extracted. The extraction system selected depends on the type of moulding/core-making process.</p> <ul style="list-style-type: none"> Natural/green sand moulding: Off-gases generated in the natural or green sand preparation areas (e.g. transport, sieving, mixing and cooling) and in the moulding areas, especially during pouring, are extracted. In the case of automatic moulding machines, appropriate extraction systems are used to collect emissions (e.g. roof extraction). In the case of hand moulding, extraction as close as possible to the emission source is achieved using mobile extraction hoods. Cold-setting, gas curing, hot-curing processes:

Technique	Description
	<p>In the case of automatic moulding machines, extraction systems are used to collect emissions (e.g. fixed extraction hoods, canopy extraction). In the case of hand moulding, extraction as close as possible to the emission source is realised using mobile extraction hoods.</p> <p>In the event that mobile hoods cannot be used due to the size of the mould and/or space restrictions, casting hall extraction is used.</p> <p>Core shooting machines are enclosed and off-gases are extracted. Extraction is also applied during checking, handling and storage of freshly made cores (e.g. by using hoods at the checking table, above the handling and temporary storage areas).</p>
Fabric filter	<p>Fabric filters, often referred to as bag filters, are constructed from porous woven or felted fabric through which gases are passed to remove particles. 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. 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.</p>
Flameless combustion	<p>Flameless combustion is achieved by injecting fuel and combustion air separately into the combustion chamber of the furnace at high velocity to suppress flame formation and reduce the formation of thermal NO_x while creating a more uniform heat distribution throughout the chamber. Flameless combustion can be used in combination with oxy-fuel combustion (see Section 4.4.1).</p>
Furnace automation and control	<p>See Section 4.4.1.</p>
Low-NO _x burner	<p>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.</p>
Optimisation of binder and resin consumption	<p>See Section 4.4.2.</p>
Oxygen enrichment of the combustion air	<p>See Section 4.4.1.</p>
Oxy-fuel combustion	<p>See Section 4.4.1.</p>
Post-combustion of off-gases	<p>Post-combustion of CO and other organic compounds contained in furnace off-gases is used to reduce emissions and for heat recovery. The generated heat is recovered with a heat exchanger and used for blast air preheating or other internal purposes. In HBC furnaces, post-combustion takes place in a separate post-combustion chamber preheated by a natural gas burner. In CBC furnaces, post-combustion takes place directly in the cupola shaft. In rotary furnaces, post-combustion is carried out using an afterburner installed between the furnace and the heat exchanger.</p>
Selection of an appropriate furnace type	<p>Selection of the appropriate furnace type(s) based on the level of emissions and technical criteria, e.g. type of process such as continuous or batch production, furnace capacity, type of castings, availability of raw materials, flexibility depending on raw materials' cleanliness and alloy change. The energy efficiency of the furnace is also considered (see technique 'Selection of an energy-efficient type of furnace' in Section 4.4.1).</p>
Substitution of alcohol-based coatings with water-based coatings	<p>Substitution of alcohol-based coatings of moulds and cores with aqueous coatings. Aqueous coatings are dried in ambient air or using drying ovens.</p>
Thermal oxidation	<p>Abatement technique which oxidises combustible compounds in a waste gas stream by heating it with air or oxygen to above its auto-ignition point in a combustion chamber and maintaining it at a high temperature long enough to complete its combustion to carbon dioxide and water. The typical combustion temperature is between 800 °C and 1 000 °C.</p>

Technique	Description
	<p>Several types of thermal oxidation are operated:</p> <ul style="list-style-type: none"> • 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.
Use of best practices for cold-setting processes	See Section 4.4.2.
Use of best practices for gas-hardening processes	See Section 4.4.2.
Wet scrubbing	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.

4.4.4 Techniques to reduce emissions to water

Technique	Description
Activated sludge process	In the activated sludge process, the microorganisms are maintained as a suspension in the waste water and the whole mixture is mechanically aerated. The activated sludge mixture is sent to a separation facility from which the sludge is recycled to the aeration tank.
Adsorption	The removal of soluble substances (solutes) from the waste water by transferring them to the surface of solid, highly porous particles (typically activated carbon).
Aerobic treatment	The biological oxidation of dissolved organic pollutants with oxygen using the metabolism of microorganisms. In the presence of dissolved oxygen, injected as air or pure oxygen, the organic components are mineralised into carbon dioxide and water or are transformed into other metabolites and biomass.
Chemical precipitation	The conversion of dissolved pollutants into an insoluble compound 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.
Chemical reduction	The conversion of pollutants by chemical reducing agents into similar but less harmful or hazardous compounds.
Coagulation and flocculation	Coagulation and flocculation are used to separate suspended solids from waste water and are often carried out in successive steps. Coagulation is carried out by adding coagulants with charges opposite to those of the suspended solids. Flocculation is carried out by adding polymers, so that collisions of microfloc particles cause them to bond to produce larger flocs.
Equalisation	Balancing of flows and pollutant loads at the inlet of the final waste water treatment by using central tanks. Equalisation may be decentralised or carried out using other management techniques.
Evaporation	Evaporation of waste water is a distillation process where water is the volatile substance, leaving the concentrate as bottom residue to be handled (e.g. recycled or disposed of). The aim of this operation is to reduce the volume of waste water or to concentrate mother liquors. The volatile steam is collected in a condenser and the condensed water is, if necessary after subsequent treatment, recycled.

Technique	Description
	There are many types of evaporators: natural circulation evaporators; short-tube vertical evaporators; basket-type evaporators; falling film evaporators; agitated thin film evaporators. Typical pollutants targeted are soluble contaminants (e.g. salts).
Filtration	The separation of solids from waste water by passing them through a porous medium, e.g. sand filtration, microfiltration and ultrafiltration.
Flotation	The separation of solid or liquid particles from waste water by attaching them to fine gas bubbles, usually air. The buoyant particles accumulate at the water surface and are collected with skimmers.
Membrane bioreactor (MBR)	MBR consists of the combination of a membrane process (e.g. microfiltration or ultrafiltration) with a suspended growth bioreactor. In an MBR system for biological waste water treatment, the secondary clarifier and the tertiary filtration step of a traditional aerated sludge system is replaced by membrane filtration (the separation of sludge and suspended solids).
Nanofiltration	A filtration process in which membranes with pore sizes of approximately 1 nm are used.
Neutralisation	The adjustment of the pH of waste water to a neutral level (approximately 7) by the addition of chemicals. Sodium hydroxide (NaOH) or calcium hydroxide (Ca(OH) ₂) is generally used to increase the pH, whereas sulphuric acid (H ₂ SO ₄), hydrochloric acid (HCl) or carbon dioxide (CO ₂) is generally used to decrease the pH. The precipitation of some substances may occur during neutralisation.
Physical separation	The separation of gross solids, suspended solids, metal particles from the waste water using for example screens, sieves, grit separators, grease separators, hydrocyclones, oil-water separation or primary settlement tanks.
Reverse osmosis	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.
Sedimentation	The separation of suspended particles and suspended material by gravitational settling.
Segregation of water streams	Water streams (e.g. surface run-off water, process 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 from waste water streams that require treatment.

