Integrated Pollution Prevention and Control

Draft Reference Document on
Best Available Techniques for the

Production of Iron and Steel

Draft July 2009
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Electronic versions of draft and finalised documents are publicly available and can be downloaded from http://eippeb.jrc.ec.europa.eu/.
EXECUTIVE SUMMARY

To be written
Preface

1. Status of this document


This document is a working draft of the European IPPC Bureau. It is not an official publication of the European Communities and does not necessarily reflect the position of the European Commission.

2. Relevant legal obligations of the IPPC Directive and the definition of BAT

In order to help the reader understand the legal context in which this document has been drafted, some of the most relevant provisions of the IPPC Directive, including the definition of the term ‘best available techniques’, are described. This description is given for information only. It has no legal value and does not in any way alter or prejudice the actual provisions of the IPPC Directive.

The purpose of the IPPC Directive is to achieve integrated prevention and control of pollution arising from the activities listed in its Annex I, leading to a high level of protection of the environment as a whole. The legal basis of the Directive relates to environmental protection. Its implementation should also take account of other European Community objectives such as the competitiveness of the Community’s industry thereby contributing to sustainable development.

More specifically, the Directive provides for a permitting system for certain categories of industrial installations requiring both operators and regulators to take an integrated, overall view of the potential of the installation to consume and pollute. The overall aim of such an integrated approach must be to improve the design, construction, management and control as well as the decommissioning of industrial processes so as to ensure a high level of protection for the environment as a whole. Central to this approach is the general principle given in Article 3 of the Directive which states that operators should take all appropriate preventative measures against pollution, in particular through the application of the best available techniques enabling them to improve their environmental performance.

The term ‘best available techniques’ is defined in Article 2(12) of the Directive as ‘the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole.’ Article 2(12) goes on to clarify further this definition as follows:

- ‘techniques’ shall include both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned
- ‘available’ techniques means those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator
- ‘best’ means those most effective in achieving a high general level of protection of the environment as a whole.
Furthermore, Annex IV to the Directive contains a list of ‘considerations to be taken into 
account generally or in specific cases when determining best available techniques ... bearing in 
mind the likely costs and benefits of a measure and the principles of precaution and prevention’. 
These considerations include the information published by the Commission pursuant to Article 17(2) of the Directive.

Competent authorities responsible for issuing permits are required to take account of the general principles set out in Article 3 of the Directive when determining the conditions of the permit. These conditions must include emission limit values, supplemented or replaced where appropriate by equivalent parameters or technical measures. According to Article 9(4) of the IPPC Directive, these emission limit values, equivalent parameters and technical measures must, without prejudice to compliance with environmental quality standards, be based on the best available techniques, without prescribing the use of any technique or specific technology, but taking into account the technical characteristics of the installation concerned, its geographical location and the local environmental conditions. In all circumstances, the conditions of the permit must include provisions on the minimisation of long-distance or transboundary pollution and must ensure a high level of protection for the environment as a whole.

Member States have the obligation, according to Article 11 of the Directive, to ensure that competent authorities follow or are informed of developments in the best available techniques.

3. Objective of this document

Article 17(2) of the Directive requires the Commission to organise ‘an exchange of information between Member States and the industries concerned on best available techniques, associated monitoring and developments in them’, and to publish the results of the exchange.

The purpose of the information exchange is given in recital 27 of the Directive, which states that ‘the development and exchange of information at Community level about best available techniques:

• should help to redress the technological imbalances in the Community
• should promote the worldwide dissemination of limit values and techniques used in the Community
• should help the Member States in the efficient implementation of this Directive.’

The Commission (Environment DG) established an information exchange forum (IEF) to assist the work under Article 17(2) of the Directive and a number of technical working groups have been established under the umbrella of the IEF. Both IEF and the technical working groups include representation from Member States and industry as required in Article 17(2) of the Directive.

The aim of this series of documents, which will be continually reviewed and updated, is to reflect accurately the exchange of information which has taken place as required by Article 17(2) of the Directive and to provide reference information for the permitting authority to take into account when determining permit conditions. By providing relevant information concerning best available techniques, these documents should act as valuable tools to drive environmental performance.

4. Information sources

This document represents a summary of information collected from a number of sources, in particular, through the expertise of the groups established to assist the Commission in its work under Article 17(2) of the Directive, and verified by the Commission services. The work of the contributors and the expert groups is gratefully acknowledged.
5. How to understand and use this document

The information provided in this document is intended to be used as an input to the determination of BAT in specific cases. When determining BAT and setting BAT-based permit conditions, account should always be taken of the overall goal to achieve a high level of protection for the environment as a whole.

The rest of this Section describes the type of information that is provided in each Section of the document.

Chapters 1 provide general information on the industrial sector concerned.

Chapter 2 provides information and data on General industrial processes used within the sector. These are horizontal matters or specific activities that do not relate to one specific iron and steel activity.

Chapters 3 to 8 provide the following information on particular iron and steel processes (sinter plants, pelletisation, coke ovens, blast furnaces, basic oxygen steelmaking, electric arc steelmaking and casting):

X.1. Information on applied processes and techniques.
X.2. Current emission and consumption levels. Data and information concerning current emission and consumption levels reflecting the situation in existing installations at the time of writing.
X.3. Techniques to consider in the determination of BAT. These describe, in more detail, the emission reduction and other techniques that are considered to be most relevant for determining BAT and BAT-based permit conditions. This information includes the consumption and emission levels considered achievable by using the technique, some idea of the costs and the cross-media issues associated with the technique, and the extent to which the technique is applicable to the range of installations requiring IPPC permits, for example new, existing, large or small installations. Techniques that are generally seen as obsolete are not included.
X.4. Best available techniques. These sections present the techniques and the emission and consumption levels that are considered to be compatible with BAT in a general sense. The purpose is thus to provide general indications regarding the emission and consumption levels that can be considered as an appropriate reference point to assist in the determination of BAT-based permit conditions or for the establishment of general binding rules under Article 9(8). It should be stressed, however, that this document does not propose emission limit values. The determination of appropriate permit conditions will involve taking account of local, site-specific factors such as the technical characteristics of the installation concerned, its geographical location and the local environmental conditions. In the case of existing installations, the economic and technical viability of upgrading them also needs to be taken into account. Even the single objective of ensuring a high level of protection for the environment as a whole will often involve making trade-off judgements between different types of environmental impact, and these judgements will often be influenced by local considerations.

Although an attempt is made to address some of these issues, it is not possible for them to be considered fully in this document. The techniques and levels presented in the Best available techniques sections will therefore not necessarily be appropriate for all installations. On the other hand, the obligation to ensure a high level of environmental protection including the minimisation of long-distance or transboundary pollution implies that permit conditions cannot be set on the basis of purely local considerations. It is therefore of the utmost importance that the information contained in this document is fully taken into account by permitting authorities.
Chapter 9 provides information on alternative ironmaking techniques that are already being applied.

Chapter 10 provides information on emerging techniques. The rest of the document provides the concluding remarks, references, glossary and annexes.

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

Edificio Expo, c/Inca Garcilaso 3, E-41092 Sevilla, Spain
Telephone: +34 95 4488 284
Fax: +34 95 4488 426
e-mail: JRC-IPTS-EIPPCB@ec.europa.eu
Internet: http://eippcb.jrc.es

6. Dynamic nature of BAT and review of BAT reference documents (BREFs)

BAT is a dynamic concept because new techniques may emerge, technologies are still developing, or new environmental processes are being successfully introduced in the industry. Since the elements of BAT change over time and industry develops, BREFs have to be reviewed and updated as appropriate.

The original BREF on production of iron and steel was adopted by the European Commission in 2001. This document is the result of the review of the Iron and Steel BREF.
Best Available Techniques Reference Document on the Production of Iron and Steel

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SCOPE

This document covers the processes involved in the production of iron and steel in an integrated works as well as the production of steel in electric arc furnace steelworks.

The main operations covered in this document include:

- loading, unloading and handling of bulk raw materials
- blending and mixing of raw materials
- coke production
- sintering and pelletisation of iron ore
- the production of molten iron by the blast furnace route, including slag processing
- the production and refining of steel using the basic oxygen process, including upstream ladle desulphurisation, downstream ladle metallurgy and slag processing
- the production of steel by electric arc furnaces, including downstream ladle metallurgy and slag processing
- continuous casting (thin slab/thin strip and direct sheet casting (near-shape).

There are certain activities in the iron and steel industry that are not covered or are only covered very superficially in this document. Table 1 provides the reader with an overview of the activities found in the iron and steel industry and where more information on BAT may be found in other BREFs.

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<th>BREF where additional information on BAT may be found</th>
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<td>Large Combustion Plants BREF (LCP)</td>
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<tr>
<td>All other steel related downstream processes like rolling, pickling,</td>
<td>Ferrous Metals Processing Industry BREF (FMP)</td>
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<td>Continuous casting to the thin slab/thin strip and direct sheet casting</td>
<td>Cement, Lime and Magnesium Oxide Manufacturing Industries BREF (CLM)</td>
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<td>Treatment of dusts to recover (e.g. electric arc furnace dust)</td>
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Table 1: Iron and steel activities/processes covered in other BREFs

[363] [394] [434] [436] [435] [437] [484] [485] [504] [505] [506] [525]

Very little information on radioactive issues, oxygen plants and reheat or heat treatment furnaces can be found in this document.

Furthermore, occupational safety and hazard risk aspects related to this sector are not covered in this document.
1 GENERAL INFORMATION

1.1 Steel production in Europe and worldwide

Iron and steel have both played an important role in the development of human civilisation over several millennia and have found uses in agriculture, construction, the generation and distribution of power, the manufacturing of machinery and equipment, in the household and in medicine.

Together with coal and cotton, iron and steel were the principal materials upon which the industrial revolution was based. Technical developments from the early eighteenth century onwards allowed dramatic increases in output, for example by replacing relatively scarce charcoal with hard coal/lignite and coke respectively and by the development of the puddling process for converting hot metal into steel.

![Crude steel production in Europe and worldwide since 1870](image)

**Figure 1.1:** Crude steel production in Europe and worldwide since 1870

**Note:** Iron production in million of tonnes per year

The world steel production has increased considerably since 2000 and exceeded 1000 million tonnes for the first time in 2004. In 2006 world steel production has risen to a world total of more than 1200 million tonnes in 2006 (see Figure 1.1). The main reason is that the steel production in China increased from 127 million tonnes to 421 million tonnes in 2006.

EU production of crude steel grew at a rate of 1.2% per year between 1985 and 1994 in terms of volume. Growth was more rapid in the three years from 1998 to 1999 (3.7% per year). Subsequently production in the EU-12 declined from 140 million tonnes to 132 million tonnes in 1992 and 1993, before recovering to reach 139 million tonnes in 1994 and 143 million tonnes in 1995. The entry of Austria, Finland and Sweden into the EU brought EU production of crude steel up to 156 million tonnes in 1995. Since 2000 the crude steel production has increased worldwide. In 2006 the production of crude steel in the EU was 198 million tonnes, compared to Russia at 120 million tonnes and Japan, the US and China of 116, 99 and 421 million tonnes, respectively.

Figure 1.1 also shows how the European share of the world steel production has steadily declined, falling to a level of 21% at the end of the period. Since the oil crisis of 1974-75, production was virtually stagnant worldwide until the middle of the 1990's, with Europe being particularly affected. With 206 million tonnes in 2006, the production of crude steel in the EU was 16% of the world production, according to Eurofer references.
Chapter 1

Figure 1.2 shows how production of oxygen steel remained fairly steady, whereas electric arc furnace steel production gradually increased. The share of total steel production of the latter reached 41.8% in 2006. Nevertheless, the blast furnace/basic oxygen furnace route is predicted to remain the dominant means of steel production, at least in the medium term.

![Graph showing steel production by electric arc furnace and oxygen steel in the EU from 1990 - 2006](image)

Figure 1.2: Steel production by electric arc furnace and oxygen steel in the EU from 1990 - 2006

1.2 Geographical distribution of iron and steel production in the EU

The locations of integrated steelworks in the EU-27 are shown in Figure 1.3, in which the concentration of steelworks along the coal belt in Central Europe is clearly visible. Nevertheless, there are integrated steelworks located in most of the Member States. Electric arc furnaces are not included in Figure 1.3.
Table 1.1 to Table 1.6 show the distribution of plants by capacities and other characteristics in the EU-27. In order to give a comprehensive overview countries without relevant production are not listed.
## Chapter 1

### EU-27 sinter and pelletisation plants

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<th>EU Member State</th>
<th>Number of iron ore sintering plants</th>
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<td><strong>130165</strong></td>
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Data for 2005; 1 Data for 2004; 2 Data for 2007; 3 Data for 2008

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<td>------------------</td>
</tr>
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<td>United Kingdom</td>
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Table 1.1: Number of sinter and pelletisation installations in the EU-27
[209] [240] [208] [318] [403] [471]

Table 1.2: Number of coke ovens in the EU-27
[478]
### EU-27 blast furnaces

<table>
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Data from 2006

References: [438] except 1

### Table 1.3: Number and rated capacity of blast furnace installations in the EU-27

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Data from 2006

References: [438]
### EU-27 electric arc furnace steelmaking

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Data from 2006

Table 1.5: Number and rated capacity of EAF installations in the EU-27

### EU-27 Continuous casting

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Data from 2006

Table 1.6: Number and rated capacity of casting installations in the EU-27
The 1990s were not been marked by a mass introduction of radical new technologies in the EU. Rather, the classical methods of production had been refined at various stages (blast furnaces, steelworks, etc.) and have been rendered much more efficient through improvements all along the production chain. These improvements have allowed significant reductions in energy use and pollution, whilst increasing product quality.

1.3 Economics and employment in the EU iron and steel industry

The globalisation of the world economy has had a profound effect on the steel industry and it continues to do so. The industry is undergoing intensive structural changes. This was characterised during the 1990's and 2000's, by the development of new concepts in steelworking (e.g. mini-electric steel mills, new concepts for electric arc furnaces, new casting techniques and direct or smelting reduction techniques). Highly competitive market conditions may accelerate this structural change and encourage consolidation in the steel industry. This is evident from the growing number of alliances, co-operative ventures and takeovers. The development of continuous casting had an extremely positive effect on the economics of the steel industry in the 1970s and 1980s.

Steel is a key sector for Europe's economy and competitiveness. The EU-25 steel industry has a total annual production of approximately 184 million tonnes and generates more than EUR 100000 million in annual turnover. It provides direct employment for around 350000 people and several times this number are employed indirectly in its processing, and in the user and recycling industries. Table 1.7 shows the development in employment in the EU-15 during 1996 and 2004.

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<td><strong>285260</strong></td>
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</table>

Table 1.7: Development of employment in the iron and steel industry in the EU from 1996 to 2004
1.4 Steelmaking process

Four routes are currently used worldwide for the production of steel: the classic blast furnace/basic oxygen furnace route, direct melting of scrap (electric arc furnace), smelting reduction and direct reduction (see Figure 1.4).

![Crude steel production methods](image)

In 2006, the steel production in the EU-27 was based on the blast furnace/basic oxygen route (approximately 59.8 %) and the electric arc furnace (EAF) route (approximately 40.2 %) (see Table 1.4 and Table 1.5). The percentage of world crude steel production via direct reduction (DR) was about 6.8 % in 2006 which corresponds to 59.8 million tonnes direct reduced iron (DRI). Taking into consideration scheduled DRI production sites the world DRI production will increase to 80 million tonnes by 2010. In Europe, the production of DRI was limited to 704000 tonnes in 2006 (580000 tonnes in Germany and 124000 tonnes Sweden), which represented approximately 1.5 % of world output. Consumption of DRI in EAF steelmaking was reported to be 1.523 million tonnes per year in the EU-27 in 2006.

By the end of 2007, a total of six smelting reduction plants have been in operation, representing an annual aggregate capacity of 7.45 million tonnes hot metal. In the EU-27, there are currently no smelting reduction units on a commercial scale. These routes are therefore not described here, but will be mentioned in the Chapter 9 'Alternative iron making techniques'.
Integrated steelworks
Of the four steelmaking routes described above, the classic blast furnace/basic oxygen furnace route is by far the most complex, taking place in large industrial complexes known as integrated steelworks, covering areas up to several square kilometres (see Figure 1.5). Integrated steelworks are characterised by networks of interdependent material and energy flows between the various production units, most of which are covered in this document (sinter plants, pelletisation plants, coke oven plants, blast furnaces and basic oxygen steelmaking plants with subsequent casting). Before describing these individual types of plants in detail, an overview of the interdependencies mentioned will be given.

Figure 1.5: Aerial view of an integrated steelworks located near the coast

Process overview
The process routes of an integrated steelworks considered in this BREF are shown in Figure 1.6. This figure gives a schematic view of the main material inputs and outputs of process related emissions and residues for each stage of the process route.

In an integrated steelworks the blast furnace is the main operational unit where the primary reduction of oxide ores takes place leading to liquid iron, so-called ‘hot metal’. Modern high-performance blast furnaces require physical and metallurgical preparation of the burden. The two types of iron ore preparation plants are the sinter plants and the pellet plants. Pellets are nearly always made from one well-defined iron ore or concentrate (see Figure 2.11) at the mine and are transported in this form. In Europe there is only one integrated steelworks also operating a pelletisation plant. Sinter is generally produced at the ironworks from predesigned mixtures of fine ores, residues and additives.

The main reducing agents in a blast furnace are coke and powdered coal forming carbon monoxide and hydrogen which reduce the iron oxides. Coke and coal also functions partly as a fuel.

Coke is produced from coal by means of dry distillation in a coke oven and has better physical and chemical characteristics than coal. In many cases, additional reducing agents/fuels are supplied by injection of oil, natural gas and (in a few cases) plastics. A hot blast provides the necessary oxygen to form the carbon monoxide (CO), which is the basic reducing agent for the iron oxides.
The blast furnace is charged at the top with burden consists of alternate layers of coke and a mixtures of sinter and/or pellets, lump ore and fluxes. In the furnace the iron ore is increasingly reduced and liquid iron and slag are collected in the bottom of the furnace, from where they are tapped.

The slag from the blast furnace is granulated, pelletised, or tapped into slag pits. The slag granules or pellets are usually sold to cement manufacturing companies. Also, slag from pits can be used in road construction.
Figure 1.6: Overview of the process route of an integrated steelworks [200]
The liquid iron from the blast furnace (pig iron) is transported to a basic oxygen furnace, where the carbon content (approx. 4%) is lowered to less than 1%, thereby resulting in steel. Upstream ladle desulphurisation of the pig iron and downstream ladle metallurgy of the steel is generally applied in order to produce steel with the required quality. On leaving the basic oxygen furnace the liquid steel is cast, either into ingots or by means of continuous casting. In some cases vacuum degassing is applied in order to further improve the quality of the steel.

Casting products, whether ingots, slabs, billets or blooms, are subsequently processed in rolling mills and product finishing lines in order to prepare them for market.

1.5 Main environmental issues in the production of iron and steel

The iron and steel industry is highly intensive in both materials and energy. Figure 1.7 presents a simplified input/output scheme illustrating and numbering the most important mass streams together with the quantity of crude steel produced in the EU-27 in 2006. The overview does not include raw material mining, water and gaseous inputs other than fuels and recycling activities. The figure illustrates that almost half of the input ends up as off-gases, process gases and solid production residues.

Figure 1.7: Overview of the inputs and outputs for the manufacture of iron and steel in the EU-27 in 2006 [438] and Table 3.2, Table 4.1, Table 5.2, Table 6.2, Table 7.3, and Table 8.1
Following the two most important steelmaking process routes via the sinter/pellet plant/coke oven/blast furnace/basic oxygen converter and the electric arc furnace, the key environmental issues for action in response to environmental concerns can be summarised as follows:

- sinter plants: sinter, as a product of an agglomeration process of materials which contain iron, represents a major part of the burden of blast furnaces. The main stack emissions of sinter plants account for up to 50% of the total dust emissions from an integrated steelworks. Other relevant pollutants in the off-gas emissions from the sinter strand and the cooler are heavy metals, SO₂, HCl, HF, PAHs and persistent organic pollutants (such as PCB and PCDD/F). Furthermore, the recovery of sensible heat and the utilisation of solid wastes are severe issues.

- pelletisation plants: pelletisation is another process used to agglomerate materials which contain iron where emissions to air dominate the environmental issues. Other main issues in pellet plants are the use of sensible heat, the treatment of waste water and the internal utilisation of process residues.

- coke oven plant: a coke plant consists of one or more coke oven batteries with a coke oven firing system (underfiring) and the process gas treatment unit where emissions to air are the most significant. The main point source for emissions to air is the waste gas from underfiring. Additionally, many of the emissions are diffuse emissions from various sources such as unloading, storage, handling, crushing and blending (preparation) of coal, the leakages from lids and adherences on frames, oven and leveller doors, the ascension pipes and charging (holes) of coal into and the pushing of coke out of the chambers, and finally coke quenching and coke grading (crushing and screening), transport, handling and storage. Diffuse/fugitive VOC emissions to air can occur from coke oven batteries and diffuse/fugitive ammonia and benzene, toluene, xylene (BTX) emissions from by-products plants which all have the potential to create odour nuisances. SO₂ emissions at coke oven plants and other plants where coke oven gas is used as a fuel is a concern. Thus the desulphurisation of coke oven gas is a measure of high priority for minimising these emissions. Waste water disposal is another major issue for coke oven plants.

- blast furnace plant: Significant emissions to all media occur where the blast furnace process for producing hot metals from materials which contain iron are used. Because of the high input of reducing agents (mainly coke and coal), this process consumes most of the overall energy input of an integrated steelworks. Relevant emissions to all media occur and these are described in detail. The main environmental issues are dust, waste water from blast furnace gas scrubbing, emissions from slag treatment such as SO₂ and H₂S which can lead to odour nuisances, dusts and sludge, and finally the minimisation of energy consumption.

- basic oxygen furnace plant: emissions to air from various sources such as primary and secondary dedusting, hot metal pretreatment and secondary steelmaking and various solid process residues are the main environmental issues in oxygen steelmaking. In addition, waste water arises from wet dedusting (when applied) and from continuous casting. Particular attention should be paid to diffuse dust emissions which occur when secondary emission collecting systems are insufficient.

- electric arc furnace plants: the direct smelting of materials which contain iron (mainly scrap) is usually performed in electric arc furnaces which need considerable amounts of electrical energy and causes substantial emissions to air and solid process residues such as wastes and by-products (mainly filter dust and slag). The emissions to air from the furnace consist of a wide range of inorganic compounds (iron oxide dust and heavy metals) and organic compounds such as persistent organic pollutants (e.g. PCB and PCDD/F).

**Energy consumption**

Energy consumption in iron and steelmaking is considerable. There are many emissions points of CO₂ in the iron and steel processes and they are related to three main factors: a) providing the sufficient temperature in order to carry out the chemical reactions and physical treatment needed, b) providing a reductant (mainly CO) to the system in order to reduce the iron oxide, and c) providing the power and steam necessary to run the steelworks.
Chapter 1

The average specific energy consumption for liquid steel, produced via the coke oven/sinter plant/blast furnace route in European steelworks is approx. 19.4 GJ primary energy demand per tonne liquid steel calculated according to Table 3.2, Table 4.1, Table 5.2, Table 6.2, Table 7.3 and Table 8.1. This amount is dominated by coal input (see Figure 1.7). Not included in this figure is the consumption of 0.35 GJ electricity per tonne liquid steel [508].

The specific energy consumption for steel production in electric arc furnaces in Europe is in average about 1.8 GJ/t liquid steel. The electricity consumption has also been multiplied by factor three. This corresponds to approx. 5.4 GL/t liquid steel by multiplying it with the factor three to make it comparable with primary energy. Additionally there is a fossil fuel input of about 0.5 GJ/t liquid steel in average (according to Table 8.1).

Specifically, because the CO₂ which is generated when energy is consumed is a greenhouse gas (GHG), energy savings have undergone a major change in purpose, and is now considered part of the solution to the problem of global warming which is a global scale environmental issue.

As mentioned in the IPCC climate change synthesis report 2007, there is no unique option for climate change mitigating policies. The solution is rather a sequence of mitigating options for the stabilisation of atmospheric greenhouse gas concentrations [507].

Regarding iron and steelmaking, the CO₂ emissions depends very much on the types and amounts of reducing agents (e.g. coke, coal, and oil) used in the blast furnace (see Sections 6.1.3.1 and 6.2.2.4). For this reason, the steel industry has actively implemented a variety of measures to reduce the energy consumption in general and emissions of GHG such as CO₂ in particular. Enhensive efforts have been made to reduce the reductant agent demand close to the stoichiometric minimum demand (see Section 6.3). Over the past 30 years the specific energy demand has been reduced from 23 GJ/t of liquid steel in 1980 to approx. 18 GJ/t liquid steel in 2004 for modern integrated steelworks [509].

The reduction of energy consumption by introducing energy saving equipment in steel manufacturing processes and improving the efficiency of energy conversion facilities such as power plants. Energy saving equipment includes waste energy recovery equipment and process elimination/process continuation. Another measure is the optimisation of energy consumption and costs by the implementation of a total energy management system. All of these measures are covered by this document.

To a certain extent DRI can be an option to reduce CO₂ emissions.

Additionally, beyond energy saving and efficiency improvements, carbon dioxide mitigation projects are being developed to capture and store CO₂ which are also covered in this document (see Sections 10.1.1 and 10.1.2).

Other issues
Other relevant issues covered by this document are nuisance by odour and noise emissions which can be quite considerable for certain processes.

Other matters of concern for the iron and steel industry not covered by this document are local soil pollution as well as groundwater pollution.
The following Table 1.8 to Table 1.10 provides an detailed overview of the releases in the different parts of the iron and steelmaking processes.

<table>
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<tr>
<th>SOURCES</th>
<th>Raw material handling</th>
<th>Sinter plant: flue-gas cleaning</th>
<th>Sinter plant: secondary emissions</th>
<th>Pellet plants</th>
<th>Coal pulverisation</th>
<th>Hot blast stoves</th>
<th>Blast furnace</th>
<th>Desulphurisation</th>
<th>Blast furnace (primary emissions)</th>
<th>BOF: blowing</th>
<th>BOF: charging</th>
<th>EAF: charging</th>
<th>EAF: melting and refining</th>
<th>EAF: steel and slag tapping</th>
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**KEY**

Main polluting substances: A – Release to Air, W – Release to Water, L – Release to Land

Other substances: a – Release to Air, w – Release to Water, l – Release to Land

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 technique employed, e.g. via collected dusts, sludges or liquors.

BOS: Basic oxygen steelmaking

Table 1.8 First table showing potential release routes for prescribed substances and other substances that may cause harm (example from UK administration)
### Sources → Releases

<table>
<thead>
<tr>
<th>Sources</th>
<th>EAF, furnace and ladle lining repair</th>
<th>Alloy</th>
<th>Ladle treatment</th>
<th>Reloading and recreation</th>
<th>Degassing</th>
<th>Decarburisation</th>
<th>Electroslag remelting</th>
<th>Vacuum induction melting</th>
<th>Induction melting</th>
<th>Ferro alloy powders</th>
<th>Continuous casting</th>
<th>Ingot casting</th>
<th>Scarfing</th>
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</tbody>
</table>

**KEY**

Main polluting substances: A – Release to Air, W – Release to Water, L – Release to Land

Other substances: a – Release to Air, w – Release to Water, l – Release to Land

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 technique employed, e.g. via collected dusts, sludges or liquors.

**Table 1.9:** Second table showing potential release routes for prescribed substances and other substances that may cause harm (example from UK administration)
<table>
<thead>
<tr>
<th>SOURCES</th>
<th>CHARGING EMISSIONS</th>
<th>TOPS LEAKAGE</th>
<th>DOOR LEAKAGE</th>
<th>PUSHING EMISSION</th>
<th>COKE OVEN FLUE-GAS (BATTERY STACK)</th>
<th>EMERGENCY VENTING</th>
<th>EMERGENCY FLARING</th>
<th>AMMONIA INCINERATOR TAIL GAS</th>
<th>EFFLUENT TREATMENT DISCHARGE</th>
<th>EFFLUENT TREATMENT SLUDGE</th>
<th>SULPHUR AND SCRUBBER LIQUOR REMOVAL AND DESULPHURISATION</th>
<th>DECANTERS AND STORAGE TANK VENTS</th>
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</table>

**KEY**

Main polluting substances: A – Release to Air, W – Release to Water, L – Release to Land

Other substances: a – Release to Air, w – Release to Water, l – Release to Land

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 technique employed, e.g. via collected dusts, sludges or liquors.

Table 1.10: Third table showing potential emission releases from prescribed substances and other substances that may cause harm (example from UK administration)

[240] [318] [460]
2 GENERAL PROCESSES AND TECHNIQUES

The process overview in Figure 1.6 shows the various production units of an integrated steelworks. The individual units are connected both in terms of product flows and internal flows of residues (mill scale, filter dusts, sludges from scrubbing BF gas or BOF gas, etc.), water (common treatment of various waste water streams, cascade usage of cooling water, etc.) and energy (COG, BF gas, BOF gas, steam from BF top pressure turbines or basic oxygen furnaces, etc.). These interdependencies have been installed in order to both minimise emissions and to optimise productivity and reduce costs.

These interdependency issues from the different production processes/units in terms of energy, by-products/residues, air and water are covered in this chapter.

2.1 Energy management in the steelmaking industry

Specific energy issues have been covered in each process-specific chapter (i.e. Chapters 3 - 8). However, this section serves to show the energy interdependencies between the different processes in an integrated steelworks.

2.1.1 Energy flow and process gas utilisation in integrated steelworks

Energy interdependency in an integrated steelworks can be complex. Figure 2.1 and Figure 2.3 illustrate examples of the input and output flows of different types of energy and reducing agents together with the internal energy flow of an integrated steelworks.

The dominant inputs are coal, heavy oil and, if bought from an external supply, coke. These inputs are mainly used for the production of coke in the coke oven plant and as reducing agents in the blast furnace. It is common to use alternative reducing agents in the blast furnace, such as coal or oil that are injected to the blast furnace at the tuyère level. Used oils, fats, various gases (e.g. coke oven gas) and other hydrocarbons, such as waste plastics, may also be injected (see Section 6.3.12). The amounts of coal, coke, fuel oil, natural gas and power are illustrated in Figure 2.1.
Chapter 2

Figure 2.1: Example of the input and output flows in an integrated steelworks, energy and reducing agents utilisation system

The quality (calorific value and cleanliness) and volume of the different gases varies significantly and these factors have an impact on where the fuels can be usefully used. To optimise energy efficiency, it is necessary that each fuel gas is consumed at the most appropriate plant.