5 EMERGING TECHNIQUES

5.1 Emerging techniques for smitheries

No information has been submitted on emerging techniques.

WORKING DRAFT IN PROGRESS

5.2 Emerging techniques for foundries

5.2.1 Fossil-free recycling of residues

Description

Hydrogen-based process to reduce metal oxides, mainly iron, to pure metal without GHG emissions.

Technical description

This flexible technique can be used to recycle oxidised scale, filter dust, grinding swarf, mine tailings and produce sponge iron from iron ore.

- the process and system solution is a hydrogen-based process to reduce metal oxides, mainly iron, to pure metal without GHG emissions.
- the process and system solution is also suitable for the reduction of other metal oxides in accordance with the Ellingham diagram, such as lead, zinc, nickel, copper, cobalt and molybdenum.

The technique consists of a closed-circuit bell furnace with electrical heating units.

The main drivers of the process are the laws regarding temperature, pressure differences and mass:

- hydrogen's affinity to pair with oxygen at 550°C.
- the relatively cold steam formed in the reduction process (endothermic process) will be forced downwards by the surrounding hot hydrogen
- water steam is heavier than hydrogen and therefore forced downwards (9 times heavier than H₂).
- the condensation of water steam creates a pressure difference between the top and bottom area of the furnace (volume reduction 1:1 244 from steam to water)

The furnace is loaded with a charge of pellets created from iron ore or residues as oxidised scale, filter dust, grinding swarf etc. The furnace is evacuated and flushed with nitrogen in order to guarantee the absence of oxygen. The hydrogen is then added under pressure, and the hydrogen reacts with the oxygen in the material and water steam is formed. The oxides in the residual products are reduced and the pure metal that is retained in the pellets in the charge can be reintroduced as raw material in the production process.

Achieved environmental benefits

The main environmental benefits are

- no CO₂ emissions.
- increases the proportion of recycling, which will decrease the requirement of virgin material and its processing through CO₂ intensive blast furnaces.
- reduces the need of transport.

The only output from the process is pure metal and water.

The furnace is small and has a low capital expenditure. Therefore, it can be placed at sites, where the residues and waste are created or collected, with the benefit of reducing transportation. Transporting non-oxidised material reduces transported weight by up to 30%.

Environmental performance and operational data

The process energy requirement is 1650 – 2100 kWh per tonne of iron-containing material depending on the oxidation level of the input material.

Waste from a foundry plant has been received and the pure metal in the form of pellets has been sent back for melting with good results.

The technology should not be confused with the two production methods that major steel producers have currently (2022) applied using natural gas and which in the future are expected to be used with largely hydrogen, thus DRI production with a shaft furnace or fluidising bed furnace. The only similarity is the use of hydrogen; however, the feedstock, temperature and product are different.

Cross-media effects

The water formed in the process may contain some impurities which need to be removed prior to release. The amounts of impurities depend on the input being processed. Prior to processing the material is analysed and a water treatment facility ensures that no water containing harmful substances is released.

From the furnace there are zero gaseous emissions since all gases are converted to water or reused.

The hydrogen used in the process can be produced through electrolysis which would require green electricity to have a lower environmental impact. Alternatively, it can be produced through gasification of biomass to hydrogen. These are hydrogen production methods offered in the market.

Technical considerations relevant to applicability

A furnace with 5 tons charge capability is small, but modular and thus fully scalable. One furnace can process approximately 40 000 tonnes of matter per annum. Two or more furnaces can be operated in parallel. A multi furnace solution operated in asynchronous mode will enable further energy savings by heating the charge to be processed with the hot gases from the cooling process of the previous charge, thus not releasing and losing any energy.

The furnace can be installed at foundries, steel plants, metal manufacturers, recycling centers and at mines with suitable mine tailings.

The technique is applicable for new and existing foundries.

Economics

The total cost is estimated to EUR 250 per tonne to reduce waste material, like oxidised scale or filter dust, back to the original metal. The estimation is based using prices (January 2022) for green hydrogen, which accounts for 85 % of the energy consumption. In addition to hydrogen, the cost of EUR 250 per tonne also cover the costs for electricity, pelletising, maintenance, water cleaning, insurance, personal costs and the capital cost plus depreciation of the furnace and other equipment like the pelletiser, cranes, storage bins and conveyors.

With the cost of electrolysis steadily falling, while the cost for emission rights is expected to increase, the cost-competitive position of this technique compared to existing fossil-based solutions is expected to improve even more over time. [210, TWG 2022]

Driving force for implementation

The main drivers for implementation are to contribute to the reduction of CO₂ emissions as well as increased recycling.

Date of implementation

The production furnace is in the final design phase with Seco/Warwick. Linde Gas is providing the hydrogen and the testing is performed in a pilot plant located at a Linde Gas facility in Stockholm.

A realisation of a full-scale commercial size plant is in progress.

Example plants

At the Linde Testing Facility in Stockholm, Magnetite and Hematite have been reduced to pure iron with 100 % reduction and 100 % metallisation. The experiments show a robustness for a variety of metals.

Reference literature

[136, SE 2020], [210, TWG 2022]

5.2.2 Online analysis of temperature and chemical composition

Description

Online analysis of temperature and chemical composition of slag and molten metal by using broadband spectral thermometry (BST) and laser-induced breakdown spectroscopy (LIBS).

Technical description

Within the context of the EU CONSENSO project, equipment for online analysis of temperature and chemical composition was developed. This equipment is based on broadband spectral thermometry (BST) and laser-induced breakdown spectroscopy (LIBS). Installations are planned at various production steps in the iron and steel-making process; typically at the AOD converter and moulding pot.