The primary task of energy management in the steel industry is the efficient distribution and use of the process gases and purchased fuels. A good plant layout can further facilitate this task. Coke oven gas (COG), blast furnace gas (BF gas) and basic oxygen furnace gas (BOF gas) constitute the basis of the energy system in an integrated steelworks. Most of the energy demand is satisfied by these gases; the remaining part must be balanced with purchased energy, normally electrical power and natural gas. These aspects are illustrated in Figure 2.3 and Figure 2.2.
Figure 2.2: Flow sheet of typical gas utilisation in integrated sinter, coke and hot metal production

[206]
Figure 2.3: Example of the energy flow in an integrated steelworks

[430]
Fuels in integrated steelworks

Coke oven gas (COG)
COG generated during carburisation (coking) is usually cleaned before using it as a fuel gas. Cleaning includes the removing of tar, naphthalene, light oil, compounds which contain sulphur and the removal or cracking (to hydrogen) of ammonia. As Figure 2.4 indicates, in integrated steelworks there are several options for using the COG. Since it has the highest caloric value of all process gases, it is usually used to enrich the calorific value of the other process gases for use in blast furnace stoves and at the reheating furnaces of the hot strip mills and other high temperature processes or for the underfiring of the coke ovens. The surplus COG may be utilised at the blast furnace as an alternative reducing agent and also used in power plants. A significant portion of the cleaned coke oven gas that is generated is employed within the coke batteries to effect carburisation. The remaining cleaned coke oven gas (COG), which has the highest calorific value and the highest flame temperature of all the process gases can be used at the reheating furnaces of the hot strip mills and other high temperature processes. The surplus COG may be utilised at the blast furnace as an alternative reducing agent but more often it is used to enrich the calorific value of the other gases (BOF gas and BF gas), e.g. for use in blast furnace stoves, which is then used in the power plant. An example of the uses of COG in an integrated steelworks is shown in Figure 2.4.

![Coke oven gas diagram](image_url)

**Figure 2.4:** Example of use of the COG in an integrated steelworks [430]
Blast furnace and basic oxygen furnace gases (BF gas and BOF gas)

Blast furnace gas is the gas with the lowest calorific value and flame temperature. As a consequence, it is most appropriately used in low temperature processes such as the blast furnace itself (hot blast stoves) and the coke oven plant (underfiring). The stoves of the blast furnace can be heated exclusively on BF gas. Any remaining BF gas can be used in the power plant to produce electrical power and process steam. BOF gas can be used as an enrichment gas in order to improve the calorific value of the BF gas. An example of the flows of both BF and BOF gases is presented in Figure 2.5.

![Diagram of BF and BOF gas recovery in an integrated steelworks](image)

**Figure 2.5:** Example of BF and BOF gas recovery in an integrated steelworks

Gas generated during the BOF process consists mainly of carbon monoxide. The gas is cleaned or scrubbed in the cleaning plant. After the gas is cleaned, it is fed to the BOF gas recovery installation. The installation consists of a cooling station, surge tank and gas pumping station. After BOF gas is mixed with BF gas, it is burnt in the rolling mill or combined heat and power (CHP) plants.

### 2.1.2 Steam and heat management in integrated steelworks

In an integrated steelworks there is a need for steam, on the one hand, for heating purposes. On the other hand, steam is needed for specific processes. The most important process steam consumers are blast furnace operations, the coking plant (steam turbine for gas exhausting, for example) and for vacuum treatment in the steel plant. Other activities, not covered in this document, such as for cleaning processes at the galvanising and annealing plants and pretreatment in the pickling plants also consume steam.
Where appropriate and feasible, it should be possible to produce most of the steam demand by heat recovery. There are many sources such as gas treatment in the coking plant (e.g. sulphuric acid plant) and suppressed combustion systems in combination with waste heat boilers at the BOF plant. Other activities such as hot rolling (e.g. evaporative skid cooling in walking beam furnaces, boilers in pusher type furnaces) and the use of reheating furnaces (e.g. continuous annealing line, continuous galvanising), are not covered in this document, but are also places where steam may be generated. The heat should ideally be recovered as steam at as high a temperature and pressure as possible. The amount of waste heat recovered is basically dependent on the continuous demand for steam. In some cases the delivery of waste heat to district heating networks has a positive influence on the amount of waste heat recovered.

In order to achieve a suitable steam supply, it is necessary to have a backup system for steam production in order to supply the steam demand when the plants are off for maintenance, for example. The power plant can often be used to fulfil this role and additionally to control the pressure in the steam grid.

Heating for offices and occupied areas of the plant can be provided from the steam grid obviating the need for a separate heating system. An example of steam production and the use of industrial waste heat in an integrated steel plant is shown in Figure 2.6.
Figure 2.6: Example of steam production and the use of industrial waste heat in an integrated steel plant [430]
Note: Some activities in this picture (e.g. hot rolling mill, galvanising and annealing line) are not covered in this BREF
2.1.3 Energy flow in EAF steelmaking

In EAF steelmaking plants, heat recovery can be applied in a similar way from cooling systems. Depending on the suitability of existing systems and demand, this energy can be used either for internal or local external heating purposes. More information can be found in the Industrial Cooling Systems BREF (ICS) [506].

2.2 Power plants in iron and steel works

Reference should be made to the BREF on Large Combustion Plants (LCP) [434]. The LCP BREF contains extensive information related to applied techniques and abatement measures for large combustion plants when using commercial fuels such as natural gas.

Power plants (Figure 2.7 shows a typical power plant of an integrated steelworks) play an important role in an integrated steelworks as they consume the excess process gases and provide the necessary steam and power to all the key processes. These fuels (BF gas, COG and BOF gas) are, of course, also used in other areas of the integrated works and, in order to supplement these fuels, most integrated steelworks also utilise purchased fuels (oil and natural gas, for example) in the power plant.

The power plant can utilise both low calorific and high calorific gases. Dependent on the energy situation of a plant, the power plant can be set up to produce electrical power, steam and/or district heat. Where appropriate and feasible, additional electrical power can be generated at the blast furnace plant with a top gas recovery turbine (see Section 6.3.13).

![Figure 2.7: View of a power plant in an integrated steelworks](image)

2.2.1.1 Applied processes and techniques

Within the constraints identified above, the efficient use of process gases from iron and steel works in a power plant in an integrated steelworks is usually realised in:

- gas-fired boilers
- gas turbines (in combined cycle gas turbines).
Gas-fired boiler

Figure 2.8 shows a typical gas-fired boiler with a steam turbine in a steelworks.

This relatively simple arrangement can achieve a high level of availability and is designed to use process gases with a low calorific value (CV) (mainly BF gas). For the same thermal input, a higher volume of this low CV gas has to be used compared, for example to natural gas, and consequently the volume of waste gas will be correspondingly higher. Additionally, the use of coke oven gas results in a higher waste gas temperature. The energy efficiency of such a combination is about 15 - 20 % lower compared to a commercial power station. Table 2.2 and 2.3 show examples of efficiency values when using low CV gas.

<table>
<thead>
<tr>
<th>Plant type</th>
<th>Electrical efficiency (%) Existing plant</th>
<th>Electrical efficiency (%) New plant</th>
<th>Fuel utilisation (%) New and existing plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas-fired boiler</td>
<td>32 - 41</td>
<td>34 - 44(^1)</td>
<td>54 - 56(^2)</td>
</tr>
</tbody>
</table>

\(^1\) Higher values of electrical efficiency are observed in the case of natural gas-fired plants predominantly and electricity production only.

\(^2\) With additional heat production (40 MW), the upper value for electrical efficiency is reduced to about 42 %. In this case the fuel utilisation is about 54 - 56 %.

Table 2.2: Efficiency of gas fired boilers when using low calorific value gas

Most power stations using process gases are operated in a combined heat and power (CHP) mode, also called 'cogeneration'. This reflects the use of a heat engine or a power station to simultaneously generate both electricity and useful heat. The overall fuel efficiency can be optimised by generating electricity and decoupling heat for industrial processes and/or district heating. Since most integrated steelworks sites have a surplus of heat, there is often no internal demand. If there are no private or commercial consumers available to use decoupled heat, power plants are operated to combust the surplus gases aiming to maximise the amount of electrical energy. Figure 2.9 shows an example of a larger boiler with reheating and decoupling of heat for district heating.
Chapter 2

Gas turbines

Gas turbines fired with process gases are usually not used in Europe because of the low calorific value of the gases. In addition, there are various problems with cleaning and operation as a consequence of using such feed gases.

More information on this issue is available in the Large Combustion Plants BREF (LCP) [434].

In a combined cycle power plant (CCPP), or combined cycle gas turbine (CCGT) plant, a gas turbine generator generates electricity and this last step enhances the efficiency of electricity generation.

Process gases are normally not applied for single gas turbines. Natural gas is the fuel of choice for gas turbines. In order to improve the efficiency, these turbines are coupled with a heat recovery boiler with additional firing using process gases. The heat is used to make steam to generate additional electricity via a steam turbine. Such an arrangement is called combined cycle power plant (CCPP) or combined cycle gas turbines (CCGT). It can be operated in different modes for the generation of electricity only, and in CHP mode.

Figure 2.9: Example of a boiler/generator arrangement with reheating (85 MW el.) [430]
Table 2.3: Efficiency of gas-fired boilers when using low calorific value gas from iron and steel works

<table>
<thead>
<tr>
<th>Plant type</th>
<th>Electrical efficiency (%)</th>
<th>Fuel utilisation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Existing plant</td>
<td>New plant</td>
</tr>
<tr>
<td>CCGT</td>
<td>No data provided</td>
<td>No data provided</td>
</tr>
<tr>
<td>Combined cycle for electricity only</td>
<td>No data provided</td>
<td>No data provided</td>
</tr>
<tr>
<td>Combined cycle in CHP mode</td>
<td>46(^1)</td>
<td>45 - 55</td>
</tr>
<tr>
<td></td>
<td>60(^2)</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) If the maximum range of electricity is produced.
\(^2\) If the maximum range of steam is produced.

Figure 2.10 shows a gas turbine with a heat recovery boiler and supplementary firing, which is operated in combined cycle in CHP mode. In this configuration, an electrical efficiency of 46% can be obtained.

![Gas turbine with heat recovery boiler and supplementary firing](image)

Figure 2.10: Example of a gas turbine (38 MW) and steam turbine (30 MW) in combined cycle in CHP mode

[430]
2.2.1.2 Current emission and consumption level

The overall generation efficiency of an integrated steelworks power plant is lower compared to a commercial power station and the emission characteristics, e.g. in relation to SO\textsubscript{X}, NO\textsubscript{X} and particulates, are substantially different. The operation of power plants in integrated steelworks, which are fired with BF/BOF gas and/or COG is dependent on the production of the whole plant. When comparing these with commercial large combustion plant installations, which are optimised with regard to the energy output, variations in amounts and compositions of the fuels input should be considered.

2.2.1.2.1 Emissions to air

Table 2.1 provides achieved emission levels for more than 20 power plants operated in European integrated steelworks.

<table>
<thead>
<tr>
<th>Annual Averages</th>
<th>mg/Nm\textsuperscript{3}</th>
<th>NO\textsubscript{X}</th>
<th>SO\textsubscript{2}</th>
<th>CO</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean.</td>
<td>87.9</td>
<td>97.7</td>
<td>7.7</td>
<td>6.4</td>
<td></td>
</tr>
<tr>
<td>Max.</td>
<td>190</td>
<td>305</td>
<td>33</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>Min.</td>
<td>14</td>
<td>1.1</td>
<td>0.8</td>
<td>0.8</td>
<td></td>
</tr>
</tbody>
</table>

Table 2.1: Achieved emission values for gas fired boilers and turbines when using process gases from iron and steel works

2.2.1.2.1.1 Abatement of dust emissions

Fuel gases such as BF gas and BOF gas are usually dedusted before they are applied. COG is treated in a by-product plant and their content of particulate matter is also reduced. Precursors for particulate matter such as sulphur are reduced. The residual dust content in the exhaust gas after combustion is comparatively low without any further abatement techniques and emission concentrations of 0.8 - 31 mg/Nm\textsuperscript{3} are achieved at 3 % O\textsubscript{2} for boilers and 15 % for turbines. On average, the annual mean is reported to be 6.4 mg/Nm\textsuperscript{3} (see Table 2.1).

2.2.1.2.1.2 Abatement of SO\textsubscript{2} emissions

COG contains relevant amounts of sulphur mostly as H\textsubscript{2}S. For this reason COG becomes desulphurised before it is used as a fuel. With wet oxidative desulphurisation the residual sulphur content can be reduced very efficiently (see 5.3.12.4). After combustion no further abatement of the exhaust gas takes place.

Compared to the combustion of NG higher emission values occur with respect to SO\textsubscript{2}. Emissions values in Austrian process gas-fired power plants are in the range of 66 - 84 mg/Nm\textsuperscript{3} (annual averages), 120 - 140 mg/Nm\textsuperscript{3} (half-hourly averages, 93 percentiles) or 120 - 160 mg/Nm\textsuperscript{3} (half-hourly average, 97 percentiles). All data are based on an O\textsubscript{2} content of 3 % for boilers and 15 % for turbines. The values include all operating conditions including start-up and shutdown operations [494].

For more than 20 power stations/boiler plants operated on European integrated steelworks, the annual average emission values range from 1 to approx. 100 mg/Nm\textsuperscript{3} (see Table 2.1).

Table 2.2 shows some SO\textsubscript{2} emissions concentration values in the exhaust gas of five Austrian process gas fired power generating units.
<table>
<thead>
<tr>
<th>Generating Unit 3</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>81</td>
<td>89</td>
<td>103</td>
<td></td>
</tr>
<tr>
<td>Generating Unit 4</td>
<td>91</td>
<td>112</td>
<td>114</td>
</tr>
<tr>
<td>Generating Unit 5</td>
<td>89</td>
<td>95</td>
<td>98</td>
</tr>
<tr>
<td>Generating Unit 6</td>
<td>92</td>
<td>94</td>
<td>78</td>
</tr>
<tr>
<td>Busbar</td>
<td>89</td>
<td>77</td>
<td>85</td>
</tr>
<tr>
<td>Gas and steam turbine</td>
<td>13</td>
<td>10</td>
<td>21</td>
</tr>
</tbody>
</table>

**Note: Annual Averages**

1) O₂ reference content 3%.
2) O₂ reference content 15%.

|SO₂ emissions for five process gas fired units in Austria [511]|

**2.2.1.2.1.3 Abatement of carbon monoxide (CO) emissions**

CO gets burned almost completely in the power plant and very low emission values can be achieved in the exhaust gas without any further measure (see Table 2.1).

**2.2.1.2.1.4 Abatement of NOₓ emissions**

The NOₓ value strongly depends on the efficiency of the plant, on the nitrogen content of the fuel, and on the related oxygen content in the waste gas. Table 2.3 shows a typical composition of steelworks process gases.

<table>
<thead>
<tr>
<th>BF gas</th>
<th>COG</th>
<th>BOF gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
<td>Units</td>
<td>Min.</td>
</tr>
<tr>
<td>CO</td>
<td>Vol-%</td>
<td>19</td>
</tr>
<tr>
<td>H₂</td>
<td>Vol-%</td>
<td>8</td>
</tr>
<tr>
<td>CO₂</td>
<td>Vol-%</td>
<td>16</td>
</tr>
<tr>
<td>N₂</td>
<td>Vol-%</td>
<td>44</td>
</tr>
<tr>
<td>CH₄</td>
<td>Vol-%</td>
<td>15.7</td>
</tr>
<tr>
<td>CₓHᵧ</td>
<td>Vol-%</td>
<td>1.4</td>
</tr>
<tr>
<td>Caloric value Hu*</td>
<td>kJ/Nm³</td>
<td>3000</td>
</tr>
<tr>
<td>Dust content</td>
<td>mg/Nm³</td>
<td>0</td>
</tr>
<tr>
<td>Sulphur total</td>
<td>mg/Nm³</td>
<td>170</td>
</tr>
</tbody>
</table>

**Building mechanism (general)**

Nitrogen oxide (NOₓ) occurs during high temperature combustion processes by oxidation of nitrogen, which is part of the combustion air and also through oxidation of the contained nitrogen of the fuel gas. Nitrogen monoxide (NO) is generated most often, while nitrogen dioxide (NO₂) occurs after the combustion and only with enough oxygen in the waste gas and the atmosphere. Because all of NO will finally be converted to NO₂, the total NOₓ emissions are measured in NO₂ (mg/Nm³).

In principle, the formation of both, thermal and fuel related NO can be distinguished depending on temperature and concentration, dwell time and kind of fuel. The formation of thermal NO starts at 1300 °C and rises greatly with an increasing temperature.
BF gas: Because of the comparably low temperature of the flame burning BF gas, there is usually no significant formation of thermal NO. The amount of fuel NO burning the BF gas depends on the nitrogenous components. Fuel-NO leads to emissions of 40 - 90 mg/Nm³ (refer to 3 % O₂) at a daily average in the flue-gas without any reduction measurements.

COG: Fuel-NO results from the oxidation of the ammonia and organic nitrogen as contained in e.g. the COG. Because of considerable amounts of ammonia and organic nitrogen in COG, fuel NO is generated. By burning higher caloric COG (and natural gas) the formation of thermal NOX is also considerable due to higher temperatures.

Table 2.4 shows the interconnection between COG nitrogen components in the fuel gas and NOX emission concentration in the power plant exhaust gas without any primary measures.

<table>
<thead>
<tr>
<th></th>
<th>Min.</th>
<th>Max.</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>N content of the COG</td>
<td>200</td>
<td>800</td>
<td>mg/Nm³</td>
</tr>
<tr>
<td>Fuel NO</td>
<td>90</td>
<td>320</td>
<td>mg/Nm³</td>
</tr>
<tr>
<td>Thermal NOX</td>
<td>150</td>
<td>120</td>
<td>mg/Nm³</td>
</tr>
<tr>
<td>Total NOX</td>
<td>260</td>
<td>440</td>
<td>mg/Nm³</td>
</tr>
</tbody>
</table>

Note: All daily averages.

Table 2.4: Typical NOX emission values for burning COG in power plants

In integrated steelworks, COG is often mixed with BF gas and BOF gas which will lead to lower emission values for the aforementioned reasons. COG can be used in any range from 0 - 100 % mixed with BF gas and BOF gas.

2.3 Materials management

Integrated steelworks installations are large complex sites highly intensive in materials. A works producing 3 - 5 million tonnes per year of steel will handle 8 - 12 million tonnes of raw materials such as ores, pellets, scrap, coal, lime, limestone (in some cases also heavy oil and plastics) and additives, auxiliaries and process residues such as by-products and wastes.

These materials are usually transferred to the site by bulk carriers i.a. road, rail or water transport. These materials and the intermediate products, such as coke and sinter, are being stored on stockyards or silos and transported to the individual processing plants, usually by a conveyor belt. Figure 2.11 shows a typical material flow diagram of all input materials in an integrated steelworks.

Integrated steelworks are characterised by high levels of resource efficiency achieved through applying a range of advanced techniques for the well-organised and sophisticated management of materials.

From an environmental point of view, storage and handling of large quantities of solid materials can give rise to significant releases of dust. Part of the particulate release will be in the form of fine particulate matter (PM₁₀). Compared to the releases from point sources where the share of PM₁₀ in the clean gas after abatement is between 90 and 99 %, the share of PM₁₀ in dust emissions from bulk material storage and handling can be estimated at 20 %. In Germany the contribution of PM₁₀ emissions from bulk material storage and handling to the overall national PM₁₀ emissions is approx. 5 %.
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There are and have been problems in achieving the EU ambient air quality standard for PM$_{10}$ in the neighbourhoods surrounding major steel works across the EU (e.g. in Germany, the Netherlands, Belgium and the UK). A review of sources of PM$_{10}$ at a large integrated iron and steel works site in the UK has identified that in terms of contributions to local air quality levels, releases from tall stacks are not significant contributors. In contrast, contributions from low level diffuse sources are significant, as indicated by the use of multiple air quality monitoring sites, co-located with wind direction and strength monitoring. Using good quality monitoring information significant sources can be identified through triangulation and pollution roses [527] [528].

The main focus of the Iron & Steel Bref has to be on the key process activities operated in this sector of industry. However, it is clear than ancillary operations at such sites are environmentally significant sources of dust and PM$_{10}$ and therefore operators must use BAT to minimise releases from these generally fugitive and diffuse sources. The Reference Document on BAT on Emissions from Storage [435] covers many of these areas in detail and it is strongly recommended that the reader should refer to this document for that detail.

In this section general techniques for reducing the dust emissions from materials storage, handling and transfer are given. The main fugitive and diffuse and generally low-level release sources of dust and PM$_{10}$ at integrated steelworks may include:

**For input materials**
- ship, barge, train or truck unloading
- conveyors
- stockpiles
- blending and burden preparation
- transport
- roads and tracks across site
- ground which is uncovered and not covered by vegetation.

**For output materials**
- processing and conveying of process residues
- storage of process residues
- loading procedures for process residues such as by-products and waste.

Information on fugitive and diffuse low-level sources others than material storage, handling and transfer e.g. on-site processing of residues, emissions released from insufficient extraction during crushing, screening, charging, melting, tapping, usually referred to as secondary off-gases, can be found in the specific sectors.

### 2.3.1 Storage and handling of input materials

Wind borne dust from the stockyards and conveyor belts, including transfer points, can be a significant source of emissions. When material including leachable compounds and materials such as hydrocarbons from mill scale or scrap is stored in unpaved stockyards, attention also should be paid to soil and groundwater pollution and to runoff water. In some countries, material with leachable components must be stored on grounds with adequate soil protection. Figure 2.11 shows the typical mass flows in an integrated steelworks.
Figure 2.11: Flow diagram of a typical material handling process in an integrated steelworks [200]
Iron ores management
The ore blending process is aimed at homogenising the chemical composition of the respective fines and producing blended ore with a uniform chemical composition and graining. It consists of laying thin layers of magnetite iron ore fines in heaps with a rectangular base and a triangular or trapezoid shaped cross-section. These fines are mixed with other iron-bearing materials (in the vast majority of cases, with usable materials generated in successive technological processes - sludge, dust, BOF slag and scale). Preliminary blending of aglofines or concentrates is carried out on a buffer yard by creating partial heaps.

The mix produced is stored and stabilised in blended ore piles. Stabilising consists of storing mixed and moistened ores (especially concentrates and fines) together with quicklime additives for at least a couple of days. During this period, processes take place in the pile which result in an agglomeration of fines and concentrated grain.

Scrapyards and handling
The European steel scrap specifications have been agreed upon by most commercial firms in the EU-27 that are involved in the recycling and processing of ferrous scrap. The specifications classify scrap into six categories: old scrap, new uncoated scrap with low residuals, shredded scrap, steel turnings, high residual scrap and fragmentised scrap from incineration. These specifications also contain environmental, health and safety related considerations such as the content of dangerous, flammable and explosive substances, Cu, Sn, Cr, Ni, Mo, S and P and radioactive materials [502]. The definitions of the items in this list of specifications apply only to non-alloy carbon steel scrap as raw material for the steel industry.

Scrap metal is normally stored outside on large, uncovered and often unpaved ground. The ferrous scrap is loaded into baskets by magnets or by grabs. The handling minimises any rogue non-magnetic material like stones, wood or non-ferrous metals from entering the process.

Some types and quality of scrap may lead to the deposition of residual materials on the ground, as well as to the deposition of heavy metals and hydrocarbons, during metal storage and handling operations.

Depending upon the types and qualities of the scrap being processed, handling operations (i.e charging, discharging) may also lead to inorganic (dust) and organic emissions (e.g. oily splinters), under certain weather conditions.

In addition, some types of scrap handling may also give rise to noise emissions.

Fluxes management
Fluxes are crushed e.g. by a hammer crusher and screened to a fraction of 0 - 4 mm for usage in sinter plants.

Management of materials/wastes from external sources in the integrated steelworks
Integrated steelworks can receive wastes from other sectors such as used oils and greases, lime, oil/water emulsions, waste plastics, etc. Carbon and iron from these materials can be recovered in processes such as coke ovens and blast furnaces. For example, it is possible to directly inject some reducing agents at the tuyère level of the blast furnace.

Radioactivity in scrap
[215] [373] [417] [503]
Control of radioactivity of input scrap is an important issue, which is followed in detail by an expert group from the United Nations Economic Commission for Europe (UNECE). The UNECE Group of Experts developed in 2006 provide a framework of recommendations and examples of good practice based, as much as possible, on existing national, regional and international instruments and standards and on national experience. Their works include:

- recommendations on monitoring and response procedures for radioactive scrap metal
international training and capacity building strategy for monitoring and response procedures (2007)

Report on the Improvement of the Management of Radiation Protection Aspects in the Recycling of Metal Scrap, ISBN 92-1-116789-2 (2002). These guidelines represent the industrial reference for handling this issue, which is not exclusive to the steel companies but to all the stakeholders involved, from the administration departments to recovery and recycling in metal industries (www.unece.org/trans/radiation/radiation.html).

2.3.2 Management of production residues

The integrated steelmaking process produces a wide range of materials, including steel as a main product. Other materials outputs from the steelmaking processes are blast furnace slag and various steel slags, ammonium sulphate, sulphur or sulphuric acid from the coke oven gas desulphurisation plant, coke tar, coke pitch and (crude) benzene from the coke oven gas by-product plant and other materials such as iron scrap.

Some of these materials are often used as raw materials in other sectors. Through process optimisation, including maximising the internal recirculation of carbon and iron-bearing dusts, residues that are surplus to the requirements of the integrated steelworks production processes are minimised. A range of uses, including a variety of recovery processes, has been developed for such materials, resulting in that a relatively small proportion of total residues requiring disposal. In addition to the management of materials arising within the processes, integrated steelworks receive residues, including wastes, from other installations and sectors.

Figure 2.12 shows a typical example of the management of production residues such as by-products and wastes in an integrated steelwork.
Figure 2.12: Example for the management of production residues such as by-products and wastes in an integrated steelworks [405]
2.3.2.1 Internal use of integrated steelworks residues

Most of the residues arising within an integrated steelworks have a high content of iron, carbon, calcium and other useful components and can replace primary raw materials such as iron ores, coal, slag formers, heavy oil and cokes. Indeed, the management of residues in an integrated steelworks is characterised by the application of advanced integrated processing techniques designed to retain, as much as possible, all of the useful components contained in residues within the steelmaking process.

The identification and separate collection by material categories (e.g. by chemical composition, particle size, or oil content) are necessary preliminary conditions to ensure proper use inside the steelworks without negative effects in terms of production efficiency, product quality and environmental protection.

The iron-bearing fraction of the various types of crude slag, iron and carbon-bearing dusts and sludges from gas cleaning systems, used oil, new scrap and scale can be recirculated back through sinter plants, pellet plants, coke ovens, blast furnaces, and BOF plants. The fine materials tend to be recirculated through the sinter plant whereas coarser materials are more often returned to the blast furnace or BOF plant. In order to return certain fractions to the blast furnace and BOF plant, briquetting plants are often employed, where all sorts of fine graded residues are combined into cold bonded bricks/briquettes that are easier to handle and can be used elsewhere within the process. In particular, the dusts or sludges from the steelmaking plant can be briquetted or pelletised and afterwards used in the steelmaking plant when the non-ferrous content is not too high.

In Section 2.5.4.4 specialised recycling facilities for iron-rich residues are described. Some of these facilities make the direct recovery of liquid iron possible; others serve as a pretreatment stage to re-use the residues in the blast furnace or the electric arc furnace. The presence of high concentrations of unwanted compounds such as alkalis, heavy metals and mineral oil sets limits to the recycling of iron-rich residues.

Table 2.5 shows a compilation of different uses for steel slags in Europe.

<table>
<thead>
<tr>
<th>Use of steel slags</th>
<th>%</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement production</td>
<td>1</td>
<td>152</td>
</tr>
<tr>
<td>Road construction</td>
<td>45</td>
<td>6840</td>
</tr>
<tr>
<td>Hydraulic engineering</td>
<td>3</td>
<td>456</td>
</tr>
<tr>
<td>Fertiliser</td>
<td>3</td>
<td>456</td>
</tr>
<tr>
<td>Internal recycling</td>
<td>14</td>
<td>2128</td>
</tr>
<tr>
<td>Interim storage</td>
<td>17</td>
<td>2584</td>
</tr>
<tr>
<td>Final deposit</td>
<td>11</td>
<td>1672</td>
</tr>
<tr>
<td>Other</td>
<td>6</td>
<td>912</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15200</td>
</tr>
</tbody>
</table>

Note: Figures are from 2004 and corresponding to 12 EU member states (AT, BE, DE, DK, ES, FR, FI, LU, NL, UK, SE, SLO).

'Steel slags' refers to slags from BOF, secondary metallurgy and EAF.

Table 2.5: Use of steel slags in Europe [365]

2.3.2.2 External applications of integrated steelworks residues

Zinc-rich sludges and dusts are generated during BOF gas cleaning and BF gas cleaning. Nevertheless, the zinc content is not high enough to make re-use economic. Only some of these sludges and dusts can be used, so almost all iron and steel plants have a large deposit of zinc-rich sludges and wastes.
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If the non-ferrous metal content of the dusts or sludges arising in the integrated steelworks is sufficiently high enough to ensure its technical and economic feasibility, some non-ferrous metals can be recovered in external metal production and recycling plants. For example, steelmaking dusts with enriched zinc concentrations can be used as a raw material within the zinc sector instead of zinc ores.

2.3.2.3 Disposal of integrated steelworks residues

Small parts of the overall quantity of residues from an integrated steelworks have no economic use (either internally, within the installation, or externally) and some disposal is inevitable. Materials usually requiring disposal include:

- fine dust/sludge from BF gas cleaning
- wrecked runner refractory rubble from the blast furnace
- fine dust from BOF gas scrubbing (if a wet cleaning process is used)
- in some cases, the dust which contains high amounts of alkali chlorides and heavy metal chlorides from the last field of electrostatic precipitators, bag filters or scrubbers treating the off-gas from sinter strands.

Many integrated steelworks have their own internal, certified landfill facilities whilst other companies rely on external landfill sites. In all cases, landfill sites must be authorised to receive the particular wastes.

2.4 Water and waste water management

In an integrated steelworks, water is used, e.g. for direct and indirect cooling, gas cleaning, scale breaking and washing operations including waste gas cleaning with scrubbers.

There can be various water systems in operation: completely closed, semi closed or open circuits and they can have different global schemes.

There are only few completely closed loops. Only for some cooling circuits operated with demineralised or softened water at specific equipments, e.g. at the continuous casting mould or at the boilers at power plants, which are generally cooled through an exchanger water/water, the second circuit of water being used as semi-closed circuit with cooling tower.

The following are three examples where semi-closed systems are used:

- in cooling towers for decreasing the water temperature. There is a need to bleed off a small discharge flow to limit the salt concentration in the water preventing the deposition of these salts and consequently corrosion and further possible leakages
- for the recycling of waste water after treatment for further uses not requiring such high quality water as for the first use. Since some undesirable substances can build up a small amount of water has to be bleed off and led to a waste water treatment plant before final discharge. This amount needs to be replenished with fresh water
- for process water which can be led in a close cycle since some undesirable substances can build up a small amount of water is led to a waste water treatment plant before discharging. This amount needs to be replenished with fresh water.