The main components of the LIBS technique are: laser, optics, spectrometer. The working-principle is as follows: Laser-pulses are focused on the sample to create a plasma. The atoms and ions in the plasma then emit light characteristic to each element. The light is then analysed with a spectrometer. By analysing the spectral data the chemical composition of the sample can then be derived. No chemicals or gases are needed for the equipment, only electricity. In the CONSENSO project LIBS is developed for analysis of chemical composition of slag and iron in the form where it is still hot and thus will be useful for process control. Primarily the technique is developed for quick and easy inline sampling, but could also be applied for online measurement directly in the production process without sampling.

BST is composed of optics and spectrometer only. The principle is the same as conventional pyrometry. The object emits radiation which is analysed based on Planck's law for black body radiation. In contrast to normal pyrometry BST uses information in a wide spectral range and can therefore better cope with interferences such as smoke or other unwanted material that is obscuring the sight of the material of interest.

Achieved environmental benefits

The main advantage of the technique is enhanced process control, which ensures that the material has the right quality when it is being produced and thus less products are rejected and turned to waste. With the chemical analysis it can be ensured that no excess material is used, and hence enables a more efficient use of resources. Due to a quicker analysis the time spent heating the metal can be reduced and thus considerable energy savings are possible. With better control of the chemistry, it is also possible that the slag composition can be adjusted so that it can be used as a secondary resource reducing waste.

Environmental performance and operational data

The CONSENSO project was carried out during the period 2018-2021.

The techniques developed in CONSENSO will not directly reduce emissions or energy consumption. They instead enable a more efficient process control, which in turn will lead to reduced emission and use of raw material.

Cross-media effects

No negative environmental effects.

Technical considerations relevant to applicability

BST can be used in most sectors where there is a need for temperature control. The greatest need is seen in the metals production since the harsh environment makes other available techniques less suitable.

Economics

Equipment is under development and costs are therefore not known.

Driving force for implementation

BST and LIBS are the only known techniques that work under these requirements. LIBS uses a high power laser that may cause eye-damage. But in the format that the techniques are used in CONSENSO, no safety measures are needed.

Example plants

It has not been installed anywhere yet.

Reference literature

More information: <https://eitrawmaterials.eu/project/consenso/>

5.2.3 Spark Plasma Sintering**Description**

Fast production of high-performance parts using pressure and heat.

Technical description

The special feature of Spark Plasma Sintering (SPS) is based on the heat generation thanks to the passage of a high-intensity current as close as possible to the workpiece via the graphite mould. This leads to a situation in which temperature rises extremely fast (up to 100°C/min) and sintering cycles only take a few minutes. In comparison to natural or conventional sintering, Spark Plasma Sintering, has the advantage of reducing the sintering duration and temperatures. Grain growth in the material is therefore very limited and the materials obtained have much better performances. Better control of microstructures is therefore possible within the parts obtained while also achieving densification rates close to the theoretical density.

The advantages of parts obtained by SPS could be resumed in:

- increase of mechanical performance ;
- reduction of material loss (less than 5%) ;
- reduction of production time (less than 1h).

The target materials could be metal, ceramic or composite. One specificity of SPS is also to work on metal/ceramic assembly. The control of thermal gradient and holding time allows the operator to manage stress in the material during the cooling.

Achieved environmental benefits

SPS technology is based on powder metallurgy. The preparation of specific tools allows the operator to make directly near net shape parts in one step (<1 h of thermal treatment). The material losses are drastically reduced compare to all the traditional process and can be less than 5 %.

This advantage is very useful for high value material used for aerospace, automotive, defence and energy application.

The SPS process is also an opportunity to renew design and composition of critical material with strategic dependence for sourcing. For example, developments are running to reduce or avoid the cobalt amount in tungsten carbide cutting tools. These results will lead to a reduction of strategic needs from non-European countries.

Environmental performance and operational data

No information provided.

Cross-media effects

Buy to fly ratio is one of the more important parameters check in aerospace. The material lost during process could be more than 80% of the material bought initially which is considered high.

SPS is one of the leading technologies which could provide such solution thanks to its two advantages:

- low material loss ;
- possibility to develop smarter material design and composition.

Technical considerations relevant to applicability

SPS technology is not limited to one sector, the problematic of material loss and increasing the material properties are common to all the industries.

Economics

No information provided.

Driving force for implementation

No information provided.

Example plants

Spark Plasma Sintering is now being commercialised. A European SPS machine provider is one of the top two leaders in the world (FCT Systeme GmbH).

Producers are now available in France (Toulouse or at Sintermat). Other stakeholder have invested in the technology as Sandvik Coromant or Mecachrome for their development.

Reference literature

More information: <https://eitrawmaterials.eu/>

5.2.4 Use of biocoke in cupolas

Description

Use of biogenous solid fuels ('bio-coke') as a carbon-neutral substitute for anthracite coke in cupola furnaces for efficient melting and carburising of cast iron melts.

Technical description

Cast iron materials are important construction materials, e.g. in vehicle construction (axle support), mechanical engineering (gear housing), and wind turbine construction (rotor hub, etc.)

The cupola furnace is an efficient melting aggregate for middle to long series production of cast irons. It has advantages in continuous production of a uniform base iron. Waste heat is efficiently used.

About 50 % of the liquid iron (e.g. 2 million tonnes in Germany) is melted in cupola furnaces. They melt liquid iron from steel scrap and anthracite (hard coal) coke. In Europe, there are about 200 cupola furnaces in operation.

Cupola furnaces can melt unalloyed and low alloyed steel scrap of relatively low quality. The slight oxidative atmosphere around the tuyères can remove some undesired trace elements:

- The metallurgical process in the cupola furnace is carburisation of steel scrap (0.1 % C) to > 3 % C to achieve the material properties.
- Carbon has a dual use in cast iron: material use (> 3 % C) and energy. Cast iron is an in-situ composite with free graphite in its structure.

Biocoke is an immediate option to at least partly defossilise the cupola operation:

- Biocoke is processed from biomass carbonisate by compaction (extruder, hydraulic press) using a sustainable binder (cereal, lignin).
- Biomass carbonisate is generated in a rotating furnace usually by high-temperature carbonisation of white biomass (woody or plant residuals). The carbon content is around 90 %. Waste heat can be recovered from this autothermal process.

Use of biocoke is possible for all cupola iron foundries without any furnace modification. Biocoke trials started in the EU in 2017 and are ongoing. In mid-2023, a partial substitution of anthracite coke up to 40 % is possible.