The water management in an integrated steelworks primarily depends on local conditions, above all on the availability and quality of freshwater and on legal requirements.
Figure 2.13 gives an example of water management with an indication of the water treatment of an integrated steelworks with almost unlimited freshwater availability, thus explaining the presence of once-through cooling systems, resulting in a specific water intake of more than 100 - 200 m³/t of steel. This is valid for plants close to large bodies of water, e.g. big rivers.

A driving factor for steadily improving the intake and outlet of water are the costs. Specially the costs for waste water treatment and releasing costs based on legal tax on discharging water into the municipal system can be considerable. Another cost related factor is that the water taken from the aforementioned bodies depending on the water quality for many applications has to undergo a conditioning step before it can be used. Furthermore the pumping of such big water flows requires much electric energy.

For these reasons the water consumption was constantly reduced over the last 30 years.

In particular, at sites with very low fresh water availability, where the water demand should be covered by groundwater or spring water, there may be a need to reduce water consumption intensely. In such cases, the specific water consumption can be lower than 5 m³/t of steel and the interdependencies are much more intensive.
Table 2.6 illustrates a comparison between the intake water requirements of a once-through system and a system involving extensive recirculation in a typical integrated steelworks. The extensive recirculation in indirect and direct cooling systems reduces the total water intake to 2.4 percent of the requirement of the once-through system.

<table>
<thead>
<tr>
<th>Water Use</th>
<th>Quality</th>
<th>Water intake</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Once-through</td>
<td>Extensive recirculation</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>m³/min</td>
<td>% of total</td>
<td>m³/min</td>
<td>% of total</td>
</tr>
<tr>
<td>Indirect cooling</td>
<td>General</td>
<td>675</td>
<td>70.7</td>
<td>7.4</td>
<td>32</td>
</tr>
<tr>
<td>Direct cooling</td>
<td>General</td>
<td>265</td>
<td>27.8</td>
<td>6.2</td>
<td>26.8</td>
</tr>
<tr>
<td>Process water</td>
<td>Low grade</td>
<td>7.7</td>
<td>0.8</td>
<td>5.1</td>
<td>22.1</td>
</tr>
<tr>
<td>Potable water</td>
<td>High grade</td>
<td>1.5</td>
<td>0.2</td>
<td>1.5</td>
<td>6.5</td>
</tr>
<tr>
<td>Evaporation losses</td>
<td></td>
<td>4.8</td>
<td>0.5</td>
<td>2.9</td>
<td>12.6</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>954</td>
<td>100</td>
<td>23.1</td>
<td>100</td>
</tr>
</tbody>
</table>

Note: It is not known if this data also includes the water used in downstream operations (not included in this document, e.g. rolling).

Table 2.6: Comparison in water intake for integrated steelworks with once-through systems and extensive recirculation [279]

The following two figures are presenting other examples of two different global systems from two integrated steelworks with separate circuits due to local design of the plant (see Figure 2.14) and with a cascade system at counter-flow with steel production steps (from cold rolling mill to the blast furnace) (see Figure 2.15).
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Figure 2.14: Example for the water management of an integrated steelworks with separate circuits [524]

Remark: circulation cooling e.g. BF, steel mill* others: compressed air station, steam production
Figure 2.15: Example for the water management of an integrated steelworks using a cascade system [524]
In the example plant related to Figure 2.14 the overall quantity of water in 2005 is nearly 1.2 billion m$^3$/yr. The recirculation rate in this case is 97.2% and only 2.8% need to be replenished with fresh water. The discharge as waste water is only 1.2% and the rest are losses of about 1.6%.

As a result the water intake is about 3.16 m$^3$/t crude steel.

Techniques which led to a reduced water intake and a minimised amount of discharged waste water in the aforementioned case include:

- avoiding the use of potable water for production lines
- increasing the number and/or capacity of water circulating systems when building new plants or modernising/revamping old plants
- centralising the distribution of incoming freshwater
- using the water in cascades until single parameters reach their legal or technical limits
- using the water in other plants if only single parameters of the water are affected and a further usage is possible
- keeping treated and non-treated waste water separated. By this measure it is possible to dispose of waste water in different ways with reasonable costs
- using rainwater whenever possible.
2.5 General techniques to consider in the determination of BAT

This section sets out techniques considered generally to have potential for achieving a high level of environmental protection in the industries within the scope of the document. Management systems, process-integrated techniques and end-of-pipe measures are included, but a certain amount of overlap exists between these three when seeking the optimum results.

Prevention, control, minimisation and recycling procedures are considered as well as the re-use of materials and energy.

Techniques may be presented singly or as combinations to achieve the objectives of the IPPC Directive. Annex IV to this Directive lists a number of general considerations to be taken into account when determining BAT and techniques within this section will address one or more of these considerations. As far as possible, a standard structure is used to outline each technique, to enable comparison of techniques and an objective assessment against the definition of BAT given in the IPPC Directive.

The content of this section is not an exhaustive list of techniques and others may exist or be developed which may be equally valid within the framework of IPPC and BAT.

The standard structure used to outline each technique, is shown in Table 2.7:

<table>
<thead>
<tr>
<th>Type of information considered</th>
<th>Type of information included</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Technical description of the technique (including drawings, schematics if necessary)</td>
</tr>
<tr>
<td>Achieved environmental benefits</td>
<td>Main environmental benefits (including energy, water, raw material savings, as well as production yield increases, energy efficiency, etc.) addressed by the technique</td>
</tr>
<tr>
<td>Cross-media effects</td>
<td>Main environmental side effects and disadvantages to other media caused by using the technique. Details of the environmental effects of the technique in comparison with others</td>
</tr>
<tr>
<td>Operational data</td>
<td>Data on consumption and emission levels from operational plants using the technique (including any reference conditions and monitoring methods used). Any other relevant information on how to operate, maintain and control the technique</td>
</tr>
<tr>
<td>Applicability</td>
<td>Indication of the type of plants in which the technique may be applied, considering, e.g. plant age (new or existing), plant size (large or small), techniques already installed and type or quality of product</td>
</tr>
<tr>
<td>Economics</td>
<td>Information on costs (both investment and operational) and any possible savings (e.g. reduced raw material or energy consumption, waste charges) or revenues including details on how these costs/savings or revenues have been calculated/estimated</td>
</tr>
<tr>
<td>Driving force for implementation</td>
<td>Local conditions or requirements which lead to, or may stimulate, implementation. Information on reasons other than environmental ones for implementation (e.g. increase in productivity, safety)</td>
</tr>
<tr>
<td>Example plants</td>
<td>Reference to (a) plant(s) in which the technique is applied and from which information has been collected and used in writing the section</td>
</tr>
<tr>
<td>Reference literature</td>
<td>Literature or other reference material (e.g. books, reports, studies, websites) that was used in writing the section and that contains more details on the technique</td>
</tr>
</tbody>
</table>

Table 2.7: Information breakdown for each technique described in this section
2.5.1 Environmental management systems

Description
The best environmental performance is usually achieved by the installation of the best technology and its operation in the most effective and efficient manner. This is recognised by the IPPC Directive's definition of ‘techniques’ as “both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned”.

For IPPC installations an Environmental Management System (EMS) is a tool that operators can use to address these design, construction, maintenance, operation and decommissioning issues in a systematic, demonstrable way. An EMS includes the organisational structure, responsibilities, practices, procedures, processes and resources for developing, implementing, maintaining, reviewing and monitoring the environmental policy. Environmental Management Systems are most effective and efficient where they form an inherent part of the overall management and operation of an installation.

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

![Figure 2.16: Continuous improvement in an EMS model](image)

Within the European Union, many organisations have decided on a voluntary basis to implement environmental management systems based on EN ISO 14001:2004 or the EU Eco-Management and Audit Scheme (EMAS). EMAS includes the management system requirements of EN ISO 14001, but places additional emphasis on legal compliance, environmental performance and employee involvement. It also requires external verification of the management system and validation of a public environmental statement (in EN ISO 14001 self-declaration is an alternative to external verification). There are also many organisations that have decided to put in place non-standardised EMSs.

While both standardised systems (EN ISO 14001:2004 and EMAS) and non-standardised (‘customised’) systems in principle take the organisation as the entity, this document takes a narrower approach, not including all activities of the organisation, e.g. with regard to their products and services, due to the fact that the regulated entity under the IPPC Directive is the installation (as defined in Article 2 of the Directive).
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An Environmental Management System (EMS) for an IPPC installation can contain the following components:

(a) commitment of top management
(b) definition of an environmental policy
(c) planning and establishing objectives and targets
(d) implementation and operation of procedures
(e) checking and corrective action
(f) management review
(g) preparation of a regular environmental statement
(h) validation by a certification body or an external EMS verifier
(i) design considerations for end-of-life plant decommissioning
(j) development of cleaner technologies
(k) benchmarking.

These features are explained in somewhat greater detail below. For detailed information on components (b) to (h), which are all included in EMAS, the reader is referred to the reference literature indicated below.

(a) Commitment of top management:

The commitment of top management is the precondition for a successful EMS. It is important that top management:

- place environmental management high on the company agenda, make it visible and give it credibility
- identify one top manager with responsibility for environmental management
- help create an environmental management culture and create the necessary driving forces for implementation
- define a strategy (long-term visions) to achieve environmental objectives
- set company targets to achieve these environmental objectives
- define short and medium term concrete actions to achieve the long-term vision
- provide the platform to integrate decision-making in order to achieve integrated pollution prevention and control, particularly for when planning new installations or significant upgrading
- guide the company to make investment and purchasing decisions that achieve integrated pollution prevention and control on a continuing basis. Integrated pollution prevention and control is achieved through integrated decision-making and actions, including the buying of utilities and capital equipment, planning, production, and maintenance as well as environmental management
- define an environmental policy, see (b) below.

(b) Definition of an environmental policy:

Top management are responsible for defining an environmental policy for an installation and ensuring that it:

- is appropriate to the nature, scale and environmental impacts of the activities
- includes a commitment to pollution prevention and control including the efficient use of raw materials, energy and water
- includes a commitment to comply with all relevant applicable environmental legislation and regulations, and with other requirements to which the organisation subscribes
- provides the framework for setting and reviewing environmental objectives and targets
- is documented and communicated to all employees
- is available to the public and all interested parties.
(c) Planning and establishing objectives and targets:

It is important to have:

- procedures to identify the environmental aspects of the installation, in order to determine those activities which have or can have significant impacts on the environment, and to keep this information up-to-date
- procedures to evaluate proposals for new processes, units and equipment, change in raw and auxiliary materials or fuels, upgrades, rebuilds and replacements in order to identify the environmental aspects and to influence the planning and purchasing to optimise the environmental performance of the installation with regard to the objectives of the IPPC Directive
- procedures to authorise the modifications indicated above and to undertake checks after modifications have been implemented and before the process starts up
- procedures to identify and have access to legal and other requirements to which the organisation subscribes and that are applicable to the environmental aspects of its activities
- establishing and reviewing documented environmental objectives and targets, taking into consideration the legal and other requirements to which the organisation subscribes and the views of interested parties
- establishing and regularly updating an environmental management programme, including designation of responsibility for achieving objectives and targets at each relevant function and level as well as the means and timeframe by which they are to be achieved
- carrying out audits to review, e.g. the efficient use of energy, water, raw and auxiliary materials.

(d) Implementation and operation of procedures:

It is important to have systems in place to ensure that procedures are known, understood and complied with, therefore effective environmental management includes:

(i) structure and responsibility:
- defining, documenting, reporting and communicating roles, responsibilities and authorities, which includes appointing one specific management representative (in addition to a top manager (see (a) above)
- providing resources essential to the implementation and control of the environmental management system, including human resources and specialised skills, technology and financial resources

(ii) training, awareness and competence:
- defining, documenting and communicating skills and competencies required for each job
- identifying training needs to ensure that all personnel whose work may significantly affect the environmental impacts of the activity have received appropriate training for all modes of operations they can encounter, i.e. preparation, start-up, routine operation, shutdown and abnormal conditions

(iii) communication
- establishing and maintaining procedures for internal communication between the various levels and functions of the installation, as well as procedures that foster a dialogue with external interested parties and procedures for receiving, documenting and, where reasonable, responding to relevant communication from external interested parties
(iv) employee involvement
- involving employees in the process aimed at achieving a high level of environmental performance by applying appropriate forms of participation such as the suggestion book system or project-based group works or environmental committees

(v) documentation
- establishing and maintaining up-to-date information, in paper or electronic form, to describe the core elements of the management system and their interaction and to provide direction to related documentation

(vi) efficient process control
- adequate control of processes and equipment (including pollution prevention and control equipment) under all modes of operation, i.e. preparation, start-up, routine operation, shut-down and abnormal conditions
- identifying the key performance indicators (e.g. flow, pressure, temperature, composition, quantity) and methods (e.g. weighting systems, metering systems, calculations, sampling and analysis) for measuring and controlling these parameters
- documenting and analysing abnormal operating conditions to identify the root causes and then addressing these to ensure that abnormal events do not recur (this can be facilitated by a ‘no-blame’ culture where the identification of causes is more important than apportioning blame to individuals)

(vii) maintenance programme
- establishing a structured programme for maintenance (including preventive and corrective maintenance) based on technical descriptions of the equipment, norms, etc. as well as any equipment failures and consequences of the failures
- identifying from routine maintenance, breakdowns and/or abnormalities, possible decreases in environmental performance, or where environmental performance could be improved
- supporting the maintenance programme by appropriate record keeping systems and diagnostic testing
- clearly allocating responsibility for the planning and execution of maintenance

(viii) emergency preparedness and response
- establishing and maintaining procedures to identify the potential for and response to accidents and emergency situations, and for preventing and mitigating the environmental impacts that may be associated with them

(e) Checking and corrective action (see also benchmarking (e)):

(i) monitoring and measurement
- establishing and maintaining documented procedures to monitor and measure, on a regular basis, the key characteristics of operations and activities that can have a significant impact on the environment. This includes the recording of information for tracking performance, relevant operational controls and conformance with the installation's environmental objectives and targets (see also the Reference Document on the General Principles of Monitoring (MON) [505])
- establishing and maintaining a documented procedure for periodically evaluating compliance with relevant environmental legislation and regulations
(ii) corrective and preventive action
- establishing and maintaining procedures for defining responsibility and authority for handling and investigating non-conformance with permit conditions, other legal requirements and commitments as well as objectives and targets
- taking action to mitigate any impacts caused by abnormal events and for initiating and completing corrective and preventive actions that are appropriate to the magnitude of the problem and commensurate with the environmental impact encountered

(iii) records
- establishing and maintaining procedures for the identification, maintenance and disposition of legible, identifiable and traceable environmental records, including training records and the results of audits and reviews

(iv) audit
- establishing and maintaining a programme (or programmes) and procedures for periodic environmental management system audits. Such a programme (or programmes) includes discussions with personnel, inspection of operating conditions and equipment and reviewing of records and documentation. Each audit results in a written report, to be carried out impartially and objectively by employees (internal audits) or external parties (external audits), covering the audit scope, frequency and methodologies, as well as the responsibilities and requirements for conducting audits and reporting results, in order to determine whether or not the environmental management system conforms to planned arrangements and has been properly implemented and maintained
- completing the audit or audit cycle, as appropriate, at intervals of no longer than three years, depending on the nature, scale and complexity of the activities, the significance of associated environmental impacts, the importance and urgency of the problems detected by previous audits and the history of environmental problems - more complex activities with a more significant environmental impact are audited more frequently
- having appropriate mechanisms in place to ensure that the audit results are followed up

(v) periodic evaluation of legal compliance
- reviewing compliance with the applicable environmental legislation and the conditions of the environmental permit(s) held by the installation
- documentation of the evaluation.

(f) Management review:
- reviewing, by top management, at intervals that it determines, of the environmental management system, to ensure its continuing suitability, adequacy and effectiveness
- ensuring that the necessary information is collected to allow management to carry out this evaluation
- documentation of the review.
(g) Preparation of a regular environmental statement:

- preparing an environmental statement that pays particular attention to the results achieved by the installation against its environmental objectives and targets. It is regularly produced - from once a year to less frequently depending on the significance of emissions, waste generation, etc. This statement considers the information needs of relevant interested parties and it is publicly available (e.g. in electronic publications, libraries etc.). When producing a statement, the operator may use relevant existing environmental performance indicators, making sure that the indicators chosen:
  
  i. give an accurate appraisal of the installation’s environmental performance
  ii. are understandable and unambiguous
  iii. allow for year on year comparison to assess the development of the environmental performance of the installation
  iv. allow for comparison with sector, national or regional benchmarks as appropriate
  v. allow for comparison with regulatory requirements as appropriate.

(h) Validation by a certification body or an external EMS verifier:

- having the management system, audit procedure and environmental statement examined and validated by an accredited certification body or an external EMS verifier can, if carried out properly, enhance the credibility of the system.

(i) Design considerations for end-of-life plant decommissioning:

- giving consideration to the environmental impact from the eventual decommissioning of the installation at the stage of designing a new plant, as forethought makes decommissioning easier, cleaner and cheaper
- decommissioning poses environmental risks for the contamination of land (and groundwater) and generates large quantities of solid waste. Preventive techniques are process-specific but general considerations may include:
  
  i. avoiding underground structures
  ii. incorporating features that facilitate dismantling
  iii. choosing surface finishes that are easily decontaminated
  iv. using an equipment configuration that minimises trapped chemicals and facilitates drain-down or cleaning
  v. designing flexible, self-contained units that enable phased closure
  vi. using biodegradable and recyclable materials where possible.

(j) Development of cleaner technologies:

- environmental protection should be an inherent feature of any process design activities carried out by the operator or its contractors, since techniques incorporated at the earliest possible design stage are both more effective and cheaper. Giving consideration to the development of cleaner technologies can, for instance, occur through R&D activities or studies. As an alternative to internal activities, arrangements can be made to keep abreast with – and where appropriate – commissioned work by other operators or research institutes active in the relevant field.

(k) Benchmarking:

- carrying out systematic and regular comparisons with sector, national or regional benchmarks, including for energy efficiency and energy conservation activities, choice of input materials, emissions to air and discharges to water (using for example the European Pollutant Emission Register, EPER), consumption of water and generation of waste.
Standardised and non-standardised EMSs
An EMS can take the form of a standardised or non-standardised (‘customised’) system. Implementation and adherence to an internationally accepted standardised system such as EN ISO 14001:2004 can give higher credibility to the EMS, especially when subjected to a properly performed external verification. EMAS provides additional credibility due to the interaction with the public through the environmental statement and the mechanism to ensure compliance with the applicable environmental legislation. However, non-standardised systems can, in principle, be equally effective provided that they are properly designed and implemented.

Achieved environmental benefits
Implementation of, and adherence to, an EMS focuses the attention of the operator on the environmental performance of the installation. In particular, the maintenance of, and compliance with, clear operating procedures for both normal and abnormal situations and the associated lines of responsibility should ensure that the installation’s permit conditions and other environmental targets and objectives are met at all times.

Environmental management systems typically ensure the continuous improvement of the environmental performance of the installation. The poorer the starting point is, the more significant short-term improvements can be expected. If the installation already has a good overall environmental performance, an EMS helps the operator to maintain the high performance level.

Cross-media effects
Environmental management techniques are designed to address the overall environmental impact of the installation, which is consistent with the integrated approach of the IPPC Directive.

Operational data
All significant consumptions (including energy) and emissions are managed in a co-ordinated manner by the operator for the short, medium and long term, in conjunction with financial planning and investment cycles. This means that e.g. adapting short-term end-of-pipe solutions to emissions may tie the operator to long-term higher energy consumption, and postpone investment in potentially more environmentally beneficial solutions overall. This requires some consideration of the cross-media issues, and guidance on these and the costing and cost-benefits issues is given in the Reference Document on Economics and Cross-Media Effects (ECM) [525] and in the BREF on Energy Efficiency (ENE) [504].

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

Economics
It is difficult to accurately determine the costs and economic benefits of introducing and maintaining a good EMS. A number of studies\(^1\) have been made but do not reflect the size or complexity of the iron and steel manufacturing sector. There also economical benefits that are the result of using an EMS and this varies widely from sector to sector.

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In some Member States reduced supervision fees are charged if the installation has a certification.

External costs relating to verification of the system can be estimated from guidance issued by the International Accreditation Forum (http://www.iaf.nu).

The following information about the costs of implementing EMS in the iron and steel manufacturing sector and some of the savings made are provided below.

A number of studies are presented below. However, these are just examples and their results are not entirely coherent. They might not be representative for all sectors across the EU and should thus be treated with caution.

Some of these studies show that there is an inverse relationship between company size and the cost of implementing an EMS. A similar inverse relationship exists for the payback period of invested capital. Both elements imply a less favourable cost-benefit relationship for implementing an EMS in small and medium enterprises (SMEs) compared to larger companies.

A Swedish study carried out in 1999 surveyed all 360 ISO-certified and EMAS-registered companies in Sweden. With a response rate of 50 %, it concluded among other things that:

- the expenses for introducing and operating EMS are high but not unreasonably so, save in the case of very small companies. Expenses are expected to decrease in the future
- a higher degree of co-ordination and integration of EMS with other management systems is seen as a possible way to decrease costs
- half of all the environmental objectives and targets give payback within one year through cost savings and/or increased revenue
- the largest cost savings were made through decreased expenditure on energy, waste treatment and raw materials
- most of the companies think that their position on the market has been strengthened through the EMS. One-third of the companies report increasing revenue due to EMS.

According to a Swiss study, the average cost for building and operating ISO 14001 can vary:

- for a company with between 1 and 49 employees: CHF 64000 (EUR 44000) for building the EMS and CHF 16000 (EUR 11000) per year for operating it
- for an industrial site with more than 250 employees: CHF 367000 (EUR 252000) for building the EMS and CHF 155000 (EUR 106000) per year for operating it.

These average figures do not necessarily represent the actual cost for a given industrial site because this cost is also highly dependent on the number of significant items (pollutants, energy consumption, ...) and on the complexity of the problems to be studied.

A recent German study shows the following costs for EMAS for different branches [501].

Costs for building (EUR):

- minimum - 18750
- maximum - 75000
- average - 50000

It can be noted that these figures are much lower than those of the Swiss study quoted above. This is a confirmation of the difficulty to determine the costs of an EMS.

Costs for validation (EUR):

- minimum - 5000
- maximum - 12500
- average - 6000
A study by the German Institute of Entrepreneurs (Unternehmerinstitut/Arbeitsgemeinschaft Selbständiger Unternehmer UNI/ASU, 1997, Umweltmanagementbefragung - Öko-Audit in der mittelständischen Praxis - Evaluierung und Ansätze für eine Effizienzsteigerung von Umweltmanagementsystemen in der Praxis, Bonn.) gives information about the average savings achieved for EMAS per year and the average payback time. For example, for implementation costs of EUR 80000 they found average savings of EUR 50000 per year, corresponding to a payback time of about one and a half years.

**Driving forces for implementation**
Environmental management systems can provide a number of advantages, for example:

- improved insight into the environmental aspects of the company
- improved basis for decision-making
- improved motivation of personnel
- additional opportunities for operational cost reduction and product quality improvement
- improved environmental performance
- improved company image
- reduced liability, insurance and non-compliance costs
- increased attractiveness for employees, customers and investors
- increased trust of regulators, which could lead to reduced regulatory oversight
- improved relationship with environmental groups.

**Example plants**
The features described under (a) to (e) above are elements of EN ISO 14001:2004 and the European Community Eco Management and Audit Scheme (EMAS), whereas features (f) and (g) are specific only to EMAS. These two standardised systems are applied in a number of IPPC installations. As an example, in the UK, the Environment Agency of England and Wales carried out a survey among IPPC (the precursor to IPPC) regulated installations in 2001. It showed that 32 % of respondents were certified to ISO 14001 (corresponding to 21 % of all IPPC installations) and 7 % were EMAS registered. All cement works in the UK (around 20) are certified to ISO 14001 and the majority are EMAS registered. In Ireland, where the establishment of an EMS (not necessarily of a standardised nature) is required in IPPC licenses, an estimated 100 out of approximately 500 licensed installations have established an EMS according to ISO 14001, with the other 400 installations having opted for a non-standardised EMS.

Most European steelmaking plants have certified Environmental management systems whereas ISO 14001 is more often applied than EMAS. Some examples are:

- Buderus Edelstahl GmbH, Wetzlar, Germany
- Uddeholm Tooling AB, Hagfors, Sweden
- Villares Metals S:A., Sao Paolo, Brazil
- Böhler Edelstahl GmbH, Karmpfenberf, Austria
- Voestalpine Stahl GmbH, Linz, Austria
- Voestalpine Stahl GmbH, Donawitz, Austria.

**Reference literature**

2.5.2 Energy management

2.5.2.1 Techniques to improve the energy efficiency

Description
There are some special and important items, which should be mentioned in connection with an integrated steelworks in order to improve the overall energy efficiency including:

- optimising energy consumption. Typically, a change in the energy supply of one process in the steel plant influences several other processes (e.g. the use of coke oven gas in the blast furnace can result in a higher calorific value in the blast furnace top gas). Optimising tools that consider the whole integrated site may be constructed in preference to ones that consider each process as a standalone unit
- online monitoring. This is often used for the most important energy flows and combustion processes at the site. The data are stored for a long time so that typical situations may be analysed. Very important is the online monitoring for all gas flares. It is the main technique used to avoid energy losses in the flares and combustion processes. Continuous monitoring systems for all energy related process parameters can be used to optimise process control and enable instant maintenance thus achieving an undisturbed production
- reporting and analysing tools. Reporting tools are often used to check the average energy consumption of each process. In connection with cost controlling, controlling energy is the basis for optimising energy consumption and cost savings. An energy controlling system offers the possibility of comparing actual data with historical data (e.g. charts)
- specific energy consumption levels. For each process, specific energy consumption levels may be defined. Typically, the reported energy levels can be used, although these values must be checked critically. The values are compared on a long-term basis
- energy Audits. These audits are defined in the Energy Efficiency BREF as a crucial tool in energy management. These audits may also identify cost effective energy savings opportunities.

Achieved environmental benefits
The aim of energy management should be to maximise the productive use of gases arising from the processes, thereby minimising the necessity of importing supplementary energy sources into the system and optimising the specific energy consumption within the inherent constraints of the system. In order to achieve the goal there must be an adequate system dealing with the technical possibilities and costs on the one hand, and on the organisation, on the other hand. There are many attempts to explain energy management (e.g. Energy Efficiency BREF), therefore the general details are not discussed in this document.

Cross-media effects
No data submitted.

Operational data
No data submitted.

Applicability
No data submitted.

Economics
No data submitted.

Driving force for implementation
No data submitted.

Example plants
No data submitted.
2.5.2.2 Techniques to optimise process gas utilisation

Description
Some potential process-integrated techniques used to improve energy efficiency in an integrated steelworks by optimising process gas utilisation are:

- the use of gas holders for all by-product gases or adequate other systems for short-term storage and pressure holding facilities for maximising the recovery of process gases
- increasing pressure in the gas grid if there are energy losses in flares - in order to utilise more process gases with the resulting increase in the utilisation rate
- gas enrichment with process gases and different caloric values for different consumers - processes require gases with different calorific values for acceptable levels of fuel efficiency. The higher the required process temperature, the higher the amount of high calorific gases needed
- reheating fire furnaces with process gas in order to maximise the use of process gases and reduce the need to purchase natural gas or electrical power
- use of a computer controlled caloric value control system
- recording and using coke and flue-gas temperatures.

Achieved environmental benefits
By the application of the aforementioned techniques, the specific energy demand for steel production in an integrated steelworks can be reduced.

The energy efficiency can be improved by good combustion control and can eventually decrease the air emissions.

Cross-media effects
No data submitted.

Operational data
No data submitted.

Applicability
The specific energy consumption depends on the scope of the process, the product quality and the type of installation (e.g. the amount of vacuum treatment at the BOF, annealing temperature, thickness of products, etc.). Each integrated steelworks and component therein has a different spectrum of products, process configurations, raw material strategies, etc. and therefore has its own specific energy demands. Climatic circumstances also have to be taken to account when considering specific energy usage.

Economics
No data submitted.

Driving force for implementation
No data submitted.

Example plants
No data submitted.

Reference literature
[242] [430]
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2.5.2.3 Techniques to improve heat recovery

Description
Some potential process-integrated measures used to improve energy efficiency in an integrated steelworks by improved heat recovery are:

- recovery of waste heat by heat exchangers and distribution either to other parts of the steelworks or to a district heating network (if there are consumers in the vicinity)
- installation of steam boilers or adequate systems in big reheating furnaces (furnaces cover the steam demand)
- preheat the combustion air in furnaces and other burning systems to save fuel, taking into consideration adverse effects, i.e. an increase of NOx in the off-gas
- insulation of steam pipes and hot water pipes
- recovery of heat from products, e.g. sinter
- where steel needs to be cooled, use of both heat pumps and solar panels
- use of flue-gas boilers in furnaces with high temperatures
- oxygen evaporation and compressor cooling to exchange energy across standard heat exchangers
- use of top recovery turbines to convert the kinetic energy of the gas produced in the blast furnace into electric power.

Achieved environmental benefits
By application of the aforementioned techniques, the specific energy demand for steel production in an integrated steelworks can be reduced. CO\textsubscript{2} emissions and emissions of other pollutants may be avoided by replacing fossil fuel, for district heating energy production.

A significant advantage of the district heating system is the cleanliness and high temperature difference of the circulating water. In this way, it is possible to connect the production of the heat and the specific process cooling solutions.

Cross-media effects
No data submitted.

Operational data
District heating is a safe, economically feasible heating method which requires little maintenance for the customer.

In the municipal district heating system, thermal energy is delivered with the help of the closed piping for the heating of the buildings and of other premises and for the production of warm service water. The consumer always receives the heat with the help of heat exchangers. Each of the buildings has similar connections, for example, for the electrical net, for the gas net, for the clean water and the waste water nets.

The district heating systems are utilised quite generally within the city areas of the Nordic countries and Russia but nowadays it is also quite generally used in smaller communities. The heat is produced in larger towns in large power plants with combined electricity and heat production (CHP). In smaller communities, the heat is produced with separate boiler plants burning fixed fuels, heavy oil or natural gas.

The temperature of the district heating water is adjusted in the range of 75 - 120 °C. The temperature of returning water is in the range 40 - 45 °C.

One specific feature in the industrial district heating system is connected to optimisation and to control. When about 90 % of annual heat demand is produced with the waste heat of many different processes, it is quite complicated to continuously divide the optimal heat loads and to control temperatures and pressures in the other production points.
Applicability
The method is used primarily in all steelworks that use a similar cooling technique.

Combined heat and power generation is applicable for all iron and steel plants close to urban areas with a suitable heat demand. The same appears for many other process industries.

The specific energy consumption depends on the scope of the process, the product quality and the type of installation (e.g. the amount of vacuum treatment at the BOF, annealing temperature, thickness of products, etc.). Each integrated steelworks and component therein has a different spectrum of products, process configurations, raw material strategies etc. and therefore has its own specific energy demands. Climatic circumstances also have to be taken to account when considering specific energy usage.

Economics
Selling waste heat can be a remunerative business.

The construction of the district heating system is quite advantageous when utilising the technology that has been generally applied. For this reason, the system has been an extremely profitable technique to Raahé steelworks, Raahé, Finland, and moreover, there are extremely advantageous district heating tariffs in the town of Raahé for the end user. New industry which uses district heating has been developed in the area.

Driving force for implementation
The driving forces for the implementation of heat recovery are the savings in primary fuels, thus a reduction of CO₂ emissions and other environmental impacts. The driving forces for the implementation of combined heat and power production are the environmental benefits, the improved BF operation and the avoidance of high investment costs.

Example plants
At the reference plant Marienhütte in Graz, Austria about 40 GWh per year is recovered from the EAF (35 tonnes/charge) and fed to the district heating network (status in 2005). District heating is also practiced in Ovako Hofors, SSAB Luleå in Sweden and at the Ruukki sinter plant in Finland.

From a combined heat and power plant district heat is produced at SSAB-Lulekraft in Luleå, Sweden. From the start to the end of 2003, 12995 GWh of hot water was delivered to local district heating. Approximately 4.5 Mt of CO₂ would have been produced if the same amount of heat had been generated using heavy fuel oil (assuming a recovery of 90% and a specific CO₂ value of 0.0879 tonnes CO₂/GJ). Using the same conditions, the amount of NOₓ and SOₓ avoided could be calculated to approximately 1800 and 600 tonnes, respectively. The electrical power covers the need of a Swedish steel sheet manufacturer SSAB Tunnplåt AB, and also gives some surplus electricity which can be used elsewhere. The production of heat covers the total need of district heating in Luleå (which has 22000 homes). Also, a local biomass plant uses surplus energy from the system.

In 2004 the total energy delivery from a system was:

<table>
<thead>
<tr>
<th>Fuel input (GWh)</th>
<th>Energy output (GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas 2075</td>
<td>Total energy export 1472</td>
</tr>
<tr>
<td>Oil 82</td>
<td>Hot water to district heating 751</td>
</tr>
<tr>
<td></td>
<td>Electric power export 613</td>
</tr>
<tr>
<td></td>
<td>Steam export 27</td>
</tr>
<tr>
<td></td>
<td>Drying gas export 81</td>
</tr>
</tbody>
</table>

Table 2.8: Example of CHP plant to produce heat and electrical power for a community [208]
Hofors Energi AB in Sweden delivers a total of around 130 GWh per year to OVAKO Hofors and the Hofors community. A third of this is in the form of steam whereas the rest is in the form of hot water. Making use of waste heat means savings of up to a further 4000 m$^3$ per year. In total this means a reduction in CO$_2$ emissions of 23000 tonnes per year for OVAKO Hofors.

As a result of the collaboration between OVAKO Hofors and Hofors Energi AB, the community of Hofors is supplied with district heating, which reduces oil consumption in buildings by a further 4000 m$^3$ of oil per year. This means a reduction in CO$_2$ emissions of approximately 11000 tonnes per year.

The municipal district heating delivered to Raahen Energia is 160000 MWh/yr from which the use of heavy fuel oil is replaced by about 18000 t/yr. A similar amount of energy is replaced with Raahe Steelworks internal fuels, vapour and electricity which would be used for the production of the heat without the district heating system and without waste heat utilisation. Moreover, energy consumption in the steelworks is reduced when it has been possible to sell waste heat to Raahen Energia.

Another example of district heating takes place at Voestalpine Stahl, Linz, Austria with 139 GWh/yr.

**Reference literature**

[208] [424] [430]

### 2.5.2.4 Frequency controlled pumps and fans

**Description**

An analysis of the pumps used to supply district heating to the industrial area often shows that the pumps are all running continuously at high power, although the pumping power required is often very low.

Nowadays most pumps and fans can be frequency controlled and may therefore be set to any given rotation speed (rpm value) to obtain the desired set point value for the flowrate. The use of frequency controlled pumps and fans and variable speed drives enables a better and faster adjustment of water flowrates and off-gas flowrates according to the demands of different process conditions. Additional systems optimisation measures include:

- a complete separation of the pumps from the main supply when they are switched off
- a replacement of existing pumps with smaller, highly efficient pumps
- the installation of high efficiency motors.

The highest energy savings are achieved if energy-using systems are optimised as a whole rather than considering individual systems components in isolation. The campaign therefore focuses on a systems analysis; the components in a pump system include, for instance, a variable speed drive, an electric motor, a gear box, a pump and pipes and the instrument and control equipment. Measures to optimise the energy used must be developed individually for each pump system and be evaluated from an economic point of view. It is important to analyse the needs parameters (pressure, flowrate, temperature level etc.), existing operating parameters and systems components of each system individually. The fine tuning of all components and their interaction also belongs in an optimisation plan. This ensures a step-by-step determination of the best possible overall efficiency of a system and the most efficient use of energy.

**Achieved environmental benefits**

The changes result in considerable savings in electrical energy as well as fewer maintenance costs and fewer production disturbances.
The efficiency measures also play a considerable role in the mitigation of climate change. In SSAB Oxelösund AB, Sweden, savings in electrical energy on a yearly basis is 3.2 GWh. In CO₂ reduction, this means about 250 tonnes/yr.

**Cross-media effects**  
As pump system technology is an interdisciplinary technology widely used in industry and production, many different kinds of companies can profit from these experiences.

**Operational data**  
No data submitted.

**Applicability**  
The technique can be applied to the off-gas cleaning water, the cooling water of the hood and the lance, the off-gas suction fans and similar equipment, for example, at the LD process.

**Economics**  
A systems optimisation can often reduce the energy consumption of an electromotive system by 30 percent or more. The reduction in energy costs generally means that the investments pay for themselves in between two and three years, with a return on capital of between 30 and 50 percent.

The lifespan of a pump system with an energy consumption that has been optimised is also greater, and plant availability increases. A lower mechanical load also reduces the cost of maintenance.

The energy savings and efficiency parameters for the district heating Ulm GmbH, Ulm, Germany are:

- electricity savings: 64 % or 325000 kWh/yr
- cost savings: EUR 32500/yr
- investment: EUR 67000
- payback period: 2.1 years
- return on investment: 48 %.

In SSAB Oxelösund, Sweden the total savings potential for the necessary changes, exceeds EUR 55000 per year in energy savings only (at a price of EUR 0.033 kWh). In this case, this can be achieved without investments. More energy savings may be obtained but, in this case, only after investments.

**Driving force for implementation**  
The driving force is mainly regarding economics.

**Example plants**  
In SSAB Oxelösund AB, Sweden.  
District heating Ulm GmbH, Ulm, Germany runs a waste fired heating plant and a peak load heating plant in Ulm Danube Valley and supplies the residential aerea of Wiblingen, Germany.

**Reference literature**  
[208] [510]
2.5.3 Reduction of NO\textsubscript{X} in process gas fired power plants

In principle, to reduce the NO\textsubscript{X} emissions, primary as well as secondary measures can be used. The secondary measures have an influence on both thermal as well as fuel NO.

2.5.3.1 Reduction of NO\textsubscript{X} by primary measures

Description
Primary measures can only reduce thermal NO\textsubscript{X}. The following primary measures can be applied individually or in combination:

- deployment of low-NO\textsubscript{X} burners
- flue-gas recirculation
- upper air injection for the residual combustion with substoichiometric burners
- injection of reduction fuel
- air staging
- fuel staging.

All of these measures reduce the combustion temperature and the oxygen partial pressure. The result is significantly lower NO\textsubscript{X} emissions. The combustion temperature depends on the caloric value of the input gas. By mixing more flue-gas (without burnable components) to the process gas, the temperature decreases.

Assignment of low-NO\textsubscript{X} burners and flue-gas recirculation
This is one of the most effective reduction measures, which should also be used with precisely harmonised combustion techniques.

Using low-NO\textsubscript{X} burner and additionally an external flue-gas recirculation, a value of 80 - 90 mg/Nm\textsuperscript{3} thermal NO\textsubscript{X} can be attained at a daily average. With the combustion of COG in combination with natural gas (without BF gas) values of about 90 mg/Nm\textsuperscript{3} are reachable on a daily average.

The combination of both reduction measures is often named as low-NO\textsubscript{X}. With installing both, a reduction rate about 40 % is possible, although employing only low-NO\textsubscript{X} burners, 30 % and employing only flue-gas recirculation, 15 % NO\textsubscript{X} reduction can be attained.

Because of the addition of thermal NO\textsubscript{X} and fuel NO\textsubscript{X}, NO\textsubscript{X} emissions of about 210 mg NO\textsubscript{X}/Nm\textsuperscript{3} as a daily average will be reached by using this primary measure and typical COG compositions.

There are also more complex influences on NO\textsubscript{X} emissions by other process parameters like:

- furnace area load (part load/full load)
- additional combustion of BF gas at the same time (lower combustion temperature)
- upper air injection.

Upper air injection as an additional measure
It is used additionally in the combustion of the residual fuel to the assignment of Low- NO\textsubscript{X} - burners with flue-gas recirculation, but in an existing plant it is less efficient.
Upper air injection as an alternative measure

One possibility to burn the residual flue-gas is to fire one burner substoichiometric and to provide the air needed for complete combustion afterwards. Compared to an alternative to a combination of low-NO\textsubscript{X} -burner and flue-gas recirculation the NO\textsubscript{X} reduction efficiency is only a third. Furthermore technical problems occur when injecting air steadily into the furnace to burn out the flue-gas completely and with the possibility of more CO near the walls which leads to corrosion.

Injection of reduction fuel

Another possibility of NO\textsubscript{X} reduction is the injection of a reduction fuel – for instance a mixture of recycled exhaust gas and natural gas – between the last burner level and the upper air.

But this is not efficient with the usage of low-NO\textsubscript{X} burners at the same time.

Air staging

Around the flame there are some combustion zones with a different amount of oxygen. Because of this, the combustion area is bigger and the dwell time in the flame takes longer. The staging could be done directly in the burner or in the furnace area.

Fuel staging

Like in air staging, the fuel is introduced into the furnace area in usually two stages. The results of NO\textsubscript{X} reduction are similar.

Achieved environmental benefits

With these measures the NO\textsubscript{X} reduction efficiencies given in Table 2.9 can be achieved.

<table>
<thead>
<tr>
<th>Applied primary measure</th>
<th>NO\textsubscript{X} reduction efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-NO\textsubscript{X} burner</td>
<td>28</td>
</tr>
<tr>
<td>Flue-gas recirculation</td>
<td>13</td>
</tr>
<tr>
<td>Upper air injection for residual combustion with substoichiometric burners</td>
<td>23</td>
</tr>
<tr>
<td>Injection of reduction fuel</td>
<td>13</td>
</tr>
<tr>
<td>Low-NO\textsubscript{X} burner plus flue-gas recirculation</td>
<td>38</td>
</tr>
</tbody>
</table>

Table 2.9: NO\textsubscript{X} reduction efficiency for primary measures

Cross-media effects

No data submitted.

Operational data

No data submitted.

Applicability

The application of primary or process-integrated measures as the installation of low-NO\textsubscript{X} burner systems can be applied in new and fully revamped large combustion plants in the iron and steel industry.

Economics

No data submitted.

Driving force for implementation

No data submitted.

Example plants

Reference power plants: voestalpine Stahl GmbH, Linz, Austria
TKS, Huckingen-Duisburg, Germany
Chapter 2

Reference literature
[430] [471] More information about the reduction of NO\textsubscript{X} by primary measures can be found in the Large Combustion Plants BREF (LCP) [434].

2.5.3.2 Reduction of NO\textsubscript{X} by secondary measures

2.5.3.2.1 NO\textsubscript{X} reduction by selective catalytic reduction (SCR)

Description
Ammonia is injected into the flue-gas and it converts NO\textsubscript{X} to nitrogen dioxide (N\textsubscript{2}) and water (H\textsubscript{2}O). A temperature of more than 320 °C is necessary to avoid the arising of ammonia salts, which blocks the catalytic converter. Figure 2.17 shows the typical configuration of a catalytic NO\textsubscript{X} converter.

![Figure 2.17: Catalytic NO\textsubscript{X} converter](image)

Depending on the position of the catalytic converter in the plant, there are three techniques:

- high dust
- low dust
- tail end.

In a high dust plant, the catalytic converter is built in between the economiser and the air preheater. The necessary catalytic reaction temperature is in the range of 300 - 400 °C. Because of the wide variety of operating and gas inputs, a stable temperature is not given in a power plant of an integrated steelworks.
The high dust plant requires a lot of space because all of the exhaust gas must be treated at nearly 350 °C, runs through the catalytic converter outside the furnace area and has to be lead back. Normally the concentration of NOX (about 100 mg/Nm³) is low and it is therefore difficult to mix the NH₃ with the exhaust gas without a stationary mixer. Furthermore, in cold parts of the air preheater, the contending sulphur will be converted to sulphur trioxide (SO₃), which blocks the outlet of it. Another disadvantage is the high content of dust.

In low dust plants as well as in tail end plants, the exhaust gas leaves the process behind the dust filter (e.g. ESP) with a temperature of only 50 - 130 °C. The flue-gas is nearly clean of dust, but it needs to be heated before it can enter the catalytic converter. This could be done by heating systems, additional burners or steam and the result is a loss of efficiency.

**Achieved environmental benefits**

As shown in Table 2.10, with the SCR technique, the NOX emissions in the exhaust gas can be reduced to concentrations below 80 mg/Nm³ as an annual average.

<table>
<thead>
<tr>
<th>Installation</th>
<th>NOX (mg/Nm³)</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generating unit 3³</td>
<td>28</td>
<td>21</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Generating unit 4³</td>
<td>36</td>
<td>24</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Generating unit 5³</td>
<td>29</td>
<td>17</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Generating unit 6³</td>
<td>71</td>
<td>76</td>
<td>66</td>
<td></td>
</tr>
<tr>
<td>Busbar¹</td>
<td>69</td>
<td>66</td>
<td>46</td>
<td></td>
</tr>
<tr>
<td>Gas und steam turbine²</td>
<td>15</td>
<td>16</td>
<td>17</td>
<td></td>
</tr>
</tbody>
</table>

**Note:** annual averages

³) O₂ reference content 3 %.
²) O₂ reference content 15 %.

Table 2.10: Performance data for five process gas fired units using the SCR technique [511]

**Cross-media effects**

No data submitted.

**Operational data**

No data submitted.

**Applicability**

There are some new and fully revamped power plants in integrated steelworks with SCR technique installed.

Secondary measures to reduce NOX might be difficult to retrofit into existing plants. In particular the implementation for a SCR facility requires enough space.

**Economics**

No data submitted.

**Driving force for implementation**

No data submitted.

**Example plants**

Voestalpine Stahl GmbH, Linz, Austria
TKS, Duisburg-Hamborn, Germany

**Reference literature**

[424] [471] [511] [512]
More information about SCR can be found in the Large Combustion Plants BREF (LCP) [434], the Waste Incineration (WI) BREF [437] and the Cement, Lime and Magnesium Manufacturing (CLM) BREF [485].

2.5.3.2.2 NO\textsubscript{X} reduction by selective non catalytic reduction (SNCR)

Description
For the reduction of NO\textsubscript{X} no catalytic converter is necessary. This technique requires changing temperatures in a range of 900 - 1000 °C. The injection of NH\textsubscript{3} should be done in different stages, just where the optimum temperature of a load range is. This might be difficult to control and it has to be carefully tailored to the process.

Achieved environmental benefits
No data submitted.

Cross-media effects
No data submitted.

Operational data
No data submitted.

Applicability
No information on the application of SNCR in process gas fired power plants was submitted.

Economics
No data submitted.

Driving force for implementation
No data submitted.

Example plants
No data submitted.

Reference literature
[471]

More information about SNCR can be found in the Large Combustion Plants BREF (LCP) [434], the Waste Incineration (WI) BREF [437] and the Cement, Lime and Magnesium Manufacturing (CLM) BREF [485].

2.5.4 Material management

2.5.4.1 Techniques to improve the use of scrap

Description
EAF and BOF processes require different kinds of ferrous scrap according to different recipes and steel qualities. For this reason, the purchased or internally produced and recycled scrap should be stored separated. Scraps are qualified on the basis of their weight, sizes and chemical analyses. In the scrap terminal, there are separate bunkers for each different kind of scrap.
There are several techniques which can help the operators to refuse scraps which are not suitable for processing because of their content of heavy metals or other unwanted or hazardous substances. Some of these techniques can help the operator in characterising the scrap that is used. The rigour with which this characterisation is carried out is essential to the subsequent operations (e.g. EAF, BOF). Failure to adequately screen and respect the acceptance procedures may cause unexpected emissions profiles.

Some techniques for improving the use of scrap include:

- specification of acceptance criteria suited to the production profile in purchase orders for scrap
- having a good knowledge of scrap composition by closely monitoring the origin of the scrap; in exceptional cases, a melttest might help characterise the composition of the scrap
- having adequate reception facilities and check deliveries
- having procedures to exclude scrap that is not suitable to be used in the installation
- refusal of scrap supply which contains visibly unacceptable components and assemblies that may contain heavy metals and in particular mercury
- storing the scrap according to different criteria (e.g. size, alloys, degree of cleanliness) on impermeable surfaces with drainage and collection system or applying a roof can reduce the need for such a system
- putting together the scrap load for the different melts taking into account the knowledge of composition in order to use the most suitable scrap for the steel grade to be produced (this is essential in some cases to avoid the presence of undesired elements and in other cases to take advantage of alloy elements which are present in the scrap and needed for the steel grade to be produced)
- prompt return of all internally generated scrap to the scrapyard for recycling
- having an operation and management plan
- scrap sorting to minimise the risk of including hazardous or non-ferrous contaminants, particularly PCBs and oil or grease. This is normally done by the scrap supplier but the operator inspects all scrap loads in sealed containers for safety reasons. Thereby, at the same time, it is possible to check, as far as practicable, for contaminants. Evaluation of the small quantities of plastic (e.g. as plastic coated components) may be required
- removal of components which contain mercury is a requirement of the End of Life Vehicles Directive (2000/53/EC) and Waste Electrical and Electronic Equipment (WEEE) Directive (2002/96/EC). This is an obligation for the scrap processors. The following two measures may help to increase the implementation:
  - fixing the absence of mercury in scrap purchase contracts
  - refusal of scrap which contains visible electronic components and assemblies.

**Achieved environmental benefits**
Knowledge of the quality of scrap increases the possibility of anticipating unexpected emissions. The exclusion of mercury will reduce mercury emissions.

With some of these techniques the maximum amount of scrap used in the BOF was increased from 200 kg/t steel to 250 kg/t steel. A higher degree of scrap in the BOF converter results in an overall improved environmental and energy efficiency.

**Cross-media effects**
No data submitted

**Operational data**
No data submitted
Chapter 2

Applicability
The practice is, in principle, applicable to all BOF and EAF plants which have to classify scrap qualities on the basis of weight and chemical analyses.

Economics
The full recycling of all internally produced scrap and the increase in the overall scrap input can lead to cost savings. Increased steel production means a reduced amount of purchased slabs and better profitability.

Driving force for implementation
Some of the techniques mentioned here can help to increase the steel production, to save costs and to reduce environmental impacts, which represent the driving forces for implementation.

Example plants
Ruukki Production, Raahe Steelworks, Finland
Most of the described techniques are common practice in all European countries for EAF and BOF plants.

Reference literature
[208] [240] [394] [396] [417] [422] [426]

2.5.4.2 Techniques to reduce diffuse and fugitive emissions from materials storage, handling, transport and blending

Description
The BREF on Emissions from Storage (EFS) [435] covers many of these areas in detail and it is strongly recommended that the reader refers to this document details.

In integrated steelworks and electric arc furnace plants, diffuse primary emissions arise from the unloading, storage, handling and transport systems. Secondary dust emissions arise from e.g. the resuspension of dusty materials from storage areas or disposal points, suspension of dust from roadways due to traffic movements and contamination of vehicle wheels and chassis.

Diffuse or fugitive emissions are emitted from the production processes themselves. Information on fugitive and diffuse low-level sources others than material storage, handling and transport e.g. on-site processing of residues, emissions released from insufficient extraction during crushing, screening, charging, melting, tapping, usually referred to as secondary off-gases, can be found in the specific sectors.

Key techniques for minimising fugitive and diffuse dust and particulate matter smaller than 10 microns (PM$_{10}$) emissions for iron and steel works arising from the sources listes above are given below.

General techniques include:
- operation of steelworks under an environmental management system (EMS), which should be externally audited. More specifically, all steelworks should develop and operate to meet a fugitives management plan
- consideration of temporary cessation of certain operations where they are identified as a PM$_{10}$ source causing a high ambient reading. In order to be able to do this, it will be necessary to have sufficient PM$_{10}$ monitors, with associated wind direction and strength monitoring, to be able to triangulate and identify key sources of fine particulate.
Techniques for the prevention of dust releases during the handling and transport of bulk raw materials include:

- orientation of long stockpiles in the direction of the prevailing wind
- installing wind barriers or using natural terrain to provide shelter
- controlling the moisture content of the material delivered
- careful attention to procedures to avoid unnecessary handling of materials and long unenclosed drops
- adequate containment on conveyors and in hoppers, etc.
- the use of dust suppression water sprays, with additives such as latex, where appropriate
- rigorous maintenance standards for equipment
- high standards of housekeeping, in particular the cleaning and damping of roads
- use of mobile and stationary vacuum cleaning equipment
- dust suppression or dust extraction and use of a bag filter cleaning plant to abate sources of significant dust generation
- application of emissions reduced sweeping cars for carrying out routine cleaning of hard surfaced roads.

Techniques for materials delivery, storage and reclamation activities include:

- total enclosure in a building equipped with filtered air extraction of unloading hoppers for dusty materials or the hoppers should be fitted with dust baffles and the unloading grids coupled to a dust extraction and cleaning system
- limiting the drop heights to a maximum of 0.5 m
- use of water sprays (preferably using recycled water) for dust suppression
- where necessary, fitting of storage bins with filter units to control dust
- use of totally enclosed devices for reclamation from bins
- where necessary, storage of scrap in covered and hard surfaced areas to reduce the risk of ground contamination (using “just in time” delivery to minimise the size of the yard and hence emissions)
- minimisation of the disturbance of stockpiles
- restriction of the height and a controlling of the general shape of stockpiles
- use of in-building or in-vessel storage, rather than external stockpiles, if the scale of storage is appropriate
- creation of windbreaks by natural terrain, banks of earth or planting of long grass and evergreen trees in open areas. This not only has aesthetic benefits, but such vegetation is able to capture and absorb dust without suffering long-term harm
- hydro-seeding of waste tips and slag heaps
- implementation of a “greening” of the site by covering unused areas with top soil and planting grass, shrubs and other ground covering vegetation which will minimise dust lift-off from these areas
- moistening of the surface using durable dust-binding substances
- covering of the surface with tarpaulins or coat (e.g. latex) stockpiles to minimise dust lift-off
- application of storage with retaining walls to reduce the free surface.
Where fuel and raw materials are delivered by sea and dust releases could be significant, some techniques include:

- use by operators of self-discharge vessels or enclosed continuous unloaders. Otherwise, dust generated by grab-type ship unloaders should be minimised through a combination of ensuring adequate moisture content of the material as delivered, by minimising drop heights and by using water sprays or fine water fogs at the mouth of the ship unloader hopper
- avoiding seawater in spraying ores or fluxes as this results in a fouling of sinter plant electrostatic precipitators with sodium chloride. Additional chlorine input in the raw materials may also lead to rising emissions (e.g. of PCDD/F) and hamper filter dust recirculation
- storage of powdered carbon, lime and calcium carbide in sealed silos and conveyed pneumatically or stored and transferred in sealed bags since they are highly drift sensitive and need to be kept dry.

Train or truck unloading techniques include:

- use of dedicated unloading equipment with a generally enclosed design

For highly drift-sensitive materials which may lead to significant dust releases, some techniques include:

- use of transfer points, vibrating screens, crushers, hoppers and the like, which may be totally enclosed and extracted to a bag filter plant
- use of central or local vacuum cleaning systems rather than to washing down for the removal of spillage, since the effects are restricted to one medium and the recycling of spilt material is simplified.

Techniques for handling and processing of slags include:

- keeping stockpiles of slag granulate damp for slag handling and processing since dried blast furnace slag and steel slags can give rise to dust
- use of enclosed slag crushing equipment fitted with bag filters.

Techniques for handling scrap include:

- providing segregated scrap storage under cover and with concrete floors and walls to minimise dust lift-off caused by all vehicle movements.

Techniques to consider during material transport include:

- minimisation of points of access from public highways
- employment of wheel-cleaning equipment to prevent the carryover of mud and dust onto public roads
- application of hard surfaces to the transport roads by concrete or asphalt to minimise the generation of dust clouds during materials transport and the cleaning of the roads
- restriction of vehicles to designated routes by fences, ditches or banks of recycled slag
damping of dusty routes by water sprays, e.g. at slag handling operations
- ensuring that transport vehicles are not overfull, so as to prevent any spillage
- ensuring that transport vehicles are sheeted to cover the material carried
- minimisation of numbers of transfers
- using closed or enclosed conveyors
- use of tubular conveyors, where possible, to minimise material losses by changes of direction across sites usually provided by discharge of materials from one belt onto another
- good practice techniques for molten metal transfer and ladle handling
- dedusting of conveyor transfer points.
Achieved environmental benefits
The environmental benefit of the use of techniques for reducing diffuse and fugitive emissions from materials storage, handling, transfer and blending is the prevention of dust emissions.

Cross-media effects
No data submitted.

Operational data
No data submitted.

Applicability
No data submitted.

Economics
No data submitted.

Driving force for implementation
No data submitted.

Example plants
All UK iron and steel plants

Reference literature
[240] [512]

2.5.4.3 Techniques to control releases to water from raw materials handling, blending and mixing

Description
Rainwater runoff from all open areas, but in particular from ores, coal and raw material stocking areas, will contain suspended solids. This rainwater runoff should be intercepted and the suspended solids removed by settlement or other techniques. Arrangements should be made for monitoring the quality of the water discharged from the storage and blending areas where such discharges are in the vicinity of potentially vulnerable receptors.

Areas for the handling and storage of purchased scrap are potential sources of contaminated effluent due to the leaching of oil and chemicals by rainwater. The scrap should be stored on hard surfaced areas with an impermeable surface and an appropriate drainage system, including an interceptor trap prior to discharge, unless the environmental risk can be shown to be negligible (e.g. storing clean in-house sourced scrap).

Achieved environmental benefits
A reduction of pollution to water is an environmental benefit of this technique.

Cross-media effects
No data submitted.

Operational data
No data submitted.

Applicability
No data submitted.

Economics
No data submitted.
Chapter 2

Driving force for implementation
No data submitted.

Example plants
All UK iron and steel plants

Reference literature
[240]

2.5.4.4 Specialised recycling facilities for iron-rich residues

2.5.4.4.1 OxyCup® shaft furnace

Description
The integrated OxyCup® plant comprises three modular operating parts: brick production, burdening facilities as well as the OxyCup® shaft furnace. The process starts with brick making and ends with hot metal supply to the steel plant. For brick production, sludge and dust from dedusting facilities which contain carbon-, iron- and iron oxide have to be agglomerated together with other lumpy iron-bearing materials and coke. The briquetting is a cold process in which a binder and water as well as coke breeze is added to the fines, they are pressed to briquettes, dried and hardened. The cold bonded, self-reducing bricks are burdened at the top of the shaft furnace and reduced and melted to liquid iron. Hot metal and slag are tapped from the furnace as end-products.

Achieved environmental benefits
The external treatment or landfilling will be mostly replaced by the integrated recycling in an OxyCup® shaft furnace. Another advantage of this method is the similarity to the original production facilities allowing process gases and slag to be integrated into the infrastructure of an integrated plant.

Cross-media effects
No data submitted.

Operational data
The OxyCup® shaft furnace in Duisburg-Hamborn in Germany produces 170000 tonnes of hot metal per year.

Applicability
OxyCup® shaft furnace are especially suited to integrated iron and steel works. This new process is qualified for the processing of all materials, like lumpy skull, but also for fine-grained dusts and sludge with sufficient recyclable potential in terms of their carbon and iron content.

Economics
The OxyCup® plant optimally combines environmental protection and cost efficiency and makes a valuable contribution to sustainable development in order to improve resource efficiency.

Driving force for implementation
Higher ecological and economic efficiency due to sharp increases in prices for raw materials, external treatment as well as waste disposal are the driving forces for implementation.

Example plants
Thyssen Krupp Stahl, Duisburg-Hamborn, Germany

Reference literature
[520] [521] [523]
2.5.4.4.2 DK process

Description
The DK process consists of a sinter plant and a blast furnace. The process differs from typical iron-making processes in the quality of the raw materials, so they require a different pretreatment. More than 80% of the raw materials used in the DK process are dusts and sludges from the blast furnaces and BOF as well as mill scale. In addition, many other iron-rich residues can be and are used.

The first step in the preparation of the raw materials is to sinter them. In this process, dusts, sludges and mill scale are agglomerated as preparation for the burden to the blast furnace. In this agglomeration, the fine material is mixed with lime and coke breeze and a layer is put on a rotating pallet strand. A gas burner in an ignition furnace ignites the coke breeze in the upper layer. Following ignition, the combustion front (with a temperature of over 1300 °C) is drawn downwards through the layer by a suction pressure below the strand. The agglomeration process is finished when the combustion front has reached the bottom of the layer at the end of the strand. Then the agglomerates are removed and sent to a cooler.

After that, the sinter together with coke as a reductant is processed into special foundry pig iron in the blast furnace. The liquid iron is cast on a pig caster and sold to foundries worldwide. Due to the high zinc content in the raw materials (2 - 3% on average) used in the DK process, the sludge cleaned from the blast furnace gas is recovered as a pure zinc concentrate which is used in the zinc industry.

Achieved environmental benefits
The DK process has been used since the beginning of the nineteen eighties when the facilities were adapted to the processing of steelwork residues. Since then, more than 5 million tonnes of waste materials have been processed, making a considerable contribution to environmental protection and to resource efficiency. Proof of the high value of the process is the fact that less than 4% of the waste materials utilised end up as waste that needs to be landfilled.

Cross-media effects
The metallurgical conditions of the agglomeration step can result in PCDD/F in the waste gas. Therefore, the waste gas is treated in several steps.