Achieved environmental benefits

Substitution of anthracite coke by a carbon-neutral biocoke with:

- unchanged ferrous recyclate percentage of about 90% (unalloyed or low alloyed steel scrap, cast iron returns);
- unchanged amount of melting energy;
- CO₂ emissions that are fossil-free (CO₂ circle within one generation).

The overall efficiency of decarbonisation has yet to be determined (see tabled values in the Annex to Renewable Energy Directive RED II⁸) following the current industrial trials.

Environmental performance and operational data

Plant-specific performance:

- Charge coke: requires to date (mid-2023) a higher substitution of anthracite coke due to the different properties of biocoke (same calorific value but earlier ignition point and lower thermal stability).
- Coke injection: carbonisate fines can be blown into the hearth via the tuyères to enhance reaction efficiency. However, it cannot be applied yet in every furnace (requires specific injection equipment).

Emissions to air and water:

- No pollutants to air (or water) when selecting a suitable biogenic residual (compared to anthracite coke, no SO₂, HCl, etc.)

Residuals:

- Unchanged fraction of waste (slags), with possible use as secondary building material (road construction, etc.)

Cross-media effects

None.

If the cascading principle (Renewable Energy Directive - RED III) were to be enforced for energetic biomass use in cupolas, e.g. obligatory use of residual wood classes A_{III} and A_{IV}, this would result in intolerable emissions, partly damaging furnace materials. Chemicals used for wood impregnation or binders (e.g. in chipboards) do contain chlorine etc., possibly resulting in PCDD emissions. Chlorine will increase corrosion of steel (furnace steelwork) and of the refractory lining.

Technical considerations relevant to applicability

Limiting factors for a 100% substitution are to date (mid-2023):

- availability of suitable biomass on the EU market;
- high-temperature strength (thermal stability) of biocoke, currently under investigation.

⁸ DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the promotion of the use of energy from renewable sources (recast)

In mid-2023, a substitution rate of up to 40 % is possible, depending on furnace type, size, operation mode and base iron. Anthracite coke is still required to stabilise the charge in the furnace column. Increasing the thermal stability will further increase the substitution rate.

Current R&D focuses on:

- improving high temperature strength of bio-coke bricks;
- optimising sustainable binders (type and fraction);
- adapting production processes (briquetting);
- developing combined alloy-biocarbon bricks.

Testing of bio-coke properties is being established. As this is a new material, a database with composition and basic material properties (cold strength, coke strength after reaction (CSR), coke reactivity index (CRI)) is being collected and benchmarked against anthracite coke. This is required to assess the quality of biocoke bricks.

Future R&D will focus on the suitability of lower-grade biogenous carbon, processed by high-temperature or even hydrothermal carbonisation. Care must be taken in the selection of biomass, regarding possible emissions and/or potentially detrimental trace elements.

Economics

On the European market there is currently (mid-2023) limited availability of biomass carbonisates due to:

- publicly funded use of white biomass (wood residuals) for co-combustion in coal-fired power plants;
- publicly funded use of white biomass for private home pellet heating;
- publicly funded use of biomass residuals in biogeneous power plants or composting plants;
- competition by other industrial sectors, e.g. for climate-neutral (cement) or climate-positive (agriculture) use.

This situation results in the import of sustainable biomass from outside the EU which is not desirable due to the CO₂e ‘backpack’ of shipping and safety measures to avoid self-ignition in moist environments. This impacts the price of biomass, making it uneconomical for foundries (by mid-2023, the bio-coke cost was higher compared to the cost of EU ETS certificates). Sustainability assessment / certification will be an additional cost driver.

Driving force for implementation

Defossilisation of iron foundry cupola melting shops without the need for a furnace rebuild and with immediate applicability (avoiding electricity net overload of additional electric furnaces).

As analysed in the study InnoGuss (BDG, June 2023), there are few options:

- Electrification (requires availability of 100 % green electricity with high CAPEX (high-voltage power line, entirely new melting shop), high OPEX (electricity cost within EU compared to outside EU).
- Hydrogen (requires availability of 100% green hydrogen), high CAPEX (infrastructure and safety), high OPEX (hydrogen cost). Other: too noble to combust, no reduction process required for iron melting.
- CCU (requires additional infrastructure), high CAPEX, high OPEX (energy) and limited sales of the new product.
- CCS (requires additional infrastructure), high CAPEX (cleaning, compression for transport) and OPEX (cleaning, water treatment).
- Biomass (no rebuild, some development).

Additionally, cupola furnaces can melt steel scrap of a lower quality. This is a future competitive advantage over the induction furnace, as unalloyed steel scraps will become scarce by 2026 due to the transformation of the steel industry.

Example plants

- Japan: Kindai Biocoke in an iron pipe foundry cupola 30 t/h, blend bamboo/wood, 20 % substitution achieved by end 2021.
- Sweden: Volvo in Skövde, 40 % substitution achieved by end 2022.
- Germany: small-volume tests in 15 foundries (e.g. MeierGuss, Fondium Singen, Linde Material Handling Weilbach).

Reference literature

- CAEF submission in [\[237, TWG 2023\]](#)

6 CONCLUDING REMARKS AND RECOMMENDATIONS FOR FUTURE WORK

Timing of the review process

The key milestones of the review process are summarised in Table 6.1 below.

Table 6.1: Key milestones of the SF BREF review process

Key milestone	Timing
TWG reactivation	July 2018
Call for wishes	January 2019
Kick-off meeting	17-20 September 2019
Data and information collection	April 2020 – March 2021
Draft 1 (D1) of the revised SF BREF	February 2022
Commenting period (1 565 comments received)	February – April 2022
Revised proposals for the draft BAT conclusions and Background Paper for the Final TWG Meeting	April 2023
Final TWG meeting	26 – 30 June 2023

During the BREF review process, a total of 10 foundries were visited in Belgium, France, Spain and Sweden.

In addition, the following events were organised by the EIPPCB to improve the exchange of information:

- Workshop to finalise the questionnaire template (February 2020);
- 1st data assessment workshop (April 2021);
- 2nd data assessment workshop (March 2023);

Sources of information and information gaps

The main sources of information for the review process were:

- scientific and technical literature;
- 158 filled-in questionnaires from operators of foundries and 9 filled-in questionnaires from operators of smitheries;
- additional information from SF TWG members;
- 1 565 comments on Draft 1 of the revised SF BREF;
- 491 comments on the revised version of the draft BAT conclusions (June 2022);
- information gathered from site visits;
- outcomes of the workshops mentioned above.