Zinc, alkalis and lead have an adverse effect on blast furnace operations and therefore special attention should be paid to them. They lead to a higher coke consumption, the formation of accretions and increased wear of the refractory material.

Operational data
- waste residue processing: 500000 tonnes/yr
- pig iron production: 300000 tonnes/yr
- blast furnace slag production: 120000 tonnes/yr
- zinc concentrate production: 20000 tonnes/yr.

Applicability
The DK process can be used for processing dusts and sludges from the BOF and blast furnaces. Furthermore, mill scale and other iron-rich residues can be utilised. The zinc content can be up to 10% (2 - 3% on average).

Economics
The use of pig iron in the foundry industry as well as the zinc concentrate in the zinc industry guarantees a qualitatively high value and long-lasting usage of the products that are created. Landfilling is replaced by the recycling in the DK process.
Driving force for implementation
Avoiding the depositing of waste materials and the promotion of the recycling of iron and zinc residues are the driving forces for implementation.

Example plants
DK Recycling und Roheisen GmbH, Duisburg, Germany

Reference literature
[518] [520] [522]

2.5.4.4.3 Smelting reduction processes

Description
In general the pyrometallurgical smelting reduction of metals from oxidic residues requires a reduction of the relevant oxides (normally using carbon as a reductant) and a subsequent melting to separate the metals from the other slag-forming components.

There are two different types of processes (the Primus® technique and the Redsmelt® process) which are described below.

The Primus technique using a two-step process, consists of the combination of a multiple hearth furnace (MHF) (the Primus® Pre-Reduction Unit) aiming to dry, heat up and initiate reduction followed by an electric arc furnace (EAF) (the Primus® Melting Unit) leading to complete iron reduction and providing hot metal, slag formation and finalise a finalisation of the zinc reduction. This technique permits the treatment of all typical iron and steelmaking residues which cannot normally be recycled within the existing plant, such as EAF dust, BF sludge, steelworks sludge and oily mill scale sludge.

In the MHF, the mix of residues (pre-pelletised if very fine), and coal are charged from the top. Rotating arms stir and transport the charge, which is dropped from one hearth to the next while being dried, preheated and pre-reduced by a countercurrent flowing stream of gas.

The carbon for reduction and the energy for the process are entirely supplied by the volatile coal.

The subsequent melting unit (a specially-designed electric arc furnace) is continuously hot-charged through a chute between the electrodes. Complete reduction, iron and slag melting and full de-zincing are achieved in this electric smelter. Zinc and lead are transferred to the off-gas system and recovered as a marketable zinc oxide concentrate. The iron content of the feed material is recovered as liquid pig iron or tapped in a pig-caster. The resulting slag, similar to blast furnace slag, can be used for road construction.

In the Redsmelt® process, the residues are pelletised together with the carbon reductant (anthracite or low volatile coal), pre-reduced in a single rotary hearth furnace (RHF) and then hot-charged in an electric furnace for melting.

The pellets are uniformly spread on the rotary hearth in a thin layer and are processed in a single furnace revolution, using gas burners for energy supply. This pre-reduction furnace is also followed by an electric smelter.

Achieved environmental benefits
The process achieves total recovery of iron, zinc and lead and a slag which can be used for road construction thus avoiding the landfilling of these process residues.

Cross-media effects
No data submitted.
Operational data
The two types of pre-reduction furnaces (MHF and RHF) have different abilities.

MHF can handle wet and oily materials as well as materials, with a high content of zinc and needs simpler material preparation and consumes less fuel. During transfer through the MHF, the intense mixing of the input materials promotes their rapid heating and hence maximises process productivity. Metal oxides undergo pre-reduction by CO and H$_2$. The energy requirement for the pre-reduction process is basically supplied by the combustion of coal volatiles and the post-combustion of CO evolved during pre-reduction. The following table Table 2.11 gives some operational data for the Primus plant in Differdange in Luxembourg.

<table>
<thead>
<tr>
<th>Data</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple hearth furnace</td>
<td></td>
</tr>
<tr>
<td>Hearth internal diameter</td>
<td>7.7</td>
</tr>
<tr>
<td>Number of hearths</td>
<td>8</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>800 - 1000 °C</td>
</tr>
<tr>
<td>Coal consumption</td>
<td>300 kg/t</td>
</tr>
<tr>
<td>Electric arc furnace</td>
<td></td>
</tr>
<tr>
<td>Vessel internal diameter</td>
<td>3.5 m</td>
</tr>
<tr>
<td>Electrical power</td>
<td>10 MW</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>1500 °C</td>
</tr>
<tr>
<td>Electricity consumption</td>
<td>800 - 900 kWh/t</td>
</tr>
</tbody>
</table>

Table 2.11: Operational data for the PRIMUS plant at Differdange designed for a nominal throughput of 10 t/h

The Primus plant at Primorec S.A, Differdange, Luxembourg consists of a 8 hearth MHF and three-phase AC arc melting furnace, equipped with a full off-gas treatment for zinc recovery. The off-gases from the MHF and the EAF are merged and dedusted by a bag filter. Volatile metals are extracted from the melting and pre-reduction units and recovered in the bag filter. After the injection of lime and activated carbon, a second cleaning step takes place before the emissions are released via the stack. The following Table 2.12 shows the achieved clean gas concentrations for the main directed off-gas flow:
## Table 2.12: Achieved clean gas concentrations for the directed PRIMUS process off-gas (MHF and EAF)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit(^1)</th>
<th>Average (^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
<td>m³/h</td>
<td>113000</td>
</tr>
<tr>
<td>HCl</td>
<td>mg/m³</td>
<td>1.30</td>
</tr>
<tr>
<td>HF</td>
<td>mg/m³</td>
<td>0.09</td>
</tr>
<tr>
<td>CO</td>
<td>mg/m³</td>
<td>295</td>
</tr>
<tr>
<td>NO(_x) as NO(_2)</td>
<td>mg/m³</td>
<td>85</td>
</tr>
<tr>
<td>SO(_2)</td>
<td>mg/m³</td>
<td>10</td>
</tr>
<tr>
<td>TOC</td>
<td>mg/m³</td>
<td>6</td>
</tr>
<tr>
<td>Dust</td>
<td>mg/m³</td>
<td>0.3</td>
</tr>
<tr>
<td>As</td>
<td>mg/m³</td>
<td>&lt;0.0027</td>
</tr>
<tr>
<td>Pb</td>
<td>mg/m³</td>
<td>&lt;0.0064</td>
</tr>
<tr>
<td>Cd</td>
<td>mg/m³</td>
<td>&lt;0.0008</td>
</tr>
<tr>
<td>Cr</td>
<td>mg/m³</td>
<td>&lt;0.0047</td>
</tr>
<tr>
<td>Co</td>
<td>mg/m³</td>
<td>&lt;0.0017</td>
</tr>
<tr>
<td>Cu</td>
<td>mg/m³</td>
<td>&lt;0.0108</td>
</tr>
<tr>
<td>Mn</td>
<td>mg/m³</td>
<td>&lt;0.0035</td>
</tr>
<tr>
<td>Ni</td>
<td>mg/m³</td>
<td>&lt;0.0019</td>
</tr>
<tr>
<td>Hg</td>
<td>mg/m³</td>
<td>0.0621</td>
</tr>
<tr>
<td>Va</td>
<td>mg/m³</td>
<td>&lt;0.0021</td>
</tr>
<tr>
<td>Zn</td>
<td>mg/m³</td>
<td>&lt;0.0567</td>
</tr>
<tr>
<td>Sum heavy metals</td>
<td>mg/m³</td>
<td>0.1534</td>
</tr>
<tr>
<td>PCDD/F (I-TEQ)</td>
<td>ng/m³</td>
<td>0.0001</td>
</tr>
<tr>
<td>PAH (EPA)</td>
<td>µg/m³</td>
<td>0.829</td>
</tr>
<tr>
<td>Sum PCB (^3)</td>
<td>µg/m³</td>
<td>0.072</td>
</tr>
</tbody>
</table>

Measurements from November 2007

\(^1\) related to the volume of waste gas under standard conditions (273 K, 1013 mbar).

\(^2\) Average of three half-hourly mean values.

\(^3\) Sum PCB28, PCB52, PCB101, PCB118, PCB153, PCB180, PCB184, PCB180.

The following Table 2.13 shows the achieved clean gas emission concentrations for the extracted MHF and EAF doghouse off-gas emissions after cleaning by a bag filter. The cleaned off-gas is released via the stack together with the cleaned directed off-gas.
### Table 2.13: Achieved clean gas concentrations for the doghouse PRIMUS process off-gas (MHF and EAF)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Average ²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
<td>m³/h</td>
<td>50000</td>
</tr>
<tr>
<td>HCl</td>
<td>mg/m³</td>
<td>1.06</td>
</tr>
<tr>
<td>HF</td>
<td>mg/m³</td>
<td>0.02</td>
</tr>
<tr>
<td>CO</td>
<td>mg/m³</td>
<td>37</td>
</tr>
<tr>
<td>NOx as NO₂</td>
<td>mg/m³</td>
<td>&lt;4</td>
</tr>
<tr>
<td>SO₂</td>
<td>mg/m³</td>
<td>9</td>
</tr>
<tr>
<td>TOC</td>
<td>mg/m³</td>
<td>6</td>
</tr>
<tr>
<td>Dust</td>
<td>mg/m³</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>As</td>
<td>mg/m³</td>
<td>&lt;0.0060</td>
</tr>
<tr>
<td>Pb</td>
<td>mg/m³</td>
<td>&lt;0.0074</td>
</tr>
<tr>
<td>Cd</td>
<td>mg/m³</td>
<td>&lt;0.0007</td>
</tr>
<tr>
<td>Cr</td>
<td>mg/m³</td>
<td>&lt;0.0040</td>
</tr>
<tr>
<td>Co</td>
<td>mg/m³</td>
<td>&lt;0.0018</td>
</tr>
<tr>
<td>Cu</td>
<td>mg/m³</td>
<td>&lt;0.0111</td>
</tr>
<tr>
<td>Mn</td>
<td>mg/m³</td>
<td>&lt;0.24</td>
</tr>
<tr>
<td>Ni</td>
<td>mg/m³</td>
<td>&lt;0.0028</td>
</tr>
<tr>
<td>Hg</td>
<td>mg/m³</td>
<td>0.0005</td>
</tr>
<tr>
<td>Va</td>
<td>mg/m³</td>
<td>&lt;0.0028</td>
</tr>
<tr>
<td>Zn</td>
<td>mg/m³</td>
<td>&lt;0.044</td>
</tr>
<tr>
<td>Sum heavy metals</td>
<td>mg/m³</td>
<td>0.32</td>
</tr>
<tr>
<td>PCDD/F (I-TEQ)</td>
<td>ng/m³</td>
<td>&lt;0.00013</td>
</tr>
<tr>
<td>PAH (EPA)</td>
<td>µg/m³</td>
<td>43.8</td>
</tr>
<tr>
<td>Sum PCB ³)</td>
<td>µg/m³</td>
<td>&lt;0.07</td>
</tr>
</tbody>
</table>

Measurements from November 2007

1) Related to the volume of waste gas under standard conditions (273 K, 1013 mbar).
2) Average of three half-hourly mean values.

A RHF can work at a higher temperature (as material sticking is not as problematic with unstirred materials), therefore a higher metallisation degree can be achieved with it. Moreover, as it can be built up to a very large diameter, the capacity for a single unit can be much greater.

**Applicability**

The Primus® Process permits the treatment of all typical iron and steel, making residues and additionally non-ferrous metals residues. It can be applied by a mini-mill and integrated steelworks operators who wants to reduce waste disposal costs and who want to efficiently recycle residues.

**Economics**

No data submitted.

**Driving force for implementation**

Avoiding the depositing of waste materials and the promotion of the recycling of iron and zinc residues are the driving forces for the implementation of this technique.
Chapter 2

Example plants

- Primus plant at Primorec S.A, Differdange, Luxembourg which processes 60000 tonnes EAF dust and 15000 tonnes of rolling mill sludge per year
- Dragon Steel Company, Taiwan decided on the implementation of a 100000 tonnes per year Primus® plant aiming to treat EAF dust, blast furnace sludge as well as mill scales. The plant started in April 2009
- several RHF installations are in operation in Japan
- the first European plant is being operated at the Lucchini steelworks in Piombino, Italy, processing 60000 tonnes per year of integrated steelmaking sludge. The installation will be started in the summer 2009. In this case, the melting step will be done in the blast furnace of the Lucchini plant.

[470] [471]

Reference literature
[470] [471] [519] [520]

2.5.4.4.4 Cold bonded pellets/briquettes

Description
In some integrated steelworks in Europe the blast furnace burden consists mostly of pellets supplied from outside of the works and no sinter is used. Under these circumstances, ore fines can be generated from handling and screening operations that if agglomerated could be returned to the ironmaking process. One means of returning these ore fines to the ironmaking operation together with other materials which contain Fe and/or carbon arising in the works is to agglomerate them using cold bonding techniques.

Two types of cold bonded agglomerates are made: one briquette type with the materials which contain carbon such as blast furnace (BF) off-gas dust and coke breeze, and one briquette type with materials which contain iron such as pellets fines, fine scrap, mill scale, other filter dusts, etc. The briquettes are produced in a block-making machine with cement as a binder.

The production and use of cement bonded briquettes started around 1975 and since 1993 these briquettes have become an important constituent of the BF burden (about 40 - 50 kg/t of hot metal in Sweden in 2004). The amount of briquettes used is largely dependent on the availability of in-plant materials but there is past experience with amounts above 100 kg/t of hot metal in the burden. The block machine technique started operation in 1993 at SSAB Tunnplåt and in 1996 at SSAB Oxelösund [208].

The use of a briquetting plant is an established technique and consists of a raw material handling station, a block-making machine and a curing chamber. The materials handling part includes silos for fines of dry dust and binders, bins for coarser, damp material and a mixer. The briquetting blend is transported to the block-making machine and the briquettes produced are transferred to the curing chamber. After 24 hours of curing, the hardening of the briquettes is completed with over three weeks outdoors before they are charged to the blast furnace.

Achieved environmental benefits
Cold bonding techniques do not emit SOX and NOX. Cold bonded pellets/briquettes cannot completely replace sinter or pellet agglomerates.

Cross-media effects
The return of in-plant fines decreases the potential requirement for deposit to landfill and the use of virgin material.
Operational data
No data submitted.

Applicability
These techniques could be applied at any integrated plant but are most suited for works without sinter plants. The production of briquettes is a conventional technique and their use in the BF burden is reliable and well established.

Economics
The economic particulars are known, but the recovery of valuable iron units and the avoidance of costs associated with disposal are strong econometric drivers.

Driving force for implementation
The driving forces for implementation are environmental benefits and the savings of space and costs for landfill as well as the cost of a sinter plant.

Example plants
At presents, the following three works operate cold bonded briquettes schemes to return materials to the blast furnace:

- SSAB Tunnplåt AB, Luleå, Sweden
- SSAB Oxelösund AB, Sweden

Reference literature
[29] [208]

2.5.5 Monitoring in iron and steel plants
[424]

2.5.5.1 Continuous parameter and air emissions monitoring

Description
In modern steelworks, most processes are monitored and controlled from control rooms by means of modern computer-based systems. In order to optimise the processes, to increase energy efficiency and maximise the yield-relevant parameters should be determined and adjusted continuously on-line.

Additional continuous monitoring of emissions from relevant sources allows for accurate quantification of the emissions and in the case of poor performance of abatement systems for taking prompt action.

Important parameters which should be measured continuously in the iron and steel manufacturing processes include:

- pressure
- temperature
- O₂ content
- CO
- input material flows
- output material flows.

Additional information on the description of continuous monitoring systems can be found in the BREF on General Principles of Monitoring (MON) [505].
Chapter 2

Achieved environmental benefits
In the case of poor performances of the abatement systems, prompt action can be taken. Overall emission can be reduced. Continuous measurements allow for accurate quantification of the emissions from relevant sources.

Cross-media effects
Continuous measuring allows to optimise the production processes, to minimise the energy demand and to maximise the yield.

Operational data
No data submitted.

Applicability
For large emission sources at integrated steelworks, the main pollutants are usually monitored continuously.

Economics
No data submitted.

Driving force for implementation
No data submitted.

Example plants
Monitoring concepts for continuously measured air emissions for Voestalpine Stahl, Linz, Austria is presented in Table 2.14 (if not indicated differently; limits are based on half-hour average values). The data is transferred on-line to the local authorities. Annual emissions reports including data evaluation should be provided to local authorities [513].

<table>
<thead>
<tr>
<th></th>
<th>Dust</th>
<th>NOx</th>
<th>SO2</th>
<th>CO</th>
<th>H2S</th>
<th>HF</th>
<th>Reference</th>
<th>O2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coke oven</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>H2S in coke oven</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulphuric acid plant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Sinter plant</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sinter strand</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dedusting of building</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Blast furnaces</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cast house dedusting BF 5 &amp; 6</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Cast house dedusting BF A</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>BOF plant</td>
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<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Dedusting Unit 1</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Dedusting Unit 2.1</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Second dedusting 2.1</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Second dedusting 2.2</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
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<td>X</td>
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<td></td>
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<tr>
<td>Gas and steam turbine</td>
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<td>X</td>
<td>X</td>
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<tr>
<td>Unit 6</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

X: Hourly average value.
2) Ref. 06/2007, the current emission limit value is under revision. Continuous measurement should be performed for SO2 emissions.
Notes: Status 06/2007. Emissions which are measured discontinuously are not included in the table. Permit conditions might change in the course of the actual environmental impact assessment ‘Voestalpine L6’. Where limit values have been set up are marked with an X (based on half-hour average values).

Table 2.14: Monitoring concepts for continuously measured air emissions
In the UK, the coke ovens for dust emissions from underfiring are monitored continuously by obscurcation meters and in sinter plants the dust emissions are monitored continuously. In blast furnaces, monitoring of the cooling water flow is of relevance. SO\textsubscript{X}, NO\textsubscript{X}, PM and CO are monitored on hot stove releases. Releases of dust from cast houses are monitored.

Reference literature
[242] [424] [513]

2.5.5.1.1 Continuous measurement of dust emissions from secondary dedusting systems in basic oxygen furnaces

Description
The monitoring system at SSAB Oxelösund AB, Sweden allows a continuous control of the bag filter performance. The measurement results are reported daily, weekly and monthly. The BOF operations (charging, blowing, tapping) are very closely controlled.

A continuous dust measurement system is installed in the exhaust gas system after the secondary dedusting filter. There are two instruments for measuring dust emissions in the channels after the secondary dedusting filter and two in the roof openings as well. The measuring principle is gravimetric (mg/Nm\textsuperscript{3}). The equipment are calibrated once per year by an external company. The collected data are saved in SSABs own database. The control of the bag filter function is done by SSABs own operators. Revision is made once per year. The fluorescence method is used to detect leakage.

Dust emissions from the LD furnace (BOF) (excluding primary off-gas) are also closely monitored and reported as an environmental performance during three separate process phases: charging, blowing and at other times.

Achieved environmental benefits
In the case of poor performances of the secondary dedusting system, prompt action can be taken. Overall emissions can be reduced. Figure 2.18 shows the weekly averages which has been achieved with the aforementioned monitoring system over a period of one year.
Figure 2.18: Dust quantity from secondary dedusting system presented as weekly averages [208]

Cross-media effects
No data submitted.

Operational data
The system calibration according to the measured values happens once a year. The calibration period takes two days.

Applicability
The technique is applicable both for existing and new steel plants.

Economics
No data submitted.

Driving force for implementation
No data submitted.

Example plants
SSAB Oxelösund AB, Sweden.

Reference literature
[208]
2.5.5.1.2 Continuous monitoring after bag filters in EAF plants

Description
The EAF steelworks consist of a whole building evacuation and a separate dust suction from the EAF itself. Scrap preheating is used, mainly because of snow and ice. The filter plant installation is equipped with efficient spark arresting and cyclones, from which the dust (>5 micron, 30% of the total amount) is charged back to the EAF together with the scrap. The main fans (average 620000 Nm³/h) have a rotation speed control. The bag house has a conservative (large) dimensioning (9400 m²) and the filter bags are a normal needle felt type with PTFE coating. The filter bags are cleaned with a pulse-jet system.

Continuous monitoring and a careful service of the bag house works in the following ways:

- it monitors dust emissions, no real calibration. It is important to detect any change of emissions level (leakage in one bag can immediately be detected)
- it continuously monitors via two separate instruments:
  - a tribometric measuring system, SINTROL
  - an optical measuring system, SICK [360]
- it visually checks all bags for spark holes and intensity: every second week, one worker for three hours. The "clean" side of the bags should be kept totally clean. Holes of 1 mm diameter can be detected without difficulty so no fluorescense method is needed.

Achieved environmental benefits
In the case of poor performances of the bag filter system, prompt action can be taken. Overall emissions can be reduced.

Cross-media effects
This measure also provides clean surroundings inside and outside of the steel plant.

Operational data
No data submitted.

Applicability
The monitoring system is well applicable to both existing and new plants.

Economics
No data submitted.

Driving force for implementation
The driving forces for implementation are environmental benefits.

Example plants
Ovako Imatra, Finland.

Reference literature
[208] [242]
2.5.5.2 Monitoring of process gases

Description
At Voestalpine Stahl, Linz, Austria the monitoring of process gases is required according to the permit of the environmental impact assessment. Table 2.15 presents the conditions of the permit. Data is regularly transferred to the local authorities.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Blast furnace gas</th>
<th>Coke oven gas</th>
<th>BOF gas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Continuous</td>
<td>Discont.</td>
<td>Continuous</td>
</tr>
<tr>
<td>H₂</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>CO</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>CO₂</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Hydrocarbons</td>
<td>x ³)</td>
<td></td>
<td>x ³)</td>
</tr>
<tr>
<td>N (chem. bond)</td>
<td>x ³)</td>
<td></td>
<td>x ³)</td>
</tr>
<tr>
<td>Cl (total)</td>
<td>x ³)</td>
<td></td>
<td>x ³)</td>
</tr>
<tr>
<td>S (total)</td>
<td>x ³)</td>
<td></td>
<td>x ³)</td>
</tr>
<tr>
<td>Hg</td>
<td>x ³)</td>
<td></td>
<td>x ³)</td>
</tr>
<tr>
<td>Pb</td>
<td>x ³)</td>
<td></td>
<td>x ³)</td>
</tr>
<tr>
<td>Cr</td>
<td>x ³)</td>
<td></td>
<td>x ³)</td>
</tr>
<tr>
<td>Cd</td>
<td>x ³)</td>
<td></td>
<td>x ³)</td>
</tr>
<tr>
<td>Ni</td>
<td>x ³)</td>
<td></td>
<td>x ³)</td>
</tr>
<tr>
<td>F (total)</td>
<td>x ³)</td>
<td></td>
<td>x ³)</td>
</tr>
<tr>
<td>Dust (total)</td>
<td>x ³)</td>
<td></td>
<td>x ³)</td>
</tr>
</tbody>
</table>

¹) Contents of heavy metals (Hg, Pb, Cr, Cd, Ni), dust and fluorides have to be measured discontinuously, typically 4 times per year (status 06/2007).
²) No limit values are set (status 06/2007).
³) Continuous measurements should be performed under the condition that approved instruments are available on the market (status 06/2007) [513].
⁴) As of 06/2007, no instruments for continuous measurements were available for Cl (total) and N (chem. bond). As regards hydrocarbons, CH₄ and higher hydrocarbons were measured discontinuously. Methods for continuous measurements of S (total) are still under evaluation. For discontinuous measurements, intervals are set in depending on the parameter, typically monthly; voestalpine, Linz, Austria [513].

Table 2.15: Permit conditions for the monitoring of process gases status 06/2007 [424] [513]

Achieved environmental benefits
The monitoring of process gases provides information about the composition of process gases and about indirect emissions from the combustion of process gases, such as emissions of dust, heavy metals and SO₂.

Cross-media effects
The quality (calorific value and cleanliness) and volume of the different process gases vary significantly and these factors have an impact on where the fuels can be usefully used. To optimise energy efficiency, it is necessary that each fuel gas is consumed at the most appropriate plant. For this reason, gases have to be analysed continuously.

Operational data
No data submitted.

Applicability
This techniques is considered to be generally applicable.

Economics
No data submitted.

Driving force for implementation
No data submitted.
Example plants
Voestalpine Stahl, Linz, Austria

Reference literature
[424]

2.5.5.3 Discontinuous air emissions monitoring

Description
Regular, periodic discontinuous measurements at relevant channelled sources have to be carried out for the following pollutants (some of them as a total and their relevant chemical oxidation states):

- TOC
- CO
- Heavy metals such as Hg, Tl, Cd, As, Co, Ni, Se, Te, Pb, Cr, Cu, Mn, V, Sn
- VOC
- NMVOC
- H₂S
- HCl
- HF
- CN
- NH₃
- PCDD/F
- BTX
- PAH (e.g. EPA 16, Borneff 6)
- PCB (e.g. Ballschmiter PCBs, WHO-TEF, total PCB).

However, it is also possible to measure and monitor TOC, NH₃, HCl, and HF continuously and to sample PCDD/F and PCB continuously for analysis from 1 to 30 days. Furthermore, continuous Hg monitoring is carried out recently.

The measuring frequency varies very strongly across the Member States. The resulting emission value should be regarded as an average over the sampling period, normally at least half an hour. For PCDD/F, the sampling period is usually between 6 and 8 hours.

Table 2.16 gives some examples of important measuring methods for discontinuous emission monitoring.

<table>
<thead>
<tr>
<th>Component in the flue-gas</th>
<th>Measuring method</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO₂</td>
<td>VDI 2462</td>
</tr>
<tr>
<td>H₂S</td>
<td>VDI 3486</td>
</tr>
<tr>
<td>NOₓ as NO₂</td>
<td>VDI 2456</td>
</tr>
<tr>
<td>CO</td>
<td>VDI 2459</td>
</tr>
<tr>
<td>Dust</td>
<td>ON EN 13824; Ö-NORM M 5861, VDI 2066</td>
</tr>
<tr>
<td>TOC</td>
<td>DIN EN 12619, VDI 3481 part 1</td>
</tr>
<tr>
<td>HCl</td>
<td>DIN EN 1911, VDI 3480,</td>
</tr>
<tr>
<td>HF</td>
<td>VDI 2470 part 1</td>
</tr>
<tr>
<td>NH₃</td>
<td>VDI 3496</td>
</tr>
<tr>
<td>Metals (As, Cd, Co, Cr, Cu, Hg, Mn, Ni, Pb, Sb, Se, Tl, V, Zn)</td>
<td>VDI 3868</td>
</tr>
<tr>
<td>Hg</td>
<td>DIN EN 13211</td>
</tr>
<tr>
<td>PCDD/F</td>
<td>VDI 3499 part 1</td>
</tr>
<tr>
<td>PAH</td>
<td>3873 part 1</td>
</tr>
</tbody>
</table>

Table 2.16: Examples of measuring methods
[200] [424]
Chapter 2

Achieved environmental benefits
No data submitted.

Cross-media effects
No data submitted.

Operational data
No data submitted.

Applicability
Discontinuous measuring and the corresponding measuring methods are considered to be generally applicable.

Economics
No data submitted.

Driving force for implementation
No data submitted.

Example plants
Voestalpine Stahl, Linz, Austria

In the UK in sinter plants, NO\textsubscript{X} and SO\textsubscript{X} are monitored quarterly. Dioxin monitoring is carried out between two and four times per year [242].

Reference literature
[242] [424]

2.5.5.4 Monitoring of PCDD/F

Description
[209]

For the determination of dioxin and dioxin-like PCB loads in flue-gas, different methods exist. The sampling conditions and the analysis method to be used depend on the existing process and the flue-gas parameters. Substantial parameters are:

- the dioxin concentration range
- dust load of the flue-gas
- temperature range
- amount of carbon particles in the flue-gas
- changing process conditions, e.g. continuous or batch process; unsteady operation, etc.
- potential of memory effects.

For manual sampling, EN 1948 is the European standard guideline. The guideline describes the determination of the mass concentration of dioxins and dioxin-like PCBs from stationary sources. This guideline is developed and validated for waste incineration plants to check the compliance to the emission limit value of 0.1 ng I-TEQ/m\textsuperscript{3}. In many European countries, EN 1948 is the basis for national standard guidelines for the determination of the dioxin emissions (e.g. CSN EN 1948; DIN EN 1948 and VDI of 3499, etc.) VDI 3499 parts 1 - 3 is the German standard guideline for the determination of dioxin emissions from stationary sources. The guideline describes two measurement procedures:
Part A is an example for application of DIN EN 1948 for PCDD/F-emissions at levels of about 0.1 ng I-TEQ/m³.

In Part B the measurement method is modified for PCDD/F concentrations in excess of 0.1 ng I-TE/m³. Only the determination of PCDD/F content of flue-gases is validated. The determination of other organic pollutants (e.g. PCB) is possible as well, but is not yet validated.

EPA 23 A is the manual sampling method valid in the US, which is likewise developed for the determination of the dioxin emissions from stationary sources of waste incineration plants.

Besides EN 1948, there are further standardised sampling methods which are used in the EU. For example VDI 3499, part 1 - 3 and EPA 23 A.

Achieved environmental benefits
In the cases of poor performances of the abatement systems, prompt action can be taken.

Overall PCDD/F emissions can be reduced.

Cross-media-effects
No data submitted

Operational data
For PCDD/F, the sampling period is usually between 6 and 8 hours.

Applicability
In practice, the manual (discontinuous) standardised and validated measurement methods (e.g. EN 1948) are used. These measurement methods, developed for waste incineration plants, are transferable to the metallurgical industry and are already in use there.

Regular periodic discontinuous measurements at relevant sources are generally applicable.

Economics
The measurement costs are estimated to be much lower than the gross margin or production costs of enterprise. The metallurgical industry, generally speaking, can afford the cost of any reasonable measurement requirement. Table 2.17 gives the costs for sampling and analysing of PCDD/F and dioxin like PCBs.

<table>
<thead>
<tr>
<th>Method</th>
<th>Cost range (EUR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual sampling according to EN 1948 - 1 sample (one day) inclusive PCDD/F analysis without travel cost</td>
<td>1800 - 3500</td>
</tr>
<tr>
<td>Manual sampling according to EN 1948 - 3 samples (three days) inclusive PCDD/F analysis without travel cost</td>
<td>4000 - 6500</td>
</tr>
<tr>
<td>PCDD/F – analysis (EN 1948)</td>
<td>450 - 800</td>
</tr>
<tr>
<td>Dioxin-like PCB – WHO PCB (EN 1948)</td>
<td>110 - 600</td>
</tr>
</tbody>
</table>

Table 2.17: Total cost for a PCDD/F measurement according to EN 1948

Driving force for implementation
Driving forces for implementation are to reduce the uncertainty on current dioxin emission data, in the iron and steelmaking industry and to ensure an appropriate awareness and monitoring of dioxin emissions by competent authorities at the national, regional and local level.

Example plants
Table 2.18 presents requirements for dioxin monitoring in several Member States [209].
Table 2.18: Monitoring requirements for PCDD/F in the metallurgical industry in different Member States

<table>
<thead>
<tr>
<th>MS</th>
<th>Limit values</th>
<th>Monitoring frequency</th>
</tr>
</thead>
</table>
| Austria       | • National ELV: iron and steel installations, new sinter plants. Units in ng I-TEQ/Nm³.  
• Other plants: case by case | one time every three years for iron and steel plants, for sinter plants one time every three years (one time every six years if very low) |
| Belgium       | • ELV for existing metallurgical plants, Sinter plants and guide. Units in I-TEQ/Nm³  
• ELV for new plants and guide. Units in I-TEQ/Nm³ | three times per year according to law,  
one time every month for sinter plants,  
six times a year for EAF |
| France        | Case by case limits for all potential metallurgical dioxin sources            | one time a year at least                                   |
| Germany       | • General ELV. Unit in I-TEQ/Nm³ or µg/h  
• Particular ELV: sinter plant with a target | one time a year to one time every three years              |
| Luxembourg    | EAF                                                                          | one – two every year + one – two additional measurements |
| Netherlands   | Case by case                                                                 | no information; criterion: raw gas > 2 g I-TEQ/yr         |
| Slovenia      | Case by case                                                                 | one time a year                                           |
| United Kingdom|                                                                              | dioxin monitoring is carried out between two and four times per year |

Reference literature
[209] [242] [424]

2.5.5.5 Monitoring of diffuse and fugitive emissions
[415]

Fundamentals of diffuse emissions of gases, odours and dusts are described in VDI 3790 part 1 "Emissions of gases, odours and dusts from diffuse sources – fundamentals". This includes the characterisation of diffuse emission sources, the formation of diffuse emission, the definition of source strengths and usual emissions factors, the technical measurement and the determination of diffuse dust emissions from storage and transhipment of bulk materials [517].

Diffuse emissions in principle can be measured by [500]:

- direct measurement methods where the emissions are measured at the source itself. In that case, concentration and mass streams can be measured or determined
- indirect measurement methods where the emission determination takes place in a certain distance from the source. A direct measurement of mass stream and concentration is not possible
- calculation with emission factors.
2.5.5.5.1 Direct or quasi-direct measurement

Examples for direct measurements are measurements in wind tunnels, with hoods or other methods like the quasi-emissions measurement, i.e. on the roof of an industrial installation. In this case, the wind velocity and the area of the roofline vent is measured and a flowrate is calculated. The cross-section of the measurement plane of the roof-line vent is subdivided into sectors of identical surface area (grid measurement). The sampling equipment employed must be designed for infinitely variable suction control. By selecting different sampling probe diameters, the sample flowrate can be adapted to the prevailing off-gas flow velocity. The dust in the gas streams is collected on a filter medium and determined by gravimetric methods. Together with the off-gas evaluation, a dust concentration and a dust mass stream can be derived [500]. If a cascade impactor is used, different size fractions can be determined. If feasible, direct measurements should be preferred to indirect ones.

Four specific methods were applied to measure diffuse emissions both along the bag house and the building evacuation in two electric arc furnace plants.

- the first one, DEKATI cascade impactor is based on inertial classification
- the second one, DSI spectrometer, is based on diffusive and inertial classification
- the third one, laser diffractometer, is based on an optical classification
- and the last one, ELPI low pressure impactor, is based on electric and inertial classification.

Any of these methods gives the size distribution and concentration of particulate matter (PM$_{0.1}$, PM$_1$, PM$_{2.5}$, and PM$_{10}$) which also indicates their relevance for the air quality. Implementing one of these methods indirectly allows a better control over diffuse emissions. [415]

In [500], measurements have been carried out on a stainless steel manufacturing plant before and after the emission collection system at the converter was

- newly designed
- optimised by enlarged hoods and increased exhaust gas volume
- and the replacement of a venturi scrubber by a bag filter.

The dust measurements were carried out according to the VDI 2463 part 1 "Particulate matter measurement – gravimetric determination of mass concentration of suspended particulate matter in ambient air – general principles". The results showed, that the diffuse dust emissions have been reduced by 50 %. The PM$_{10}$ portion on the total dust is approx. 70 %. Cr and Ni have been mitigated accordingly. Metal fumes are much better collected than before.

2.5.5.5.2 Indirect measurements

Examples of indirect measurements are such using tracer gases, the reverse dispersion modelling methods (RDM) and the mass balance method.

Methods using tracer gases includes:

- the release of a known amount of a gas which is not emitted by the source to be examined
- concentration measurements downwind of the spring
- A good representation of the geometry of the source.
The reverse dispersion modelling (RDM) method includes:

- integral or selective concentration measurements
- realisation of a propagation calculation with a fictive source strength
- measurement of meteorological parameter necessary at the time of the measurements
- realisation of back calculation
- validating of the RDM with the help of gas release emission tests.

For both the tracer gas method and the RDM method, SF6 is often used as a tracer gas. The concentration measurement can be carried out, e.g. by remote atmospheric measurements near ground with Fourier transform infrared (FTIR) spectroscopy.

In [500] two examples using the RDM method are given to evaluate benz(a)pyrene (BaP) emissions from a coke plant. In one case, the evaluation is based on BaP concentration measurements in 750 m distance. The RDM is based on a Gauss-Lagrange model without consideration of the influence of buildings and the plant geometry on the dispersion modelling. In the other case, the evaluation is based on BaP concentration measurements in 200 m distance. The RDM is based on an Euler model with consideration of the influence of buildings and the plant geometry on the dispersion modelling. In both cases, the average daily value for the emission rate was estimated to be in the range of 5 - 35 mg BaP/t of coke. With the use of standard emission factors, the emission rate can be calculated to be in the range of 10 - 25 mg BaP/t of coke (see 5.2.2.1).

The mass balance method includes:

- determining a reference area and measuring area on the upwind and downwind side of the plant to be measured
- measurement of the concentrations in several layers within these areas
- calculation and/or measurement of the wind velocities and wind directions at the places of the measurement
- calculation of the local mass flows by multiplication of concentration values and the velocity contributions perpendicularly to the planes of measurement
- integration of the mass flows over the reference area and the measuring area
- calculation of the emission rate by computing the difference of the integrated mass flows.

Light detection and ranging (LIDAR) is an optical remote sensing technology that measures properties of scattered light to find the range and/or other information of a distant target.

Short laser pulses are sent into the atmosphere and the scattered back radiation is registered and evaluated. Measurements in horizontal and vertical directions allow to determine both the expansion of a pollutant cloud and the concentration distribution of substances in the cloud. Remote measuring with LIDAR is often used for the concentration measurements in the different layers (see aforementioned list – second bullet).

The source strengths of gaseous emissions from an aera source and from smaller 3D sources can be determined using optical remote measuring procedures with an error of approx. 30 %. The tracer gas method and reverse dispersion modeling method show comparable results. Diffuse emissions from large 3D sources can be quantified with the help of remote measuring with LIDAR and the mass balance method.

Reference literature
[500] [514] [515] [516]
2.5.5.3 Calculation of emissions with emissions factors

Estimation methods for diffuse dust emissions from bulk material storage, handling and transshipment

VDI 3790 part 3 Environmental meteorology – "Emission of gases, odours and dusts from diffuse sources – storage, transshipment and transportation of bulk materials" [482] includes the characterisation of diffuse sources, definition of terms like emission rate and emission factor. The main part of this guideline describes how dust emission factors can be evaluated for the storage and handling of bulk materials and for the suspension of dust from roadways due to traffic movements taking into account site-specific characteristics, like loading and unloading devices, windspeed, drift sensitiveness of the handled materials, etc. The guideline also gives general emission factors for storage and handling.

Additional information can be found in the Reference Document on BAT on Emissions from Storage (EFS) [435] and it is strongly recommended that the reader consider this document.

Estimation method for diffuse emissions from coke ovens

Fugitive emissions occur from the ascension pipe and charging hole sealings and from the oven doors and frame seals during coking. Different methods for estimating these fugitive emissions from coke ovens are in use and all of these methods have one thing in common: experienced or certified observers visually determines the emissions.

From these results, achieved emission levels are expressed as a frequency of leaking percentage of the total number of ascension pipes and charging holes showing visible leaks) or mass/time depending on the monitoring method. For example, the EPA 303 method enables the results from the observation procedure to be expressed in percentages of leakage.

However, the DMT (Deutsche Montan Technologie GmbH) methodology, which is, to a large extent consistent with the EPA method, allows for emissions per day based on basic measurements to be calculated, assigning four different degrees of strength to the emissions and taking the duration of the visible emissions during the observation into consideration. Another method was developed by BCRA (British Carbonization Research Association). In contrast to the DMT method, the visible emissions are assigned five different degrees of strength. Another method which is used at Corus Ijmuiden in the Netherlands is described in Section 5.3.3.

One method for describing procedures for the measurement of volatile organic compounds fugitive emissions is the EPA method 21. A complete methodology for a comprehensive inventory of the leaks and the further management of fugitive emissions is described in [216].

2.5.5.6 Monitoring the discharge of waste water

Monitoring the discharge of waste water includes taking representative samples of waste water and analysing them. A great variety of standardised procedures exist for sampling and analysing of water and waste water.

Taking of samples can be carried out by:

- a random sample which refers to a single sample taken from a waste water flow
- a composite sample, which refers to a sample which is taken continuously over a given period, or a sample consisting of several samples taken either continuously or discontinuously over a given period and blended
- a qualified random sample shall refer to a composite sample of at least five random samples taken over a maximum period of two hours at intervals of no less than two minutes, and blended.
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The emission concentration in the waste water which has been reported for relevant processes in this document refer either to qualified random samples or to 24-hour composite samples. The associated BAT-AEL therefore also refer to random samples or to 24-hour composite samples.
2.6 General Best Available Techniques

In understanding this section and its contents, the attention of the reader is drawn back to the Preface of this document and in particular the fifth section of the Preface: ‘How to understand and use this document’. The techniques and associated emission and/or consumption levels, or ranges of levels, presented in this section have been assessed through an iterative process involving the following steps:

- identification of the key general environmental issues in the iron and steel industry such as environmental management systems, energy management, material management including diffuse emissions from storage, handling and transfer and the recovery of iron rich production residues, waste water management, monitoring, decommissioning and noise
- examination of the techniques most relevant to address those key issues
- identification of the best environmental performance levels, on the basis of the available data in the European Union and worldwide
- examination of the conditions under which these performance levels were achieved; such as costs, cross-media effects, main driving forces involved in implementation of this techniques
- selection of the best available techniques (BAT) and the associated emission and/or consumption levels for this sector in a general sense all according to Article 2(12) and Annex IV to the Directive.

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

On the basis of this assessment, techniques, and as far as possible emission and consumption levels associated with the use of BAT, are presented in this section that are considered to be appropriate to the sector as a whole and in many cases reflect current performance of some installations within the sector. Where emission or consumption levels ‘associated with best available techniques’ are presented, this is to be understood as meaning that those levels represent the environmental performance that could be anticipated as a result of the application, in this sector, of the techniques described, bearing in mind the balance of costs and advantages inherent within the definition of BAT. However, they are neither emission nor consumption limit values and should not be understood as such. In some cases it may be technically possible to achieve better emission or consumption levels but due to the costs involved or cross-media considerations, they are not considered to be appropriate as BAT for the sector as a whole. However, such levels may be considered to be justified in more specific cases where there are special driving forces.

The emission and consumption levels associated with the use of BAT have to be seen together with any specified reference conditions (e.g. averaging periods).

The concept of ‘levels associated with BAT’ described above is to be distinguished from the term ‘achievable level’ used elsewhere in this document. Where a level is described as ‘achievable’ using a particular technique or combination of techniques, this should be understood to mean that the level may be expected to be achieved over a substantial period of time in a well maintained and operated installation or process using those techniques.

Where available, data concerning costs have been given together with the description of the techniques presented in the previous Section 2.5. These give a rough indication about the magnitude of costs involved. However, the actual cost of applying a technique will depend strongly on the specific situation regarding, for example, taxes, fees, subsidies and the technical characteristics of the installation concerned. It is not possible to evaluate such site-specific factors fully in this document. In the absence of data concerning costs, conclusions on economic viability of techniques are drawn from observations on existing installations.
The BAT (including the associated emission and consumption levels) given in this section are ‘BAT in a general sense’ (i.e. considered to be appropriate to the sector as a whole). It is intended that they are a reference point against which to judge the current performance of an existing installation or to judge a proposal for a new installation. In this way, they will assist in the determination of appropriate ‘BAT-based’ conditions for the installation or in the establishment of general binding rules under Article 9(8) of the IPPC Directive. It is foreseen that new installations can be designed to perform at or even better than the BAT levels presented in this section. It is also considered that existing installations could move towards the BAT levels presented in this section or do better, subject to the technical and economic applicability of the techniques in each case.

While the BAT reference documents do not set legally binding standards, they are meant to give information for the guidance of industry, Member States and the public on achievable emission and consumption levels when using specified techniques. The appropriate permit conditions for any specific case will need to be determined taking into account the objectives of the IPPC Directive and the local considerations.

2.6.1 Environmental management systems (EMS)

A number of environmental management techniques are determined as BAT. The scope (e.g. level of detail) and nature of the EMS (e.g. standardised or non-standardised) will generally be related to the nature, scale and complexity of the installation, and the range of environmental impacts it may have.

1. BAT is to implement and adhere to an Environmental Management System (EMS) that incorporates, as appropriate to the local circumstances, the following features (see Section 2.5.1). The letters (a), (b), etc. below, correspond to those in Section 2.5.1):

(a) commitment of top management (commitment of the top management is regarded as a precondition for a successful application of other features of the EMS)

(b) definition of an environmental policy that include continuous improvement for the installation by top management

(c) planning and establishing the necessary procedures, objectives and targets, in conjunction with financial planning and investment

(d) implementation of the procedures, paying particular attention to:
   - structure and responsibility
   - training, awareness and competence
   - communication
   - employee involvement
   - documentation
   - efficient process control
   - maintenance programme
   - emergency preparedness and response
   - safeguarding compliance with environmental legislation.
(e) checking performance and taking corrective action, paying particular attention to:

- monitoring and measurement \(\text{(see also the Reference Document on the General Principles of Monitoring [505])}\)
- corrective and preventive action
- maintenance of records
- independent (where practicable) internal auditing in order to determine whether or not the environmental management system conforms to planned arrangements and has been properly implemented and maintained.

(f) review of the EMS and its continuing suitability, adequacy and effectiveness by top management.

Three further features are listed below, and while these features have advantages, EMS without them can be BAT:

- having the management system and audit procedure examined and validated by an accredited certification body or an external EMS verifier
- preparation and publication (and possibly external validation) of a regular environmental statement describing all the significant environmental aspects of the installation, allowing for year-by-year comparison against environmental objectives and targets as well as with sector benchmarks as appropriate
- implementation of and adherence to an internationally accepted voluntary system such as EMAS and EN ISO 14001:2004. This voluntary step could give higher credibility to the EMS. In particular EMAS, which embodies all the above-mentioned features, gives higher credibility. However, non-standardised systems can in principle be equally effective provided that they are properly designed and implemented.

Specifically for the iron and steel industry, it is also important to consider the following potential features of the EMS:

- the environmental impacts from the eventual decommissioning of the unit at the stage of designing a new plant
- the development of cleaner technologies, and to following developments
- where practicable, the application of sectoral benchmarking on a regular basis, including energy efficiency and energy conservation activities, choice of input materials, emissions to air, discharges to water, consumption of water and generation of waste.
2.6.2 Energy management
In the context of energy management, see the Energy Efficiency BREF (ENE) [504].

2. BAT is to reduce thermal energy consumption by applying a combination of the following techniques:

   I. applying improved and optimised systems to achieve a smooth and stable processing, operating close to the process parameter set points by applying:
      i. process control optimisation including computer-based automatic control systems
      ii. modern, gravimetric solid fuel feed systems
      iii. preheating to the extent possible, considering the existing process configuration.

   In this context, see Section 2.5.2.2 where several different techniques are presented, which can be applied, individually or in combination

   II. recovering excess heat from processes, especially from their cooling zones (see Section 2.5.2.3)
   III. applying an optimised steam and heat management (see Section 2.1.2)
   IV. applying process-integrated re-use of sensible heat as far as possible
   V. replacing conventional reductant agents and fossil fuels by waste fuels.

3. BAT is to reduce primary energy consumption by optimisation of energy flows and optimised utilisation of the extracted process gases such as coke oven gas, blast furnace gas and basic oxygen gas (see Section 2.1.1, 2.1.3 and 2.5.2.2)

4. BAT is to use desulphurised and dedusted surplus process gases (mixed or separately) in boilers or in combined heat and power plants to generate steam, electricity and/or heat using surplus waste heat for internal or external heating networks if there is demand from a third party (The co-operation and agreement of a third party may not be within the control of the operator, and therefore may not be within the scope of an IPPC permit).

Determination of BAT-AELs for process gas-fired power plants:
5. The information submitted for process gas-fired power plants about the achieved daily emission values was not sufficient. From the given information in Sections 2.2.1.2 and 2.5.3 it was not possible to derive BAT-AEL for dust, SO$_2$, NO$_x$ and CO. This issue should be dealt with in the review of the Large Combustion Plants BREF (LCP) [434].

6. BAT is to minimise electrical energy consumption by applying the following techniques individually or in combination (see Section 2.5.2.4):

   I. using power management systems
   II. using grinding, pumping, ventilation and conveying equipment and other electricity-based equipment with high energy efficiency.
2.6.3 Material management

7. BAT is to optimise the management and control of internal flows in order to prevent pollution, prevent deterioration, provide adequate input quality, allow re-use and recycling and to improve the process efficiency and optimisation of the metal yield (see Section 2.3).

8. BAT is to select appropriate scrap qualities and other raw material such as wastes and by-products and to undertake an appropriate inspection during reception to avoid substances e.g. PCDD/F, PCB and heavy metals, and in particular, mercury, in order to achieve low emission levels for relevant pollutants. In this context see Section 2.5.4.1, where several different techniques are presented, which can be applied individually or in combination.

9. BAT is to optimise the use of scrap by applying the techniques presented in Section 2.5.4.1, individually or in combination.

2.6.4 Internal management of process residues such as by-products and waste

10. BAT for solid residues is to apply integrated techniques and operational techniques for the minimisation of dust, slag and residues through internal or external re-use or recycling. Detailed BAT are included in the specific sectors. Special efforts in the iron and steel industry have been carried out for the recycling of iron rich residues (see Section 2.5.4.4).

11. BAT is to re-use collected particulate matter in the process wherever practicable. Detailed BAT are included in the specific Chapters 3 - 8.

12. When collected dusts are not recyclable, the utilisation of these dusts in other commercial products, when possible is BAT. Detailed BAT are included in the specific Chapters.

13. BAT is to use the best operational and maintenance practices for collection, handling, storage, transport and disposal of collected dust and sludge, and for the hooing of transfer points. Detailed BAT are included in the specific Chapters.

2.6.5 Diffuse/fugitive dust emissions from materials storage, handling and transport of raw materials and (intermediate)products

In the context of diffuse/fugitive dust emissions from materials storage, handling and transport of raw materials and (intermediate)products, see the Emissions from Storage BREF (EFS) [435].

14. BAT is to prevent or reduce diffuse/fugitive dust emissions from material storage, handling and transport (see Section 2.5.4.2) where several different techniques are presented, which can be applied individually or in combination. If abatement techniques are used, BAT is to optimise the capture efficiency and subsequent cleaning through an appropriate techniques mentioned in Section 2.5.4.2. Preference is given to the collection of the dust emissions nearest to the source.
2.6.6 Water and waste water management

15. BAT for waste water management includes prevention, separation of the waste water types, maximising internal recycling and applying an adequate treatment for each final flow. This includes techniques utilizing, e.g. oil interceptors, filtration or sedimentation. In this context, see Section 2.4, where several measures/techniques are presented, which can be applied where prerequisites are present. Detailed BAT are included in the specific sectors.

2.6.7 Monitoring

Additional information on the description of continuous monitoring systems can be found in the BREF on General Principles of Monitoring (MON) [505].

16. BAT is to measure all relevant parameters necessary to steer the processes from control rooms by means of modern computer-based systems in order to adjust continuously and to optimise the processes on-line, to ensure stable and smooth processing, thus increasing energy efficiency and maximising the yield and improving maintenance practices (see Section 2.5.5.1).

17. BAT is to measure the emissions from the main emission sources from all processes included in Chapters 3 - 8 and in Section 2.2 and 2.5.3 continuously whenever BAT-AELs included are based on daily averages.

18. BAT is to measure the emissions from the relevant emission sources from all processes included in the Chapters 3 - 8 periodically and discontinuously whenever BAT-AELs included are not based on daily averages. This applies to PCDD/F, all process gases components except sulphur (see Section 2.5.5.2), waste water and some smaller sources (see Section 2.5.5.3 and 2.5.5.4).

19. BAT is to measure diffuse emissions from relevant sources by the measurement methods mentioned in Section 2.5.5.5. Whenever possible direct measurement methods are preferred over indirect methods and evaluations based on calculations with emission factors.

2.6.8 Decommissioning

20. BAT is to apply all necessary techniques to prevent pollution upon decommissioning. These include minimisation of the risks during the design stage, implementation of an improvement programme for existing installations and development and utilisation of a site closure plan for new and existing installations.
2.6.9 Noise

21. BAT is to reduce noise emissions from several steps of the iron and steel manufacturing processes by applying a combination of the following techniques depending on and according to local conditions:

I. implementation of a noise reduction strategy
II. enclosure of the noisy operations/units
III. vibration insulation of operations/units
IV. use of internal and external lining made of impact-absorbent material
V. soundproofing buildings to shelter any noisy operations involving material transformation equipment
VI. building up of noise protection walls, e.g. construction of buildings or natural barriers, such as growing trees and bushes between the protected area and the noisy activity
VII. application of outlet silencers to exhaust stacks
VIII. use of lagging ducts and final blowers which are situated in soundproof buildings
IX. closing doors and windows of covered areas.
3  SINTER PLANTS

3.1  Applied processes and techniques

3.1.1  Purpose of the sinter process

Modern high-performance blast furnaces achieve improved performance by prior physical and metallurgical preparation of the burden which improves permeability and reducibility. This preparation entails agglomerating the furnace charge either by sintering or pelletisation (see Chapter 4). The charge of a sinter process consists of a mixture of fine ores, additives (e.g. lime, olivine) and recycled iron-bearing materials from downstream operations (e.g. coarse dust and sludge from blast furnace (BF) gas cleaning, mill scale) to which coke breeze is added to enable the ignition of the total charge. In Europe, down draft sintering on continuous travelling grates is exclusively used (see Figure 3.1 and Figure 3.2).

![Photograph of a sinter strand with the charging facility (drums or chutes) and the ignition canopy at the starting end](image)

3.1.2  Blending and mixing of raw materials

Raw materials require blending prior to the sintering operation. This generally involves layering the materials on prepared areas in the precise quantities required by the sintering operation. Some flux material may also be added at this stage, as can recycled materials from the downstream operations mentioned above. The ore beds are usually finished by covering with a layer of coarse material to prevent wind whipping. At the start of the sintering operation, the ore blend is transferred from the beds to the storage bunkers at the start of the sinter plant.

As mentioned above other additives, such as lime, olivine, collected dust and mill scale, dusts (and to a much lower extent sludges) from gas cleaning in blast furnaces and recycled sinter (particles in the <5 mm range) from sinter screening (see Figure 3.2), may be added to the ore blend at the mixing stage.
Coke breeze (small-grade coke with particle sizes of <5 mm) is the most commonly used fuel for the sintering process. It is usually obtained from an on-site coke oven plant directly as breeze or by crushing coke delivered from elsewhere. Integrated steelworks with insufficient coke capacities purchase suitable fuel supplies from external suppliers to meet the needs of their sinter plants. In this situation, anthracite can be an economic alternative to coke breeze and can be used successfully provided due care is exercised in selecting material with a low volatile matter content in order to prevent increasing emissions of hydrocarbons and PCDD/F. Table 3.1 shows some characteristics of the coke breeze used in some sinter plants.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>wt - %</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.25 mm particle</td>
<td>0.1 - 7.2</td>
</tr>
<tr>
<td>Fixed carbon</td>
<td>81.3 - 86.6</td>
</tr>
<tr>
<td>Volatile matter</td>
<td>0.8 - 2.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Elemental analysis</th>
<th>wt - %</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>82.0 - 88.1</td>
</tr>
<tr>
<td>H</td>
<td>0.55 - 1.03</td>
</tr>
<tr>
<td>S</td>
<td>0.42 - 1</td>
</tr>
<tr>
<td>N</td>
<td>1.06 - 1.23</td>
</tr>
<tr>
<td>Cl</td>
<td>0.0050 - 0.0235</td>
</tr>
<tr>
<td>Ash</td>
<td>10 - 15</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ash composition</th>
<th>wt - %</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO2</td>
<td>44.3 - 55.5</td>
</tr>
<tr>
<td>Al2O3</td>
<td>22.1 - 27.7</td>
</tr>
<tr>
<td>Fe2O3</td>
<td>4.0 - 17.4</td>
</tr>
<tr>
<td>CaO</td>
<td>1.28 - 3.27</td>
</tr>
<tr>
<td>TiO2</td>
<td>0.93 - 1.31</td>
</tr>
<tr>
<td>P2O5</td>
<td>0.87 - 1.51</td>
</tr>
<tr>
<td>K</td>
<td>0.56 - 1.12</td>
</tr>
<tr>
<td>Na</td>
<td>0.27 - 0.52</td>
</tr>
<tr>
<td>S</td>
<td>0.05 - 0.09</td>
</tr>
<tr>
<td>Cu</td>
<td>0.008 - 0.020</td>
</tr>
</tbody>
</table>

Table 3.1: Characteristics of the coke breeze used

The ore blend and the coke breeze are weighed on conveyer belts and loaded into a mixing drum. Here, they are blended completely and the mixture is dampened to enhance the formation of micro pellets, which improve the permeability of the sinter bed (see Figure 3.2).

Where bunker blending and mixing are employed, the emissions are abated by the evacuation of particulate matter and subsequent purification of the collected gas.
Figure 3.2: Schematic diagram of a sinter plant showing the main emission points [137]

Other designs are also used; the plant shown in the figure uses coke crushing and bunker blending; the stacks in the figure indicate emission sources; in reality there would be fewer stacks as more than one off-gas stream may be combined in each stack.

### 3.1.3 Sinter strand operation

[7] [29] [93] [145]

The sinter plant essentially consists of a large travelling grate of heat resistant cast iron (see Figure 3.1). The material to be sintered is placed on top of a 30 – 50 mm deep layer of recycled sinter. This bottom layer prevents the mixture from passing through the slots of the grate and protects the grate from direct heat of the burning mixture.

In modern sinter plants, the layer of materials to be sintered is approximately 400 – 600 mm deep but shallower beds are common in older plants. At the start of the grate, a canopy of gas burners ignites the coke breeze in the mixture. In the down-draft process, a powerful fan draws process air through the entire length of the sinter bed into distribution chambers located underneath the grate known as windboxes. The waste gasflow from a sinter plant varies from 333000 to 1600000 Nm³/hour, depending on the plant size and operating conditions. Typically
the specific waste gasflow is between 1500 and 2500 Nm$^3$/t graded sinter. Most sinter plants with large suction areas (more than 250 m$^2$ and/or grate width of more than 3 m) have two off-gas collecting mains with separate fans and dedusting devices, which could be suitable for advanced emissions reduction measures.

As the sinter mixture proceeds along the grate, the combustion front is drawn downwards through the mixture. This creates sufficient heat (1300 – 1480 °C) to sinter the fine particles together into porous clinker referred to as sinter.

A number of chemical and metallurgical reactions take place during the sintering process. These produce both the sinter itself, and also dust and gaseous emissions. The reactions overlap and influence each other, occurring as solid-state and heterogeneous reactions between the melt, solids and gaseous phases which are present in the sintering zone. The following processes and reactions take place:

- evaporation of moisture
- pre-warming and calcination of basic compounds, ignition of the coke breeze and reactions between carbon, pyrite, chloride and fluoride compounds, and airborne oxygen
- decomposition of hydrates and cleavage of carbonates
- reaction between calcium oxide and hematite
- reaction between the silicate phase and calcium oxide and iron oxide phases to produce a silicate melt and increase the proportion of the molten phases
- formation of calcium-sulphur compounds and compounds containing fluorine together with alkali chlorides and metal chlorides
- reduction of iron oxides to metallic iron in the high temperature zone
- cavity and channel forming effects by coke combustion and moisture evaporation
- re-oxidation and recrystallisation processes with shrinking, gearing and hardening effects during sinter cooling
- formation of cracks due to thermal strain during sinter cooling and defects in the sinter microstructure.

Figure 3.3 shows the temperature and reaction zones of a sinter layer 6 minutes after ignition. Emission profiles of various parameters (H$_2$O, O$_2$) are shown in Figure 3.5 and pollutants (CO$_2$, CO, SO$_2$, NO$_X$, alkali chlorides, heavy metal chlorides and PCDD/F) are shown in Figure 3.5 and Figure 3.7.

The off-gas from sinter strands contains particulate matter (heavy metals, mainly iron compounds but also other ones especially lead compounds), alkali chlorides, sulphur oxides, nitrogen oxides, hydrogen chloride, hydrogen fluoride, hydrocarbons, carbon monoxide and also significant trace amounts of PAH and aromatic organohalogen compounds such as PCDD/F and PCB. The gaseous emissions from the sinter plant make a significant contribution to the overall emissions, (mass per unit time) from an integrated steelworks. Detailed information about formation pathways, emission quantities and sinter strand profiles for individual pollutants are given in Section 3.2.

The coke breeze is fully combusted before reaching the end of the grate and the last one or two windboxes are used to begin the cooling process. The cooler can be integrated within the sinter strand, but a separate cooler (e.g. a rotation cooler) is more common. At the end of the strand the sinter cake falls on a crash deck, where it is broken by use of a crusher. In many plants the sinter then goes through a hot screening process, in which fines measuring less than around 5 mm are separated and recycled to the feed mixture (see Figure 3.2).
3.1.4 Hot sinter screening and cooling

In most cases (i.e. cooling not integrated within the sinter strand) after crushing and hot screening, the sintered material proceeds to a cooler. The cooler is typically a rotating structure some 20 – 30 m in diameter in which the sinter is placed in a layer more than 1 m thick. The sinter is cooled by air, which is forced upwards or downwards through the layer. Sinter cooling gasflow is high and depends on the kind and age of the system used. The specific flow is between 1500 and 2500 Nm³/t sinter, which leads to flowrates of between 100000 and 1000000 Nm³/hour. The sensible heat of up to 300 °C in the sinter cooling waste gas can be used in a waste heat boiler by recirculating the hot gases for preheating combustion air in the sinter grate ignition hoods, by preheating the sinter raw mix or for the sinter process. Other designs of cooler are also known to exist.