In total, more than 200 documents have been posted in BATIS, and most of them have been referenced in the revised SF BREF.

Degree of consensus reached during the information exchange

At the Final TWG Meeting that took place in hybrid format (in person and online) on 26 to 30 June 2023, a high degree of consensus was reached on most of the BAT conclusions. However, 19 split views were expressed, which fulfil the conditions set out in Section 4.6.2.3.2 of Commission Implementing Decision 2012/119/EU. They are summarised in Table 6.2 below.

Table 6.2: Split views expressed

BAT conclusion/ Table number	Split view	Expressed by	Alternative proposed level (if any)
Proposal for a new BAT 6(bis) on a climate-neutrality plan and electrification	To add a new BAT that states: BAT is to use all of the techniques (a) to (c) and for processes using electricity BAT is to use technique (d) given below. Technique (a): Elaboration and implementation of a climate-neutrality plan; Technique (b): Selection of an electricity-based furnace type in cast iron and aluminium foundries; Technique (c): Electrification of other processes involving use of energy; Technique (d): Increased share of use of electricity produced from non-combustion based renewable energy sources.	EEB	-
BAT 12	Not to include monitoring for Cd, Cr, Ni and Pb emissions from casting, cooling and shake-out using lost moulds including full mould process.	DE and CAEF	
BAT 12	Not to include monitoring of Cd, Cr, Ni and Pb emissions from finishing processes.	DE, IT and CAEF	
BAT 13	<ul style="list-style-type: none"> Set a monitoring frequency of 'once every month'. Delete footnote ⁽³⁾ (allowing for a reduced 6-month frequency). Amend footnote ⁽²⁾ as follows <i>"The monitoring only applies when the substance/parameter concerned is identified as relevant occurs in the waste gas stream based on the inventory of inputs and outputs mentioned in BAT 2."</i> 	EEB	
BAT 16, Table 4.2	<ul style="list-style-type: none"> To set BAT-AEPLs instead of indicative levels. To reinstate as the lower ends of the BAT-AEPL ranges those proposed in Draft 1 of the SF BREF and amend footnote (1) to allow a lower end of the range of 50 % in the case of complex casting shapes and a high number of cores and/or risers/feeders. To add in the SF BREF or in a BATC a clarification for the terms 'complex' casting shapes and 'high number of cores and/or risers/feeders' with quantitative and qualitative information. 	BE and EEB	
BAT 24, Table 4.5 (NO _x)	To set a BAT-AEL for NO _x emissions from heat treatment of 50 – 150 mg/Nm ³ .	DE	50 – 150 mg-Nm ³
BAT 26, Table 4.6 (dust)	To increase the upper end of the BAT-AEL range for dust emissions from moulding using lost moulds and core-making to 10 mg/Nm ³ .	FR, PT and CAEF	<1 – 10 mg/Nm ³
BAT 26, Table 4.6 (TVOC for the core-making process)	To increase the upper end of the BAT-AEL range for TVOC emissions from core-making to 100 mg/Nm ³ .	FR	Core-making: 15 – 100 mg C/Nm ³
BAT 27, Table 4.7 (dust)	To set a BAT-AEL range for dust emissions from casting, cooling and shake-out of 2 – 10 mg/Nm ³ in foundries using lost moulds.	DE, CZ, FR, PT and CAEF	2 – 10 mg/Nm ³

BAT conclusion/ Table number	Split view	Expressed by	Alternative proposed level (if any)
BAT 27, Table 4.7 (TVOC)	To increase the upper end of the BAT-AEL range for TVOC emissions from casting, cooling and shake-out to 100 mg/Nm ³ in foundries using lost moulds including full mould process	FR	15 – 100 mg C/Nm ³
BAT 27, Table 4.7 (benzene)	To increase the upper end of the BAT-AEL range for benzene emissions from casting, cooling and shake-out to 5 mg/Nm ³	CAEF	1 – 5 mg/Nm ³
BAT 27, Table 4.7 (benzene)	To add a new footnote stating that the upper end of the BAT-AEL range is 5 mg/Nm ³ for benzene emissions to air from the full mould process	ES, IT and CAEF	-
BAT 30, Table 4.10 (dust)	To set an upper end for the BAT-AEL range for dust emissions from finishing of 10 mg/Nm ³	DE, CZ, FR, PT and CAEF	1 – 10 mg/Nm ³
BAT 36, Table 4.13 (phenol index)	To set an upper end for the BAT-AEL range for phenol index emissions of 0.2 mg/l	EEB	0.05 – 0.2 mg/l
BAT 36, Table 4.13 (TSS)	To set an upper end for the BAT-AEL range for TSS emissions of 20 mg/l	EEB	5 – 20 mg/l
BAT 38, Table 4.15 (dust)	To set a BAT-AEL range for dust emissions for HBC and CBC of 1 – 5 mg/Nm ³	EEB	1 – 5 mg/Nm ³
BAT 38, Table 4.15 (dust)	To modify footnote (1) as follows: For existing HBC plants using wet scrubbing, the upper end of the BAT-AEL range may be higher and up to 15 mg/Nm ³ until the next major upgrade of the cupola furnace	CAEF	-
BAT 38, Table 4.15 (SO ₂)	To set the upper end of the BAT-AEL range for SO ₂ emissions for HBC at 150 mg/Nm ³ .	DE	30 – 150 mg/Nm ³
BAT 43, Table 4.19 (dust)	To set an upper end for the BAT-AEL range for dust emissions of 10 mg/Nm ³	FR, PT and CAEF	1 – 10 mg/Nm ³

Concerning the smitheries sector, EUROFORGE raised concerns on 4 topics related to BAT 4, BAT 5, BAT 47 and BAT 48 (topics considered not for discussion at the Final TWG meeting). These were as follows:

BAT 4 – Emissions to soil and groundwater

- whether all of the techniques specified in BAT 4 are relevant to smitheries and
- potential applicability restrictions of techniques (b) to (e) in the case of smitheries.

BAT 5 – OTNOC (other than normal operating conditions)

- whether all of the techniques specified in BAT 5 are relevant to smitheries and
- potential applicability restrictions concerning points (i) to (vii) included in the OTNOC management plan in the case of smitheries.