Cooled sinter is transferred to screens that separate the pieces to be used in the blast furnace (4 - 10 mm and 20 - 50 mm) from the pieces to be returned to the sinter process (0 - 5 mm as "return fines", 10 - 20 mm as "hearth layer").
3.2 Current emission and consumption levels

3.2.1 Mass stream overview and input/output data

Figure 3.4 shows an overview of the input and output mass streams of a sinter plant. This overview may be used for the collection of data from sinter plants.

Using the mass stream overview, both specific input factors and specific emissions factors can be calculated. Table 3.2 and Table 3.3 shows these data for a significant number of sinter plants in Europe representing 91.13 million tonnes of sinter production in 2004.
### Table 3.2: Input raw materials for sinter making in the EU–25 for 2004

<table>
<thead>
<tr>
<th>Graded sinter production</th>
<th>Units</th>
<th>Average input</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw materials</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iron ore</td>
<td></td>
<td>813.1</td>
</tr>
<tr>
<td>Internal return fines³</td>
<td>kg/t sinter</td>
<td>250.7</td>
</tr>
<tr>
<td>Limestone/dolomite</td>
<td></td>
<td>131.1</td>
</tr>
<tr>
<td>BF return fines³³</td>
<td></td>
<td>63.0</td>
</tr>
<tr>
<td>Returned materials³⁵</td>
<td></td>
<td>51.8</td>
</tr>
<tr>
<td>Others⁶</td>
<td></td>
<td>31.4</td>
</tr>
<tr>
<td>Additives</td>
<td></td>
<td>26.4</td>
</tr>
<tr>
<td>BF gas dust²</td>
<td></td>
<td>12.7</td>
</tr>
<tr>
<td>Lime</td>
<td></td>
<td>10.2</td>
</tr>
<tr>
<td>Total raw mix</td>
<td></td>
<td>1386.4</td>
</tr>
</tbody>
</table>

### Energy

<table>
<thead>
<tr>
<th>Fuels:</th>
<th>Maximum</th>
<th>Minimum</th>
<th>Average input</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid fuel¹</td>
<td>1834</td>
<td>1254</td>
<td>1276.6</td>
</tr>
<tr>
<td>COG/BF gas/natural gas</td>
<td>185</td>
<td>35</td>
<td>67.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Electricity:</th>
<th>Maximum</th>
<th>Minimum</th>
<th>Average input</th>
</tr>
</thead>
<tbody>
<tr>
<td>For fans</td>
<td>91</td>
<td>30</td>
<td>39.4</td>
</tr>
<tr>
<td>Total electricity</td>
<td>155</td>
<td>92</td>
<td>90.5</td>
</tr>
</tbody>
</table>

Source: Eurofer technical exchange on blast furnaces and sinter plants 2004 plus data from additional plants where possible.

Total tonnage on which figures are based = 91.13 million tonnes, which equates to between an estimated 79 and 82 % of all sinter production in the EU–25 for 2004.

1) e.g. coke breeze, anthracite. In some cases, the proportion of coke breeze is lower than the minimum
2) dust from the blast furnace gas treatment (dry material)
3) materials from different I&S production activities including recovered fluxes
4) fines collected in the blast furnace operations excluding dust covered in point 2
5) fines collected from the dust abatement system of sinter plants
6) includes pellets, dust from ores, etc.

Table 3.3: Input data from five sinter plants in four different EU Member States (Austria, Belgium, Germany and the Netherlands)

<table>
<thead>
<tr>
<th>Graded sinter production</th>
<th>Units</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>m³/t sinter</td>
<td>0.35</td>
<td>0.01</td>
</tr>
<tr>
<td>Compressed air</td>
<td>Nm³/t sinter</td>
<td>3</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Input data from five sinter plants in four different EU Member States (Austria, Belgium, Germany and the Netherlands)

Table 3.4 shows the emissions from the sinter strand at the main waste gas stack (Emission point 3 in Figure 3.2).

Table 3.5 and Table 3.6 complement Table 3.4 by showing ranges of particulate emissions to the atmosphere from operations that can generate secondary emissions which can contribute to diffuse emissions if not efficiently captured and dedusted by a ‘secondary or room dedusting system’. Non captured diffuse emissions are excluded.
### Table 3.4: Averaged maximum and minimum emissions concentrations in the sinter strand waste gas after abatement for sinter making in the EU-25 in 2004

<table>
<thead>
<tr>
<th>Units</th>
<th>Max value</th>
<th>Min value</th>
<th>Number of values</th>
<th>Sinter production covered by data (kt)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Air emissions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Gas flow</strong></td>
<td>Nm³/t sinter</td>
<td>2500</td>
<td>1500</td>
<td></td>
</tr>
<tr>
<td><strong>Dusts</strong></td>
<td>g/t sinter</td>
<td>559.4</td>
<td>40.7</td>
<td>21</td>
</tr>
<tr>
<td><strong>PM₁₀</strong></td>
<td>g/t sinter</td>
<td>177.13</td>
<td>66.30</td>
<td>13</td>
</tr>
<tr>
<td><strong>As</strong></td>
<td>mg/t sinter</td>
<td>15.0</td>
<td>0.6</td>
<td>15</td>
</tr>
<tr>
<td><strong>Cd</strong></td>
<td>mg/t sinter</td>
<td>276.7</td>
<td>0.2</td>
<td>18</td>
</tr>
<tr>
<td><strong>Cr</strong></td>
<td>mg/t sinter</td>
<td>125.1</td>
<td>3.6</td>
<td>16</td>
</tr>
<tr>
<td><strong>Cu</strong></td>
<td>mg/t sinter</td>
<td>600.5</td>
<td>1.9</td>
<td>16</td>
</tr>
<tr>
<td><strong>Hg</strong></td>
<td>mg/t sinter</td>
<td>207.0</td>
<td>0.1</td>
<td>17</td>
</tr>
<tr>
<td><strong>Mn</strong></td>
<td>mg/t sinter</td>
<td>539.4</td>
<td>3.4</td>
<td>13</td>
</tr>
<tr>
<td><strong>Ni</strong></td>
<td>mg/t sinter</td>
<td>175.6</td>
<td>1.3</td>
<td>17</td>
</tr>
<tr>
<td><strong>Pb</strong></td>
<td>mg/t sinter</td>
<td>5661.2</td>
<td>26.1</td>
<td>16</td>
</tr>
<tr>
<td><strong>Se</strong></td>
<td>mg/t sinter</td>
<td>120.5</td>
<td>21.8</td>
<td>8</td>
</tr>
<tr>
<td><strong>Ti</strong></td>
<td>mg/t sinter</td>
<td>86.6</td>
<td>0.5</td>
<td>12</td>
</tr>
<tr>
<td><strong>V</strong></td>
<td>mg/t sinter</td>
<td>158.5</td>
<td>0.6</td>
<td>12</td>
</tr>
<tr>
<td><strong>Zn</strong></td>
<td>mg/t sinter</td>
<td>1931.3</td>
<td>2.1</td>
<td>17</td>
</tr>
<tr>
<td><strong>HCl</strong></td>
<td>g/t sinter</td>
<td>847.6</td>
<td>1.4</td>
<td>18</td>
</tr>
<tr>
<td><strong>HF</strong></td>
<td>g/t sinter</td>
<td>8.2</td>
<td>0.4</td>
<td>17</td>
</tr>
<tr>
<td><strong>NOₓ</strong></td>
<td>g/t sinter</td>
<td>1031.2</td>
<td>302.1</td>
<td>21</td>
</tr>
<tr>
<td><strong>SO₂</strong></td>
<td>g/t sinter</td>
<td>973.3</td>
<td>219.9</td>
<td>21</td>
</tr>
<tr>
<td><strong>CO</strong></td>
<td>g/t sinter</td>
<td>37000</td>
<td>8783</td>
<td>21</td>
</tr>
<tr>
<td><strong>CO₂</strong></td>
<td>g/t sinter</td>
<td>368000</td>
<td>161533</td>
<td>15</td>
</tr>
<tr>
<td><strong>Methane</strong></td>
<td>g/t sinter</td>
<td>412.5</td>
<td>35.5</td>
<td>12</td>
</tr>
<tr>
<td><strong>TOC without Methane</strong></td>
<td>g/t sinter</td>
<td>260.9</td>
<td>1.5</td>
<td>15</td>
</tr>
<tr>
<td><strong>Total PAH</strong></td>
<td>mg/t sinter</td>
<td>591.7</td>
<td>0.2</td>
<td>10</td>
</tr>
<tr>
<td><strong>B(a)P</strong></td>
<td>mg/t sinter</td>
<td>6.25</td>
<td>0.1</td>
<td>9</td>
</tr>
<tr>
<td><strong>PCDD/F</strong></td>
<td>µg I-TEQ/t sinter</td>
<td>16</td>
<td>0.15</td>
<td>18</td>
</tr>
<tr>
<td><strong>PCB</strong></td>
<td>ng TEQ/t sinter</td>
<td>178.0</td>
<td>24.5</td>
<td>5</td>
</tr>
<tr>
<td><strong>PCB</strong></td>
<td>ng TEQ/t sinter</td>
<td>820.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>PCB</strong></td>
<td>µg LS</td>
<td>13</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

**Production residues (waste/by-products)**

<table>
<thead>
<tr>
<th>Units</th>
<th>Max value</th>
<th>Min value</th>
<th>Number of values</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dusts</strong></td>
<td>g/t sinter</td>
<td>3641.29</td>
<td>171.05</td>
<td>5</td>
</tr>
<tr>
<td><strong>Sludge</strong></td>
<td>g/t sinter</td>
<td>4492.18</td>
<td>472.73</td>
<td>3</td>
</tr>
<tr>
<td><strong>Waste water</strong></td>
<td>m³/t sinter</td>
<td>0.06</td>
<td>0.03</td>
<td>2</td>
</tr>
</tbody>
</table>

**Notes:**
1) NOₓ nitrogen oxides expressed as NO₂
2) Total PAH (Borneff 6)
3) PCDD expressed as I-TEQ
4) PCB expressed as WHO (12) TEQ (PCBs 105, 114, 118, 156, 157, 167, 189, 77, 81, 126, 169). See more information in Annex VI, in Section 12.3
5) Values correspond to main stack emissions (Emission point number 3 of Figure 3.2). Other dust emissions from sinter plants are presented in Table 3.5
6) Sum of all PCBs, calculated from (ΣPCB 28+52+101+153+138+180) x 5 (factor 5 according to [155]) and with 2100 m³ off-gas/t sinter
7) Where carbonate iron ores are used, the concentration of CO₂ in the waste gas is increased so that the application of EOS may strongly inhibit the sinter process. The CO₂ emissions in plants which do not use carbonate ores average from 161 to 368 kg/t sinter whereas in plants which do use carbonate ores the average can be up to twice as high
8) Having a PM₁₀ min value higher than minimum dust value appears to be anomalous. This arises from the fact that some plants provided an incomplete data set (and therefore, the plant with the lowest PM value did not provide PM₁₀ data
9) Data are from reference [451] without providing the sinter production capacity
10) The gas flow average is 2100 Nm³/t sinter
Secondary dedusting systems usually consist of an efficient collecting and separate dedusting unit additional to the main dedusting system. This can include the hearth laying, the strand discharge zone with sinter crushing and sieving and transfer points of the sinter conveyor. The validation of the available data showed that the allocation of the different secondary sources is not always done unambiguously, e.g. the dedusting of the cooler is sometimes regarded separately and sometimes included in the secondary emissions.

Electrostatic precipitators or bag filters are used here, with the dust being returned to the raw sinter mix.

<table>
<thead>
<tr>
<th>Emission point</th>
<th>Sinter activity</th>
<th>Dust g/t sinter</th>
<th>Dust mg/Nm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Blending &amp; mixing</td>
<td>0.5 - 37.7</td>
<td>5.6 - 18.9</td>
</tr>
<tr>
<td>4</td>
<td>Secondary dedusting:</td>
<td>14.5 - 40&lt;sup&gt;1)&lt;/sup&gt;</td>
<td>7.7 - 25.1&lt;sup&gt;1)&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Strand discharge zone</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hot crushing/screening</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conveyor transfer points</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Sinter cooling</td>
<td>14 - 212</td>
<td>1.3 - 42.8</td>
</tr>
</tbody>
</table>

n.a. not available or too few data. Data correspond to the year 2004
<sup>1)</sup> These data may also include sinter cooler emissions
<sup>2)</sup> Excluding a value of 390 mg/Nm³ from a single plant
<sup>3)</sup> Number of the emission points in Figure 3.2

Table 3.5: Point source air emissions factors for particulate matter for the main individual operations of a sinter plant (excluding the main waste gas stack)

The cooling of sinter (see emission point number 5 in Figure 3.2 and Table 3.6) is processed with a huge amount of cooling air. Since the coolers are usually not fully covered diffuse emissions occur.

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Emissions level</th>
<th>Percentile 5 %</th>
<th>Percentile 95 %</th>
<th>Unit</th>
<th>Reference time period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sinter room dedusting</td>
<td>Dust</td>
<td>3 - 21</td>
<td>5</td>
<td>25</td>
<td>mg/Nm³</td>
</tr>
<tr>
<td>Sinter hot crusher and hand over dedusting</td>
<td>Dust</td>
<td>19</td>
<td>9.5</td>
<td>32</td>
<td>mg/Nm³</td>
</tr>
<tr>
<td>Sinter cooler dedusting</td>
<td>Dust</td>
<td>17.6</td>
<td>7</td>
<td>24.5</td>
<td>mg/Nm³</td>
</tr>
</tbody>
</table>

Notes: Table corresponds to only four EU sinter plants

Table 3.6: Emissions from sinter secondary dedusting in EU sinter plants

Table 3.7 shows achieved emission concentration values for sinter strand emissions after dedusting.
<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Emission level</th>
<th>Percentile 5%</th>
<th>Percentile 95%</th>
<th>Unit</th>
<th>Reference time period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust</td>
<td>36</td>
<td>0.73 - 0.9</td>
<td>25</td>
<td>mg/Nm³</td>
<td>HHA (c)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.17</td>
<td>0.8</td>
<td></td>
<td>DAV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.05</td>
<td>1.4</td>
<td></td>
<td>DAV</td>
</tr>
<tr>
<td>CO</td>
<td>21000</td>
<td>mg/Nm³</td>
<td>AAV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOx</td>
<td>384</td>
<td>48 - 290</td>
<td>320</td>
<td>mg/Nm³</td>
<td>HHA (c)</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>240 - 290</td>
<td>230</td>
<td></td>
<td>DAV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>240</td>
<td>260</td>
<td></td>
<td>DAV</td>
</tr>
<tr>
<td>SOx</td>
<td>250</td>
<td>495</td>
<td>200</td>
<td>mg/Nm³</td>
<td>HHA (c)</td>
</tr>
<tr>
<td></td>
<td>311</td>
<td>495 - 555</td>
<td>399</td>
<td></td>
<td>DAV</td>
</tr>
<tr>
<td>HF</td>
<td>0.6 - 0.7</td>
<td>0.34</td>
<td>&lt;1</td>
<td>mg/Nm³</td>
<td>AAV</td>
</tr>
<tr>
<td>HCl</td>
<td>0.72</td>
<td>0.31 - 3</td>
<td>&lt;1</td>
<td>mg/Nm³</td>
<td>HHA</td>
</tr>
<tr>
<td>Cd, Tl</td>
<td>0.0067</td>
<td>mg/Nm³</td>
<td>AAV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cd</td>
<td>0.0003</td>
<td>&lt;0.002</td>
<td>DAV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cd, Ni, Se, Te</td>
<td>0.02</td>
<td>mg/Nm³</td>
<td>AAV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>As</td>
<td>&lt;0.001</td>
<td>mg/Nm³</td>
<td>AAV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>As, Ni</td>
<td>0.0066</td>
<td>&lt;0.002</td>
<td>AAV</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt;0.002</td>
<td>HHA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hg</td>
<td>0.016</td>
<td>0.01</td>
<td>0.03</td>
<td>mg/Nm³</td>
<td>DAV</td>
</tr>
<tr>
<td>Pb, Cr, Cu, Mn, V</td>
<td>0.87</td>
<td>&lt;0.002 , 0.007</td>
<td>&lt;0.002</td>
<td>mg/Nm³</td>
<td>AAV</td>
</tr>
<tr>
<td>Pb</td>
<td>1.98</td>
<td>&lt;0.002</td>
<td>&lt;0.002</td>
<td>mg/Nm³</td>
<td>AAV</td>
</tr>
<tr>
<td>Pb, Cr, Cu, Mn</td>
<td>0.05</td>
<td></td>
<td></td>
<td>mg/Nm³</td>
<td>AAV</td>
</tr>
<tr>
<td>TOC</td>
<td>47 - 50</td>
<td>22</td>
<td>33</td>
<td>mg/Nm³</td>
<td>AAV</td>
</tr>
<tr>
<td>CH₄</td>
<td>18.5</td>
<td>15</td>
<td>21</td>
<td>mg/Nm³</td>
<td>HHA</td>
</tr>
<tr>
<td>PCDD/F</td>
<td>0.4</td>
<td>0.08 - 0.18</td>
<td>0.044</td>
<td>mg/Nm³</td>
<td>AAV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.05 - 0.18</td>
<td>0.057</td>
<td></td>
<td>8 HAV</td>
</tr>
<tr>
<td>BaP</td>
<td>0.1</td>
<td></td>
<td></td>
<td>mg/Nm³</td>
<td>8 HAV</td>
</tr>
</tbody>
</table>

Table 3.7: Emissions from sinter strand dedusting in five EU sinter plants [200] [407] [447]
Chapter 3

3.2.2 Environmental issues for sinter making process

As already indicated, the emissions to air from sinter plants, especially from the strand, are of high environmental significance. Another important issue is related to energy. Sections 3.2.2.1 to 3.2.2.5 below describe the most relevant environmental issues for sinter plants.

3.2.2.1 Emissions to air

3.2.2.1.1 Particulate matter emissions from handling, crushing, screening and conveying of sinter feedstock and products

When raw materials or sinter are handled, crushed, screened or conveyed, particulate matter emissions occur.

Particulate matter emissions from handling, crushing, screening and conveying can be reduced by means of proper suppression, or extraction and arrestment.

3.2.2.1.2 Off-gas emissions from the sinter strand

[101] [215]

As mentioned in Section 3.1.3 and in Table 3.4, the specific flow of waste gas is relatively high (1500 - 2500 m³/t sinter). Figure 3.5 shows information concerning mixed waste gas from the strand as a whole. Although the composition of the waste gas extracted from individual windboxes varies considerably, it shows certain characteristic features. Figure 3.5 shows the content of CO₂, CO, O₂ and H₂O in the waste gas along the sinter strand. These parameters also interfere with various reaction equilibria. Characteristic curves are also available for the temperature, HCl, SO₂, NOₓ and PCDD/F content (see Figure 3.7 and Section 3.1.4) and also may exist for further pollutants. Some parameters such as CO, CO₂, H₂O, O₂, NOₓ and SO₂ can be calculated with appropriate models.

![Figure 3.5: Typical emissions profiles of CO₂, CO, O₂ and H₂O in the waste gas (single windboxes) along the sinter strand](image)

[101]
Quantitative analysis of grain size distribution of the dust from a sinter strand before abatement shows two maxima: one for coarse dust (with a grain size of about 100 µm) and one for fine dust (0.1 - 1 µm) (see Figure 3.6). This characteristic "two component dust mixture" can be explained by the existence of two dust forming processes.

The coarse dust results from the beginning of the strand and originates in the sinter feed and the lower layer, whereas the fine dust is formed in the sintering zone after complete water evaporation from the mixture. The composition of the coarse dust is related to that of the sinter feed and can be separated in electrostatic precipitators (ESPs) with a high efficiency. The fine dust, however, consists of alkali and lead chlorides formed during the sintering process itself (see Section 4.1.3). The alkali chlorides have high specific dust resistivity (between $10^{12}$ and $10^{13}$ Ω cm) and thus form an insulating layer on the electrodes. This layer causes severe problems for dust removal as it reduces the efficiency of the precipitators. According to [7] alkali chlorides can only be removed with an average efficiency of about 60 %. The presence of these fine particulates in the dust means that well designed and operated conventional electrostatic precipitators cannot normally achieve emitted dust concentrations of below 100 - 150 mg/Nm$^3$. The presence of these fine particulates in the dust makes it necessary to use bag filters of well maintained ESPs with pulse discrimination or similar advanced control techniques with which dust concentrations of 50 mg/Nm$^3$ can be achieved. With Moving Electrodes Electrostatic Precipitators (MEEP), daily average values of <50 mg/Nm$^3$ have been achieved. Provided that dust from the blast furnace gas cleaning and the separated chloride rich dusts from the third and fourth field of the ESP were not recycled back to the sinter strand, daily average values of <30 mg/Nm$^3$ can be achieved [446].

Lead chlorides behave similarly to alkali chlorides; hence, the relatively high lead emissions from a sinter plant's main waste gas stacks may make more difficult the abatement of dust more difficult. Table 3.8 shows ranges found in elementary analysis of sinter dust.
### Table 3.8: Example of elementary analysis of sinter dust

[224] [231] [387] [403]

#### 3.2.2.1.2.1 Heavy metals

[7] [9] [87] [93] [143] [299] [300]

Heavy metal emissions from sinter plants can be of high significance, especially for lead.

**Lead**

During the sintering process, lead reacts to PbO-PbCl$_2$, PbCl$_2$ and probably also to PbCl$_4$. These lead compounds are relatively volatile and enter the gas phase. Their properties (volatility, no further increase of its grain size, the very fine PbCl$_2$ crystals) give rise to annual average emission rates of up to 10 g/t in the raw waste gas (which equates to an average emissions concentration in the waste gas of approximately 3 mg Pb/Nm$^3$, based on a waste gas flowrate of 2100 Nm$^3$/t sinter). Because of the specific characteristics of sinter dust (high alkali chloride content), the removal efficiency also of a well-designed conventional ESP is not high for the very fine particles. From the analysis of leaf deposits, it is known that ambient air concentrations in the impact area of sinter plants can be significantly higher compared to the overall level, even if the emissions are minimised by the application of highly efficient wet scrubbers after using a common ESP.

The most important factor in lead chloride formation is not the lead concentration in the sinter feed (normally 40 - 100 g Pb/t sinter feed) but chloride concentration (normally 200 - 700 g Cl/t sinter feed). For the chloride content, numbers ten times lower are also reported which may correlate with lower lead emissions.

The emissions profile of lead compounds along the sinter strand shows that the volatilisation of lead occurs in the first two thirds of the strand.

Many of the sinter plants in Europe are operated using closed filter-dust cycles. This means that all precipitated filter dust from the ESP is recycled to the strand. Compared to partly open filter-dust cycles (the dust from the last field of the ESP, which mainly consists of alkali and metal chlorides, is put to landfill), closed cycle plants have higher alkali and metal chloride emissions. In this context see also the measurement results in Section 3.2.1.2.1 with and without dust recycling.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>wt-%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe (total)</td>
<td>43.7 - 49.9</td>
</tr>
<tr>
<td>Cl</td>
<td>2.9 - 25.8</td>
</tr>
<tr>
<td>S</td>
<td>0.22 - 4.07</td>
</tr>
<tr>
<td>Si</td>
<td>2.73 - 6.12</td>
</tr>
<tr>
<td>C</td>
<td>2.9 - 6.12</td>
</tr>
<tr>
<td>P</td>
<td>0.01 - 0.24</td>
</tr>
<tr>
<td>K</td>
<td>3 - 9.07</td>
</tr>
<tr>
<td>Ca</td>
<td>7.55 - 7.83</td>
</tr>
<tr>
<td>Al</td>
<td>0.43 - 2.17</td>
</tr>
<tr>
<td>Mg</td>
<td>0.01 - 1.04</td>
</tr>
<tr>
<td>Zn</td>
<td>0.03 - 0.34</td>
</tr>
<tr>
<td>Mn</td>
<td>0.10 - 0.31</td>
</tr>
<tr>
<td>Cu</td>
<td>0.005 - 0.17</td>
</tr>
<tr>
<td>Cr</td>
<td>0.04 - 0.15</td>
</tr>
<tr>
<td>Pb</td>
<td>0.09 - 5.98</td>
</tr>
<tr>
<td>Na$_2$O</td>
<td>0.58 - 31.6</td>
</tr>
<tr>
<td>Ni</td>
<td>0.003</td>
</tr>
<tr>
<td>Cd</td>
<td>0.0009</td>
</tr>
<tr>
<td>TiO$_2$</td>
<td>0.099</td>
</tr>
</tbody>
</table>

Note: Dust used from an ESP of a sinter plant, working at 120 - 130 °C and contains three fields. Dust from third field. Analysis by X-fluorescence and TOC.
Depending on the fluoride content of the sinter feed, lead fluorides may also be formed. These are even more volatile and also contribute to overall lead emissions.

**Mercury**

Mercury enters the gas phase directly during the sintering process. Emission levels depend on the mercury content of the sinter feed, but are normally very low. For certain types of iron ore, (e.g. FeCO₃) the relevant amounts of mercury emissions might be considerable. In such a case, emissions of about 15 - 82 µg Hg/Nm³ or 0.1 - 207 mg Hg/t sinter are reported when well-designed and operated ESPs plus fine wet scrubbing systems are applied as abatement techniques. Such releases can lead to significantly higher environmental concentrations (e.g. determined from deposits on tree leaves) in the impact area of a sinter plant [299].

**Zinc**

The zinc content in the feed is normally in the range 70 - 200 g Zn/t sinter feed. At high temperatures in the incineration/calcination/oxidation zone (see Figure 3.3) zinc evaporates but subsequently reacts to form zinc ferrite, which either remains in the sinter or may be removed using a well designed and operated ESP with high efficiency. The temperature during the sintering process, which is mainly influenced by the coke content of the mixture, may have a significant influence on zinc volatilisation.

In the raw gas, zinc can be present at levels of up to 50 mg Zn/Nm³ or 100 g Zn/t sinter. Treated waste gas contains between 0.002 and 1930 mg Zn/t sinter which equates to an average emissions concentration of between 0.001 and 0.92 mg/m³.

3.2.2.1.2.3 Alkali chlorides

[93]

The alkali content of the sinter feed normally varies from 600 - 1000 g K₂O/t sinter feed and 250 - 500 g Na₂O/t sinter feed. In some cases, depending on the ore quality, up to 3000 g K₂O/t sinter feed have been reported. The formation of alkali chlorides during the sintering process and their adverse impact on ESP removal efficiency has already been explained above (see Section 3.2.2.1.2.1). Table 3.9 shows some information about the soluble chloride contents in some sinter feed materials.

<table>
<thead>
<tr>
<th>Material</th>
<th>Soluble chloride content (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron ores</td>
<td>27 - 159</td>
</tr>
<tr>
<td>Fluxes</td>
<td>51 - 125</td>
</tr>
<tr>
<td>Reverts</td>
<td>22 - 3800</td>
</tr>
<tr>
<td>ESP dust</td>
<td>2500 - 34074</td>
</tr>
<tr>
<td>Fuels</td>
<td>78 - 629</td>
</tr>
</tbody>
</table>

Table 3.9: Soluble chloride contents in sinter feed materials [387]

3.2.2.1.2.4 Sulphur oxides (SOₓ)

[4] [7] [65] [200] [256] [263] [300]

Sulphur oxides (mainly SO₂) in the waste gas originate from the combustion of sulphur compounds in the sinter feed. These sulphur compounds are primarily introduced through the coke breeze. The contribution from iron ore is normally about ten times smaller. Total sulphur input varies between 0.28 and 0.81 kg/t sinter. The emissions concentrations for SO₂ are normally between 200 and 1000 g SO₂/t sinter (which equates to average waste gas emissions concentrations of 95 to 480 mg/Nm³ based on a waste gas flow of 2100 Nm³/t sinter). The emissions profile along the sinter strand clearly varies, with considerable differences in SO₂
concentrations in the individual windboxes (see Figure 3.7 and Figure 3.8). Similar behaviour of emissions has been found in more recent studies [200] [256] [263].

Figure 3.7: Distribution of temperature and concentration of gas compounds in the exhaust gas from the windboxes [256]

Figure 3.8: Typical emission profile of $SO_2$ and $NO_X$ in the waste gas (individual windboxes) and the temperature profile along the sinter strand [101]
At the start of the strand, the SO$_2$ content is low. Only when higher temperatures in the lower layers of the sinter bed are reached do the emissions increase markedly. The highest concentrations occur at the end of the strand just prior to the burn-through point. This emissions profile may offer the possibility, if required, of treating only part of the waste gas (see, for example, the integrated technique referred to partial waste gas recycling in Section 3.3.5.2).

The above-mentioned SO$_2$ emissions are achieved by using raw materials with a low sulphur content and and by the improvements that have been made to reduce the consumption of coke breeze as a fuel for sinter strands. Whereas in the early eighties a coke breeze input of about 80 kg/t sinter was common, current consumption is 39 - 64 kg/t sinter (see Table 3.3). Apart from the sulphur input with the raw materials, there are other factors which influence the quantity of SO$_2$ emitted. One of these is the degree of sulphur uptake in the sinter. This depends on the basicity of the sinter feed. At basicities of up to 1, more than 90% of the sulphur volatilises. This percentage decreases at basicities of above 1.5. At a basicity of 2, 80 - 90% of the sulphur is released. In Germany, the basicity of sinter has been increased to an average of 1.7 since the seventies in order to achieve a self fluxing burden and this is representative for Europe as a whole (see Figure 3.9). This has contributed to the decrease of SO$_2$ emissions, but only slightly. Moreover, the uptake of sulphur by high-basicity sinter is only possible when CaCO$_3$ is used as the alkali and not with MgCO$_3$.

Figure 3.9: Average composition of sinter in Germany

[471]
The slightly positive effect of CaCO$_3$ on SO$_2$ emissions is counteracted by its adverse effect resulting from the increased specific dust resistivity caused by higher basicity, leading to decreased dust-removal efficiency in the ESP (see Figure 3.10).

Figure 3.10: Influence of sinter basicity (CaO/SiO$_2$) on specific dust resistivity

[7]

The grain size distribution of the coke breeze has a significant influence on SO$_2$ emissions. The use of coarser coke breeze (5 - 6 mm) instead of normal grain sizes (<3mm) can reduce SO$_2$ emissions considerably. An example has been reported in which SO$_2$ emissions of about 800 mg SO$_2$/Nm$^3$ using fine grain breeze (1 mm) were reduced to 500 mg SO$_2$/Nm$^3$ after switching to coarser coke breeze (6 mm).