BAT 47 – Material efficiency

- whether all of the techniques specified in BAT 47 are relevant to smitheries,
- whether technique (b) (use of computer-aided design) is relevant for both the product design and the forging process,
- whether the use of the techniques mentioned in bullet points 5 and 6 of technique (b) referring to ‘Centralised distribution of coolant/lubricants’ and ‘Systems for collecting and recirculating coolants/lubricants’ are relevant to smitheries, and
- whether technique (c) (recycling of process residues) is relevant to smitheries.

BAT 48 – Vibrations: applicability of vibration-reducing measures in the case of smitheries, which may depend on whether a vibration nuisance at sensitive receptors is expected and/or has been substantiated.

Consultation of the Forum and subsequent formal adoption procedure of the BAT Conclusions

To be completed at a later stage.

Recommendations for future work

The information exchange revealed a number of issues that should be addressed during the next review of the SF BREF. The recommendations for the next review include the following:

Scope – interface of SF BREF with NFM BREF

- Foundries producing semi-finished non-ferrous metal products requiring further forming (which are not covered under the scope of the SF BREF) could be covered under the next review of the NFM BREF.
- Collect more information on the interface between the scope of the SF and NFM BREFs in order to help competent authorities to better classify foundries under each respective BREF.

Energy consumption in foundries

- Collect contextual information associated with the specific energy consumption for heat treatment (e.g. temperature, type of heat treatment, duration, treatment cycles, tonnages of casting heat treated).
- Express the energy consumption performance levels for heat treatment in kWh/tonne of casting heat treated.
- Collect more data and contextual information on the specific energy consumption from NFM foundries other than aluminium foundries (i.e. Zn, Cu, Pb, Mg, bronze, brass).

Energy consumption in smitheries

- Collect contextual information and data on the specific energy consumption in smitheries (e.g. processes and their characteristics, product types, heating cycles, temperature, type of heat treatment, duration).

Operational material efficiency (foundries)

- To further clarify the concept of complex shape castings.

Emissions to air (foundries)

- Collect more information on the uptake and use of:
 - low-emission cold-setting binder systems,
 - low emission gas curing binder systems, and
 - low-emission hot-curing binder systems.
- Collect more information on the core intensity (number of cores used) and its impact on emissions from casting, cooling and shake-out.
- Collect more information on the uptake and use of electric furnaces as substitutes for cupola furnaces.
- Collect more information on emissions of dioxin-like PCBs from metal melting.
- Collect data on emissions to air by NFM metal type.

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8 ANNEXES

8.1 Annex 1 List of European Smitheries and Foundries that participated in the data collection

8.1.1 List of European foundries that participated in the data collection

Plant code	Name of the plant	City	Country	2.4 FM	2.5(b) NFM	Metal processed in 2.5 (b) NFM
AT001	Banner GmbH	Linz	Austria		x	Pb
AT002	Borbet Braunau	Braunau	Austria		x	Al
AT003	Dynacast Österreich GmbH	Weikersdorf	Austria		x	Zn, Al
AT004	EGM Industrieguss GmbH	Möllersdorf	Austria	x		
AT005	Karl Fink GmbH	Leibnitz	Austria		x	Al
AT006	Georg Fischer Fittings GmbH	Traisen	Austria	x		
AT007	GF Casting Solutions Altenmarkt GmbH & Co KG	Altenmarkt	Austria		x	Al, Mg
AT008	Striko Schmelzöfen	Herzogenburg	Austria		x	Al
AT009	Gienanth Steyr Guss GmbH	Steyr	Austria	x		
AT010	Mahle Vöcklabruck GmbH	Vöcklabruck	Austria	x		
AT011	Maschinenfabrik Liezen und Gießerei GesmbH, Foundry	Liezen	Austria	x		
AT012	MRB Guss GmbH	Herzogenburg	Austria	x		
AT013	Nemak Linz GmbH	Linz	Austria		x	Al
AT014	Schindler Fahrtreppen International GmbH	Ternitz	Austria		x	Al
AT015	Tiroler Rohre GmbH / Hall i.T	Hall i.T.	Austria	x		
AT016	Voestalpine Giesserei Linz GmbH	Linz	Austria	x		
AT017	Voestalpine Gießerei Traisen GmbH	Traisen	Austria	x		
AT018	Wagnerguss	Enns	Austria	x		
BE019	Allard-Europe	Turnhout	Belgium	x		
BE020	Dovre Weelde	Weelde	Belgium	x		
BE021	Fondatel Lecomte SA	Andenne	Belgium	x		
BE022	Proferro NV	Ypres	Belgium	x		
BE023	Vandewiele Foundry department	Kortrijk	Belgium	x		
CZ024	ZPS-Slevarna, a.s.	Zlín	Czech Republic	x		
CZ025	Slévárny v závodě Mladá Boleslav	Mladá Boleslav	Czech Republic		x	Other
CZ026	Slévárna šedé a tvárné litiny	Hodonín	Czech Republic	x		
CZ027	Kovolit a.s.	Modřice	Czech Republic		x	Al
CZ156	Liberty Engineering Products Ostrava s.r.o.	Ostrava	Czech Republic	x		

Plant code	Name of the plant	City	Country	2.4 FM	2.5(b) NFM	Metal processed in 2.5 (b) NFM
DE028	ACO- Guss GmbH	Kaiserslautern	Germany	x		
DE029	Michelau, Plant 3	Rudersberg	Germany		x	Zn
DE030	Necklinsberg, Plant 1	Rudersberg	Germany		x	Zn
DE031	AE group nentershausen gmbh	Bebra-Iba	Germany		x	Al
DE032	Alzmetall Werkzeugmaschinenfabrik und Gießerei Friedrich GmbH & Co. KG	Altenmarkt	Germany	x		
DE033	Stihl Magnesium Druckguss / Druckgießerei, Schwerkraftguss	Weinsheim	Germany		x	Mg, Al
DE034	Stihl Magnesium Druckguss / Gießerei	Weinsheim	Germany		x	Mg
DE035	BMW High pressure die-casting foundry	Landshut	Germany		x	Al
DE036	BMW Sand casting foundry sand	Landshut	Germany		x	Al
DE037	BMW foundry Gravity casting and low-pressure die-casting	Landshut	Germany		x	Al
DE038	BMW foundry Lost-Foam	Landshut	Germany		x	Al
DE039	Bosch Rexroth AG	Lohr am Main	Germany	x		
DE040	Buderus Guss Breidenbach	Breidenbach	Germany	x		
DE041	Isselguss GmbH Giessereierzeugnisse	Isselburg	Germany	x		
DE042	Dossmann GmbH Eisengießerei und Modellbau	Walldürn-Rippberg	Germany	x		
DE043	DST Defence Service Tracks GmbH - Stahlgießerei	Remscheid	Germany	x		
DE044	Edelstahlwerke Schmees GmbH - Werk Pirna	Pirna	Germany	x		
DE045	Eisengießerei Georg Funk GmbH & Co. KG, Aalen	Aalen	Germany	x		
DE046	Eisenwerk Brühl GmbH	Brühl	Germany	x		
DE047	Eisenwerk Martinlamitz	Schwarzenbach a. d. Saale	Germany	x		
DE048	EMG Casting AG	Waldkraiburg	Germany	x	x	Al
DE049	Fondium Singen GmbH	Singen Htwl.	Germany	x		
DE050	Fondium Mettmann GmbH	Mettmann	Germany	x		
DE051	Franken Guss GmbH & Co. KG	Kitzingen	Germany	x		
DE052	Gontermann Peipers GmbH, Werk Hain	Siegen	Germany	x		
DE053	Gontermann Peipers GmbH, Werk Marienborn	Siegen	Germany	x		
DE054	HegerFerrit GmbH	Sembach	Germany	x		
DE055	HegerGuss GmbH	Enkenbach	Germany	x		
DE056	Harz Guss Zorge	Zorge	Germany	x		
DE057	Kemptener Eisengießerei Adam Hönig AG	Kempten/Allgäu	Germany	x		
DE058	Eisengießerei Weilbach	Weilbach	Germany			

Plant code	Name of the plant	City	Country	2.4 FM	2.5(b) NFM	Metal processed in 2.5 (b) NFM
DE060	MAT Foundries Europe GmbH Werk Neunkirchen	Neunkirchen	Germany	x		
DE061	Eisengießerei (Werk Wehrstapel)	Meschede	Germany	x		
DE062	MeierGuss Limburg GmbH (iron foundry)	Limburg / Lahn	Germany	x		
DE063	Foundry Gütersloh	Gütersloh	Germany	x		
DE064	Copper casting plant	Andernach	Germany		x	Cu
DE065	Nemak Dillingen GmbH	Dillingen	Germany		x	Al
DE066	Formanlage 1 Buchholz	Olpe	Germany		x	Al
DE067	Gusstechnik	Olsberg	Germany	x		
DE068	Pleissner Guss	Herzberg am Harz	Germany	x		
DE069	Reinhard Tweer GmbH - Stahlgießerei	Bielefeld	Germany	x		
DE070	Robert Bosch Lollar Guss	Lollar	Germany	x		
DE072	SM Sächsisches Metallwerk Freiberg GmbH	Freiberg	Germany		x	Cu, other
DE073	Stahlwerke Bochum GmbH	Bochum	Germany	x		
DE074	Trompeter Guss Chemnitz GmbH	Chemnitz	Germany	x		
DE075	Aluminum melting furnace	St. Ingbert	Germany	x	x	Al
DE076	WESO-Aurorahütte GmbH	Gladenbach	Germany	x		
DE077	Werk Beuel	Bonn	Germany	x		
DE078	Sandguss	Sigmaringendorf-Laucherthal	Germany		x	Cu, Zn, Al, other
DE159	ZGG - Zeitzer Guss GmbH	Zeitz	Germany	x		
DK079	Vald Birn A/S	Holstebro	Denmark	x		
EL080	Sunlight Systems SA	Xanthi	Greece		x	Pb
ES082	Fuchosa, S.L.U.	Atxondo	Spain	x		
ES084	Planta de Fundición de Aluminio Bergara	Arrasate	Spain		x	Al
ES085	Planta de Fundición de Hierro de Markulete	Arrasate	Spain	x		
ES086	Planta de Fundición de Aluminio Uribarri	Arrasate	Spain		x	Al
ES087	Planta de Fundición de Aluminio de Eskoriatza	Eskoriatza	Spain		x	Al
ES088	Durango	Durango	Spain	x		
ES089	Guivisa, S.L.	Vizcaya	Spain	x		
ES090	Industrias Hergom, S.L.	Soto de la Marina (Santa Cruz de Bezana)	Spain	x		
ES091	Funderia Condals, S.A.	Manresa	Spain	x		
ES092	Martinrea Honsel Spain LPDC	Mostoles	Spain		x	Al
ES093	Martinrea Honsel Spain HPDC	Mostoles	Spain		x	Al
ES094	Metal Smelting S.A. Elorrio	Elorrio	Spain	x		
ES095	Metal Smelting S.A. Iurreta	Iurreta	Spain	x		
ES096	Saint-Gobain PAM, España	Santander	Spain	x		
ES097	Schmidt-Clemens Spain S.A.U.	Murieta	Spain	x		

Annexes

Plant code	Name of the plant	City	Country	2.4 FM	2.5(b) NFM	Metal processed in 2.5 (b) NFM
ES098	Gamesa Enegy Transmission, S.A.U.	Burgos	Spain	x		
ES099	Teknia Ampuero, S.L.U.	Ampuero	Spain		x	Al
ES100	UCB Cast Profil SAU	Villanueva de Gallego (Zaragoza)	Spain	x		
FI101	Alteams Finland Oy, Laihia	Laihia	Finland		x	Al
FI102	Porin valimo	Pori	Finland	x		
FI103	Tevo Lokomo oy Tampere	Tampere	Finland	x		
FR104	Ferry Capitain	Vecqueville	France	x		
FR105	FMGC	Soudan	France	x		
FR106	Focast	Chateaubriant	France	x		
FR107	Fonderie Bouhyer	Ancenis - Saint Géreon	France	x		
FR108	Fonderie De Plomb	Carquefou	France		x	Pb
FR109	Fonderie Venissieux SAS	Venissieux	France	x		
FR110	Kuhn SAS	Saverne	France	x		
FR111	Le Creuset SAS	Frensoy le Grand	France	x		
FR112	Linamar Montupet	Châteauroux	France		x	Al
FR113	Nidec Leroy-Somer Fonderie	Angouleme	France	x		
FR114	PSA Automobiles Fonderie de Charleville	Villers Semeuse	France	x	x	Al
FR115	PMP PSA	Charleville Mézières	France	x	x	Al
FR116	Aluminium casting / SNC Renault Cleon	Cleon	France		x	Al
FR117	ACI	Le Mans	France	x		
FR118	SG PAM Usine de Bayard sur Marne	Bayard sur Marne	France	x		
FR119	Usine de Foug	Foug	France	x		
FR120	Fondeire	Merville	France	x		
IT071	Fllispa	Fano	Italy	x		
IT121	Foam SpA	Rivoli (TO)	Italy		x	Al
IT122	Chivasso Plant	Chivasso	Italy		x	Al
IT123	Grugliasco Plant	Grugliasco	Italy		x	Al
IT124	Fonderia Baraldi S.r.L.	Montagnana	Italy	x		
IT125	Fonderia San Martino	Barberino Tavarnelle	Italy	x		
IT126	Fonderie Palmieri SPA	Calenzano	Italy	x		
IT127	Fonderie Valdelsane spa	Monteriggioni (SI)	Italy	x		
IT128	Fonderia Getti Speciali ColomboGiuseppe di Carlo & Figli S.P.A.	San Giorgio su legnano (MI)	Italy	x		
IT129	Fondinox Spa	Sergnano	Italy	x		
IT130	Massifond S.P.A.	Orbassano (TO)	Italy	x		
IT131	Officine Zen Fonderie S.r.l.	Albignasego	Italy	x		
IT132	Parola e Luraghi SPA	Magenta	Italy	x		
IT133	Tecopress SPA	Terre del Reno	Italy		x	Al
IT134	VDC S.r.l.	Camposampiero	Italy	x		

Plant code	Name of the plant	City	Country	2.4 FM	2.5(b) NFM	Metal processed in 2.5 (b) NFM
IT154	Somipress SRL	Castelfidardo (AN)	Italy		x	Al
IT155	Lead Time SPA	Caldarola (MC)	Italy	x		
IT157	O/Cava Meccanica S.P.A.	Ferrere	Italy	x	x	Mg, other
IT158	Zanardi Fonderie SPA	Mínerbe	Italy	x		
PL135	Krakodlew S.A.	Cracow	Poland	x		
PL136	Koneckie Zakłady Odlewnicze S.A.	Końskie	Poland	x		
PL137	Foundry_OLE	Olesno	Poland		x	Cu
PL138	Cast iron foundry in Ścinawka Średnia	Ścinawka Średnia	Poland	x		
PT139	Cruz Martins & Wahl, Lda	Vila Nova de Famalicão	Portugal	x		
PT140	Duritcast, S.A.	Águeda	Portugal	x		
PT141	Fucoli-Somepal, Fundação de Ferro, SA - Coimbra	Coimbra	Portugal	x		
PT142	Fundiven - Fundação Venezuela S.A.	Águeda	Portugal		x	Al
PT143	Schmidt Light Metal, Fundação Injectada, Lda	Oliveira de Azeméis	Portugal		x	Al
SE144	Holsbyverken	Vetlanda	Sweden	x		
SE145	Arvika Gjuteri	Arvika	Sweden	x		
SE146	Combi Wear Parts,kv Muttern	Ljungby	Sweden	x		
SE147	Gjuteriteknik AB	Värnamo	Sweden		x	Zn
SE148	Metallfabriken Ljunghäll AB	Södra Vi	Sweden		x	Al
SE149	Sandvik SRP AB	Svedala	Sweden	x		
SE150	Volvo Group Skövde	Skövde	Sweden	x		
SE151	Xylem Water Solutions Manufacturing AB, Emmaboda	Emmaboda	Sweden	x		
SE152	Älmhults gjuteri	Älmhult	Sweden	x		
SE153	Åkers Sweden AB	Åkers Styckebruk	Sweden	x		

8.1.2 List of European smitheries that participated in the data collection

Plant code	Name of the plant	City	Country	2.3 (b)	Other IED activities	Directly Associated Activities
DE001	Georg Group, Georg Umformtechnik	Willroth	Germany	No	-	-
DE002	Hammerwerk Fridingen GmbH	Fridingen	Germany	No	-	Blasting, Forging shop, Heat treatment, Tool shop
DE003	Karl Diederichs GmbH & Co. KG Hammerwerk, Werk 1	Remscheid	Germany	No	-	Heat treatment
DE004	Maschinenfabrik Alfing Kessler GmbH	Aalen	Germany	No	No other IED activity	Forging (counterblow hammer), Heating (batch type furnace), Heating / Forging
DE005	RUD Schöttler Umformtechnik und Systemlieferant GmbH	Hagen	Germany	No	-	Blasting, Forge shop, Heating
DE006	SIEPMANN-WERKE GmbH & Co. KG	Warstein-Belecke	Germany	No	No other IED activity	Post-treatment (finishing), Thermal treatment
DE007	Wildauer Schmiede- und Kurbelwellentechnik GmbH	Wildau	Germany	Yes	No other IED activity	Crank-shaft processing
ES008	CIE AUTOMOTIVE	Ourense	Spain	Yes	-	-
PL009	HSW Kuźnia Stalowa Wola	Stalowa Wola	Poland	Yes	No other IED activity	Mechanical treatment, Thermal treatment

8.2 Annex 2 Information on H-statements of substances currently used in foundries

A variety of substances are used in moulding and core-making as binders or catalysts and some of them carry certain hazard statements. According to the information submitted, the following hazard statements were reported for the chemical binding systems that are currently used in the foundry sector:

- H225 - Highly flammable liquid and vapour
- H302 - Harmful if swallowed
- H312 - Harmful in contact with skin
- H314 - Causes severe skin burns and eye damage
- H315 - Causes skin irritation
- H317 - May cause an allergic skin reaction
- H318 - Causes serious eye damage
- H319 - Causes serious eye irritation
- H331 - Toxic if inhaled
- H332 - Harmful if inhaled
- H334 - May cause allergy or asthma symptoms or breathing difficulties if inhaled
- H335 - May cause respiratory irritation
- H341 - Suspected of causing genetic defects
- H351 - Suspected of causing cancer
- H373 - May cause damage to organs through prolonged or repeated exposure
- H400 – Very toxic to aquatic life;
- H410 – Very toxic to aquatic life with long lasting effects
- H411 – Toxic to aquatic life with long lasting effects
- H412 – Harmful to aquatic life with long lasting effects
- H413 – May cause long lasting harmful effects to aquatic life

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