3.2.2.1.2.5 Fluorides

[300]

Fluoride emissions primarily depend on the fluoride content of the ore and on the basicity of the sinter feed. Ores rich in phosphorus contain significant amounts of fluoride (1900 - 2400 ppm). In Europe, such types of ore are especially explored and exported from Sweden. The fluoride emissions strongly depend on the basicity of the sinter feed (see Figure 3.9). The increase in basicity of sinter feed (see Figure 3.11) has lead to significantly lower fluoride emissions. As mentioned above, a disadvantage of sinter feed with higher basicity is the generation of dust with higher specific dust resistivity (see Figure 3.11). According to Table 3.4, the hydrogen fluoride emissions are in the range of 0.4 - 8.2 g F/t sinter on an annual average basis or 0.2 - 4.3 mg F/Nm$^3$ with 2100 Nm$^3$/t sinter on an annual average basis.
3.2.2.1.2.6 Nitrogen oxides (NO\textsubscript{X})

The temperatures at the flame front in the sinter bed inherently cause NO\textsubscript{X} formation. This NO\textsubscript{X} can be formed in three ways: combustion of organic nitrogen compounds in the sinter feed ("fuel NO\textsubscript{X}"); the reaction of decomposing components with molecular nitrogen (N\textsubscript{2}) in the combustion zone ("prompt NO\textsubscript{X}"); and the reaction of molecular oxygen (O\textsubscript{2}) with molecular nitrogen (N\textsubscript{2}) in the combustion air ("thermal NO\textsubscript{X}"). Fuel NO\textsubscript{X} can be the most important representing about 80\% of the total, but also thermal NO\textsubscript{X} can dominate by 60 - 70\%. In Table 3.4 emission factors are reported in the range of 300 - 1100 g NO\textsubscript{X}/t sinter, which means concentrations of 140 - 520 mg NO\textsubscript{X}/Nm\textsuperscript{3} with 2100 Nm\textsuperscript{3}/t sinter. Emissions concentrations of up to 700 mg NO\textsubscript{X}/Nm\textsuperscript{3} are reported, which relate primarily to the nitrogen content in the fuels.

When the NO\textsubscript{X} concentrations are determined at individual windboxes, it can be seen that the NO\textsubscript{X} emissions are not evenly distributed along the sinter strand. However, compared to SO\textsubscript{2} the differences are not that significant (see Figure 3.7).

From sinter strand experiments it has been shown that the nitrogen oxides in the waste gas consist mainly of NO. In addition it was found that in situations where the permeability of the sinter bed decreased, the increase in the contact time between the air and the bed facilitated the formation of NO\textsubscript{X}. 

![Graph showing relationship between sinter feed basicity and fluoride emissions.](image)

Figure 3.11: Relationship between sinter feed basicity and fluoride emissions

[7] [65] [387]
3.2.2.1.2.7 Other inorganic compounds

[229] [453]

It has been reported that the emissions of HCN for sinter plants to be quite high. In one Belgium sinter plant where anthracite is used as a fuel, HCN emissions of about 1646 kg/yr were observed. In an Australian iron and steel plant producing 5 Mt/yr of raw steel, HCN emissions from the sinter plant were detected as 1500 kg/yr in 2004/2005 and 2375 kg/yr in 2006/2007. This provides specific emissions of about 0.4 g/t sinter and a corresponding mass concentration of 0.17 and 0.2 mg/Nm³. It is worth mentioning that both plants either use anthracite as a fuel or to reduce NOX emissions, even if the possible impact on the generation of HCN is not clear.

On the other hand, two measurements taken at an Austrian and a German sinter plant showed quite the opposite results. The mass concentration was, in all cases, <0.02 mg/Nm³, which means under the detection limit. It has to be mentioned that the Austrian sinter plants apply the advanced MEROS technique. These results seems to be contradictory. As it remains unclear as to how HCN can be formed during sintering under prevailing oxidative conditions, exploratory analysis and research is recommended [486].

3.2.2.1.2.8 Hydrocarbons

[7] [45] [112] [300]

Hydrocarbon emissions mainly consist of products formed from pyrolysis and incomplete combustion of carbon-bearing raw materials. Residues containing oil are the major source of hydrocarbon emissions from sinter strands. For example, mill scale can contain up to 10 % oil. Thus, prior to recycling back into the sinter operation, a pretreatment is necessary to comply with internal standards. Most integrated steelworks have introduced internal standards for the oil content of residues recycled to the sinter strand (some are <0.1 %, some <0.5 % and some <1 % in the overall raw mix fed to the sinter strand) in order to avoid operational problems with the ESP (scaling, glow fire) and also to minimise emissions.

Hydrocarbon emissions are a result of evaporation before the oxidation/incineration zone (see Figure 3.3) reaches the lower sinter bed layers. These emissions include methane, aliphatic compounds, phenols, olefins and aromatics. From the data summarised in Table 3.4 it can be seen that the non-methane volatile organic compounds (NMVOCs) emissions range is between 1.5 and 260 g C/t sinter, expressed on an annual average basis (which equates to an average emissions concentration in the waste gas of approximately 0.7 - 120 mg/Nm³, based on a waste gas flowrate of 2100 Nm³/t sinter). The methane emissions range is from 35 to 420 g/t sinter, expressed on an annual average basis (which equates to an average emissions concentration in the waste gas of approximately 17 - 200 mg/Nm³, based on a waste gas flowrate of 2100 Nm³/t sinter).

In one Belgian sinter plant with a capacity of 3.186 Mt sinter/yr, benzene emissions of about 28176 kg/yr were measured. This provides specific emissions of about 8.84 g/t sinter and a corresponding mass concentration of 2.91 mg/Nm³. In this plant anthracite is used as a fuel. In an Australian plant where anthracite is used to reduce NOX emissions, benzene emissions of 360000 kg/yr were detected in 2004/2005 which equates to concentrations of 0.35 mg/Nm³ for an iron steel installation producing 5 Mt/yr of raw steel. The factors influencing benzene emissions are not clear but they are likely to be associated with high volatile materials in the raw mix. Further research may be necessary.
Polychlorinated dibenzo-p-dioxins and furans (PCDD/F) [224] [230] [258] [259] [300]

Table 3.4 shows a range of PCDD/F emissions from sinter plants (of 0.15 - 14.64 µg I-TEQ/t sinter), expressed on an annual average basis, with most plants being in the range of 0.2 to 6.0 µg I-TEQ/t sinter. These emissions rates equate to typical emissions concentrations in the waste gas of 0.07 - 2.86 ng I-TEQ/Nm³ (based on a waste gas flowrate of 2100 Nm³/t sinter).

This gives clear evidence that sintering is the major source for PCDD/F emissions in integrated steelworks. Thus, sintering has been the subject of several investigations carried out to evaluate where in the process and under which conditions PCDD/F emissions are generated. The objective of the research work to get a better understanding of how the formation of PCDD/F emissions can be avoided and/or what kind of eventual reduction techniques should be used and where the most effective stage for applying the technique is. Another question was to evaluate which PCDD/F emissions congeners occur together with PCDD/F emissions.

The overall mechanism of PCDD/F formation in the sinter process is complex and probably involves contributions from a variety of formation processes occurring at different positions within the bed owing to the vertical and longitudinal temperature distributions that exist there.

These formation processes are likely to involve the condensation of precursor molecules and 'de novo' synthesis. The intervention of precursor molecules is easy to envisage with potential precursors for PCDD being chlorophenols or chlorodiphenyl ethers, and with PCBs as precursors for PCDF.

'de novo' synthesis occurs on macro structural carbon under an oxidation atmosphere at relatively low temperatures. The properties of a small quantity of residual carbon particulates, or 'soot' which is suspended on the exhaust gas and metallic chlorides, seem to have a great effect on the formation of PCDD/F.

PCDD/F formation requires different ingredients. In order to explain the formation processes and requirements of precursors and subsequently appropriate abatement techniques, many investigations have been carried out. In [224], [255], [263], [266], [300], [387] further information is given on how different compounds contribute to the building of PCDD/F functioning as precursors:

- (hydro)carbon: ores generally contain small amounts of organic materials. The main source of organic material are the reverts, e.g. millscales, which might contain oil [257]. As has been reported and concluded, the nature of coke has little influence on the amount of global amounts of PCDD/F there are. It only seems to have influence on the isomer distributions. Overall it has to be stated, that the direct correlation of the amount of organics is linked to the appearance of VOC and this again has a strong correlation with the PCDD/F concentration. Investigations showed that the correlation between VOC and PCDD/F is quite weak [200]
- chlorine: volatile Cl content (e.g. NaCl, KCl, CaCl₂) and organic content are effective factors of PCDD/F occurrences [257]. Sources of chlorines are ores containing chloride and organic chlorides, e.g. in plastics. The total chloride content in iron ores is given as 12 - 720 ppm [266]. The chloride content of limestone and other fluxes is in the same range. The reverts exhibited the largest variations in chloride content with flue dusts having 1000 to 5000 ppm. Coke breezes generally have relatively low chloride contents. Correlations are described in [255], [263], [387]
- metallic catalysts: metallic catalysts, such as Cu or Fe, can be contained in minerals and coke. A range of compositions of iron ores is given in [266]. Thus the range from ten different iron ores for copper is between 10 and 70 ppm and for iron between 57.2 and 67.9 wt- %
chlorophenols and PCB: these are essentially precursors for the formation of PCDD/F and these compounds tend to predominate in sinter plant emissions (and in the emissions from other combustion sources). They are relatively volatile and may be driven off ahead of the combustion zone as the sinter bed is heated by the gaseous combustion products. Some studies have indicated that the concentrations of total PCBs in coke breezes and iron ores are around 1 to 1.6 mg/kg and calculations for one sinter plant indicated a potential PCB input of 0.85 mg/kg sinter product, which therefore potentially represents a significant source of precursor molecules from what may be considered natural sources.

PCDD/F in the reverts can also contribute to PCDD/F formation of the waste gas. The PCDD/F content of some reverts and other solid raw materials is shown in Table 3.10. Even as they are partly destroyed in the sinter strand while decomposing, the resulting compounds can contribute as precursors to the 'de novo' synthesis.

<table>
<thead>
<tr>
<th>Material</th>
<th>PCDD</th>
<th>PCDF</th>
<th>PCDD/F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ng/g</td>
<td>ng-TEQ/g</td>
<td>ng/g</td>
</tr>
<tr>
<td>Dry ESP dust</td>
<td>4.0 - 45.1 1)</td>
<td>1.90</td>
<td>24 - 87.2 1)</td>
</tr>
<tr>
<td>BF dust</td>
<td>0.2</td>
<td>0.18</td>
<td>0.37</td>
</tr>
<tr>
<td>Mill scale</td>
<td>0.064</td>
<td>0.084</td>
<td>0.15</td>
</tr>
<tr>
<td>Coke</td>
<td>0.04</td>
<td>0.07</td>
<td>0.11</td>
</tr>
<tr>
<td>Returned ore</td>
<td>0.027</td>
<td>0.016</td>
<td>0.043</td>
</tr>
<tr>
<td>Mixture</td>
<td>0.033</td>
<td>0.12</td>
<td>0.15</td>
</tr>
<tr>
<td>Produced sinter</td>
<td>0.004</td>
<td>0.0008</td>
<td>0.005</td>
</tr>
<tr>
<td>Granulated mixture</td>
<td>0.053</td>
<td>0.082</td>
<td>0.13</td>
</tr>
</tbody>
</table>

Sinter plant characteristics: dry sinter production of 9600 t/d, wet blended ore (containing dusts 4 %, LD slag 4 %, mill scale 2 %, others 4 %) 10200 t/d, wet limestone 560 t/d, wet burnt lime 120 t/d, wet coke 310 t/day, dry return sinter 620 t/d, Ni slag 70 t sinter/d, mixing water 230 m³/d.

Effective sintering area: 210 m², bed thickness: 660 mm, number of windboxes: 15

1) Dust from an ESP of a sinter plant, working at 120 - 130 °C with three fields

Table 3.10: PCDD/F concentrations of raw materials, mixed materials and produced sinter [224] [256] [263]

Temperatures in the suction pipes are ideal for the 'de novo' synthesis. Certain sections of the suction pipes have adequate temperatures (250 and 450 °C have been measured; see Figure 3.12). 'de novo' reactions may appear on the particulates or in the particulates immobilised in the inner part of the suction pipes or the sinter air pipes to the cleaning system.

The basic criteria that are required for the 'de novo' synthesis of PCDD/F are: a solid carbon structure with an imperfect or degenerate graphitic structure, inorganic chlorine, copper or iron metal ions, an oxidising atmosphere and a temperature in the range of 250 to 450 °C. Most of these criteria can be met within the sinter bed and the windboxes. Therefore a significant proportion of the PCDD/F are produced in the sintering process via the 'de novo' synthesis route. Certainly, the studies carried out up to 2009, suggest that the formation of PCDD/F occurs principally within the sinter bed itself rather than downstream in the waste gas system as is generally found in municipal waste incinerators.
Supporting evidence for the formation of PCDD/F in the sinter bed is as follows: beneath the sinter strand are the windboxes which are connected to the wind main by the wind legs. The windboxes and wind legs mass emissions profile tends to peak at, or around, the burn-through point on the strand (Figure 3.7).

This could be attributed to the fact that waste gas temperatures also follow a similar trend and that the potential for 'de novo' synthesis to occur in the windboxes and wind legs is at a maximum at this position in the strand. However, PCDD/F are present in the earlier windboxes and wind legs where temperatures are below the optimum range for 'de novo' synthesis to occur. Thus, the commonly accepted explanation of the windboxes and wind legs profile is that PCDD/F are formed in the bed and subsequently trapped by condensation on the cooler burden at lower points in the bed. As the flame front moves downwards, the trapped PCDD/F are revolatilised and swept downwards through the bed as a tight zone until a point is reached where there is no cold burden left for trapping to occur. The latter mechanism is also supported by interrupted sinter pot experiments, carried out in France, where it was demonstrated that PCDD/F were concentrated in cooler parts of the sinter bed.

In the sintering process, since the PCDD/F are formed principally within the sinter bed, little can be done to change the temperature profile of the bed without affecting the process as a whole. Attempts to prevent, or minimise, the formation of PCDD/F needs therefore to be directed towards modifying the conditions in the bed in order to prevent the 'de novo' formation of PCDD/F and any potential precursors.

Nevertheless, measurements carried out at two locations along a windbox at about 300 °C (closest point from the grate that could be practically reached and at about 3 m downstream) showed that the PCDD/F concentrations were multiplied by a factor of 10 between the two sampling points [230]. Furthermore, abatement trials using countercurrent inhibitors injected into the windboxes towards the grate showed reductions of PCDD/F concentrations which is only possible if PCDD/F are formed at least to some extent in the windboxes at this temperature.

Judging from the distribution of the PCDD/F released in the second stage, the mechanism of their formation is considered different from that of the PCDD/F formed in the first stage. In the second stage, the PCDD/F might have been produced in the windboxes, with organic substances and chlorine supplied from incomplete sinter areas or with grease and dust in the windboxes.
The concentration profiles of the 17 targeted PCDD/F homologue groups can be substantially the same for all Corus sinter plants in the UK despite differences in feedstock composition. It has also emerged from the PCDD/F formation studies carried out on sinter plants throughout Europe, that the congener profiles of sinter plant waste gas emissions appear to be substantially the same for all sinter plants regardless of the actual concentration of PCDD/F in the waste gas. These observations suggest that the congener profile is a characteristic of the process and appears not to be directly related to the I-TEQ value. These findings also suggest that the formation of PCDD/F is subject to thermodynamic control and that a common formation mechanism applies in most, if not all, sinter plants. Table 3.11 indicates that the not fully chlorinated dibenzo-dioxin and dibenzo-furan congeners dominate the emissions of polychlorinated pollutants.

<table>
<thead>
<tr>
<th>Wind leg No.</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
<th>12</th>
<th>14</th>
</tr>
</thead>
<tbody>
<tr>
<td>TetraCDD</td>
<td>0.14</td>
<td>1.49</td>
<td>0.91</td>
<td>2.45</td>
<td>0.59</td>
<td>0.85</td>
</tr>
<tr>
<td>PentaCDD</td>
<td>0.42</td>
<td>2.50</td>
<td>1.61</td>
<td>3.15</td>
<td>2.03</td>
<td>1.74</td>
</tr>
<tr>
<td>HexaCDD</td>
<td>0.63</td>
<td>2.53</td>
<td>1.31</td>
<td>2.40</td>
<td>2.49</td>
<td>2.68</td>
</tr>
<tr>
<td>HeptaCDD</td>
<td>0.51</td>
<td>1.37</td>
<td>0.79</td>
<td>1.20</td>
<td>1.51</td>
<td>1.39</td>
</tr>
<tr>
<td>OctaCDD</td>
<td>0.90</td>
<td>1.40</td>
<td>0.88</td>
<td>0.94</td>
<td>0.93</td>
<td>0.70</td>
</tr>
<tr>
<td>TetraCDF</td>
<td>22.86</td>
<td>132.48</td>
<td>73.16</td>
<td>169.17</td>
<td>184.50</td>
<td>109.87</td>
</tr>
<tr>
<td>PentaCDF</td>
<td>18.45</td>
<td>89.75</td>
<td>52.65</td>
<td>90.53</td>
<td>95.16</td>
<td>62.76</td>
</tr>
<tr>
<td>HexaCDF</td>
<td>13.72</td>
<td>51.09</td>
<td>25.92</td>
<td>41.06</td>
<td>42.35</td>
<td>31.05</td>
</tr>
<tr>
<td>HeptaCDF</td>
<td>4.20</td>
<td>13.87</td>
<td>6.36</td>
<td>9.29</td>
<td>8.65</td>
<td>8.18</td>
</tr>
<tr>
<td>OctaCDF</td>
<td>1.14</td>
<td>3.06</td>
<td>1.42</td>
<td>2.11</td>
<td>2.01</td>
<td>1.55</td>
</tr>
</tbody>
</table>

Table 3.11: Total concentrations of PCDD and PCDF homologue groups in wind leg samples [454]

3.2.2.1.2.10 Polychlorinated Biphenyls (PCB) [9] [122] [300] [387]

PCB can be formed under the same conditions as those described above for PCDD/F. However, during the formation pathway no scrambling of the phenyl rings takes place. In a further reaction, the PCB produced may undergo a ring closure to yield PCDF, but not PCDD. Thus, as is the case for PCDF, no aromatic precursors are necessary for it to be formed.

PCB may also be present in the raw materials. PCB concentrations in coke breeze and iron ores are reported to be around 1 - 1.6 mg/t and limited calculations for one sinter plant indicated a potential input of 850 µg/t graded sinter. Clearly there is a possibility that PCB could be destroyed in the incineration zone (see Figure 3.3) but it should be remembered that the combustion process is not as intense as in waste incinerators, for example, and it is thought unlikely that all the PCB in the process air are destroyed in the combustion zone.

Moreover, PCBs are relatively volatile and may be driven off as the burden is heated by the gaseous combustion products ahead of the combustion zone.

Table 3.12 shows some limited data concerning PCB emissions from sinter plants.

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Range</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCB 1)</td>
<td>1 - 13</td>
<td>mg PCB/t sinter</td>
</tr>
<tr>
<td>PCB 2)</td>
<td>24.5 - 178</td>
<td>ng/t sinter</td>
</tr>
<tr>
<td>PCB 3)</td>
<td>0.01 - 0.09</td>
<td>ng/Nm³</td>
</tr>
</tbody>
</table>

1) Sum of all PCBs, calculated from (ΣPCB 28+52+101+153+138+180) x 5 (factor 5 according to [155]. Data from two sinter plants
2) WHO-12 PCBs (dioxin-like congeners, expressed in terms of I-TEQ values), (see 12.3)
3) Range of annual average emissions concentrations using factor of 2100 Nm³/t sinter

Table 3.12: PCB emissions from sinter plants [300]
Table 3.13 shows the congeners which were found during the analysis of sinter waste gas in one sinter plant.

<table>
<thead>
<tr>
<th>PCB congeners (IUPAC number)</th>
<th>Chemical name</th>
</tr>
</thead>
<tbody>
<tr>
<td>77</td>
<td>3,3',4,4' - TCB</td>
</tr>
<tr>
<td>118</td>
<td>2,3',4,4',5 - PCB</td>
</tr>
<tr>
<td>105</td>
<td>2,3,3',4,4' - PCB</td>
</tr>
<tr>
<td>126 1)</td>
<td>3,3',4,4',5 - PCB</td>
</tr>
</tbody>
</table>

1) For toxicity, however, contribution of this congener is remarkably large.

Note: co-planar polychlorinated biphenyls (co-PCBs) amounts to 5 - 10% of the total toxicity of PCDD/F.

Table 3.13: PCB congeners found in waste gases from sinter plants

A strong correlation exists between the concentrations of PCDD/F and WHO-12 PCBs (expressed in terms of I-TEQ values) such that the contribution of WHO-12 PCBs to the overall I-TEQ concentration is typically 9 – 10% of PCDD/F. The close relationship found between PCDD/F and PCB concentrations suggests that there is a common link between the formation of these compounds (see Section 12.3).

3.2.2.1.2.11 Further organohalogen compounds

[133] [300]

The presence of PCDD/F and PCB can be considered as indicators for the formation of organohalogen compounds such as chlorobenzenes, chlorophenols, chloronaphthalenes, etc. Thus, these compounds could be expected in the waste gas of sinter plants although no investigations are known about this to date.

3.2.2.1.2.12 Polycyclic aromatic hydrocarbons (PAH)

[300] [387]

As mentioned in Section 3.1.3, the reactions in the sinter bed are complex. The combustion process is not homogenous and is incomplete, resulting in significant quantities of polycyclic aromatic hydrocarbons (PAHs) being produced. The data presented in Table 3.4 show that annual average emission factors are in the range of 0.2 - 592 mg Borneff 6/t sinter (which equates to a range of annual emissions concentrations in the range of 0.1 - 282 μg Borneff 6/Nm³.

No correlation was found between the concentrations of PCDD/F and PAHs.

No data are available for the most relevant PAH compounds emitted from sinter plants.
Visible smoke of exhaust gas from iron ore sintering plants sometimes occurs. The reasons are:

- the dust that passes through the ESP is of fine particulates, 40% of which are 10 µm or smaller in particulate size and mostly comprise iron ore powder and submicron KCl particulates
- a very small amount of SO$_3$ at a concentration of about 0.1 ppm is present in the exhaust gases from the sintering plant, and the rise in dew point owing to the SO$_3$ probably induces the formation of mist and visible smoke when the gases are cooled. The phenomenon of a long horizontal trail of smoke, which is characteristic of exhaust gases from sintering plants, is considered to be due to the effect of evaporation restraint by sulphuric acid in the mist
- the removal of dust alone by an ESP is typically not sufficient for preventing the formation of visible smoke of exhaust gases from sintering plants; desulphurisation treatment equipment also seems to be important
- during unusual operations (e.g. when a SOX processing plant is not working properly), the concentration of SO$_x$ in exhaust gas increases.

### Particulate matter emissions from sinter cooling

After falling off at the end of the sinter grate, an area known as the discharge zone, product sinter is crushed, screened and cooled. These operations have the potential for relevant dust emissions. These emissions are called secondary sinter emissions. When the hot gases from sinter cooling from the sinter screening are returned to the process in order to use the sensible heat, they can be returned to the process with or without predusting. When the air is not recycled to the process, particulate matter emissions are usually abated by means of an electrostatic precipitator. Often the waste gas from the cooler is treated together with waste gas extracted from the discharge zone. The composition of this precipitated dust is basically that of the sinter itself and it is recycled to the sinter process.

The cooling of sinter is processed with a huge amount of cooling air. Since the coolers are usually not fully covered, diffuse emissions occur. From the covered parts, the emissions can be collected and further treated. Abatement is carried out by collecting, filtering (using bag filters or ESPs) and recycling the main waste gas to the sinter strand. The limited data provided in Table 3.5 and Table 3.6 indicate a range of annual average emissions concentrations of 1 - 85 mg/Nm$^3$ at sinter cooling (a range that corresponds to 14 - 212 g/t sinter).

The composition of the dust at the discharge zone and from cooling (secondary emissions) is different from dust emitted from the sinter strand (primary emissions). In particular no or very low emissions of alkali chlorides and organic micro-pollutants occur.

### Waste water

**Rinsing water**

The type of processes in an iron and steel plant inherently cause dust deposition on the plant premises. In order to prevent runoff to surface water, this should be removed, preferably by dry techniques. A few plants, however, do use rinsing water cleaning techniques. The resulting waste water contains suspended solids (including heavy metals) and is usually treated before discharge. For example, in a sinter plant with a production of approximately 11000 tonnes of sinter per day, the rinsing water flow is about 460 m$^3$/day. This waste water is treated by means
of sedimentation in the recirculation circuit and enhanced settling prior to discharge. No data from other plants are available.

Cooling water
In the sinter plant, cooling water can be used for the cooling of the ignition hoods and the fans as well as for the sinter machines. In an integrated steelworks producing 4 Mt steel per year, the sinter plant cooling would require a water flow of approximately 600 m$^3$ per hour. The cooling water is normally completely recycled.

Waste water from waste gas treatment
Waste water from waste gas treatment will only be generated if a wet abatement system is applied. The water flow contains suspended solids (including heavy metals), persistent organic pollutants compounds such as PCDD/F and PCB, PAH, sulphur compounds, fluorides and chlorides. It is usually treated before discharge. The quantity and quality of such waste water is described in Section 3.3.2.4.

3.2.2.3 Process residues such as waste and by-products
Normally all solid process residues such as waste and by-products originating from the sinter plant (dusts from dedusting devices and sieving fractions) are recycled to the strand. However, there can be four exceptions:

- the first concerns sludge from wet waste gas treatment systems, which may be put to landfill or sometimes returned to the sinter plant. There is only one plant in Europe operating such a system, which might be shut down on a medium term
- the second exception is filter dust from the last field of electrostatic precipitators (ESP). As mentioned in Section 3.2.2.1.2.2, most European sinter plants are operated with fully closed dust cycles [7]. However, some plants exclude fine dust from the last field of the ESP. This dust mainly consists of alkali and metal chlorides. This so-called partly open filter dust cycle is carried out in order to improve the operation of the ESP or (in one case) of the bag filter, or to reduce alkali and metal chloride emissions
- the third exception concerns dusts from bag filters with high alkali, chlorides and sulphur contents which can deteriorate the abatement efficiency of ESPs (see Section 3.3.2.1)
- the fourth concerns constraints due to stringent national legal criteria for the recycling. Examples of those criteria applied in the Netherlands are shown in Table 3.14.

<table>
<thead>
<tr>
<th>Material/substance</th>
<th>Criteria for recycling back into the sinter strand</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process residue</td>
<td>$\text{FE} + \text{Fe}_2\text{O}_3 + \text{CaO} + \text{C} + \text{SiO}_2 + \text{Mg} \geq 20$</td>
<td>wt - %</td>
</tr>
<tr>
<td>Mineral oil content</td>
<td>$\leq 0.1$</td>
<td>wt - %</td>
</tr>
<tr>
<td>PCDD/F</td>
<td>$\leq 0.001$</td>
<td>mg/kg</td>
</tr>
<tr>
<td>Hg</td>
<td>$\leq 10$</td>
<td>mg/kg</td>
</tr>
<tr>
<td>Cd</td>
<td>$\leq 100$</td>
<td>mg/kg</td>
</tr>
<tr>
<td>As</td>
<td>$\leq 1000$</td>
<td>mg/kg</td>
</tr>
<tr>
<td>Ni</td>
<td>$\leq 1000$</td>
<td>mg/kg</td>
</tr>
<tr>
<td>Pb</td>
<td>$\leq 5000$</td>
<td>mg/kg</td>
</tr>
</tbody>
</table>

Table 3.14: Example of the requirements on materials that can be recycled back into the sinter strand

This can mean that most of the residues from sinter plants and as well from pelletisation plants and mill scales could be considered to be landfilled.
3.2.2.4 Energy consumption

The European Blast Furnace Committee survey of the operational data for sinter plants (2004) reveals that sinter plants use 1290 – 1910 MJ/t sinter of thermal energy (solid fuels including flue dust and ignition fuel), with an average consumption of 1344 MJ/t sinter. These are 39 - 64 kg coke breeze equivalents/t sinter, with an average of 50 kg coke breeze equivalents/t sinter. Total electrical consumption is in the range of 92 to 155 MJ/t sinter, with an average of 90.5 MJ/t sinter [299]. The consumption of heat for ignition is between 70 and 85 MJ/t sinter [404]. There is only a slight difference in fuel consumption between low basicity sinter (<1.7 CaO/SiO2) and higher basicity sinter (≥ 1.7 CaO/SiO2) [200].

Table 3.2 shows data for 20 European sinter plants. Coke is the dominant sinter plant energy input (about 88 %), with electricity and gas (COG and/or BF gas and/or natural gas) supplying the remainder. The main energy outputs are via waste gas, water evaporation, the reaction energy required and the sinter itself. Sinter cooling is often combined with the recovery of sensible heat [300].

3.2.2.5 Noise [242]

The following noise sources dominate in sintering plants:

- sinter waste gas fans
- sinter cooling fans
- sinter crushing.

Noise can be a big issue in some installations. The properties of the noise are high energy noise of low frequency. This noise is caused by fan-tip frequency (speed) and by throttling of flows through the sinter beds.

3.3 Techniques to consider in the determination of BAT for sinter plants

This section sets out techniques considered generally to have potential for achieving a high level of environmental protection in the industries within the scope of the document. Management systems, process-integrated techniques and end-of-pipe measures are included, but a certain amount of overlap exists between these three when seeking the optimum results.

Prevention, control, minimisation and recycling procedures are considered as well as the re-use of materials and energy.

Techniques may be presented singly or as combinations to achieve the objectives of the IPPC Directive. Annex IV to this Directive lists a number of general considerations to be taken into account when determining BAT and techniques within this section will address one or more of these considerations. As far as possible, a standard structure is used to outline each technique, to enable comparison of techniques and an objective assessment against the definition of BAT given in the IPPC Directive.

The content of this section is not an exhaustive list of techniques and others may exist or be developed which may be equally valid within the framework of IPPC and BAT.

The standard structure used to outline each technique is shown in Table 3.15.
### Table 3.15: Information breakdown for each technique described in this section

<table>
<thead>
<tr>
<th>Type of information considered</th>
<th>Type of information included</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Technical description of the technique (including drawings, schematics if necessary)</td>
</tr>
<tr>
<td>Achieved environmental benefits</td>
<td>Main environmental benefits (including energy, water, raw material savings, as well as production yield increases, energy efficiency, etc.) addressed by the technique</td>
</tr>
<tr>
<td>Cross-media effects</td>
<td>Main environmental side effects and disadvantages to other media caused by using the technique. Details of the environmental effects of the technique in comparison with others</td>
</tr>
<tr>
<td>Operational data</td>
<td>Data on consumption and emission levels from operational plants using the technique (including any reference conditions and monitoring methods used). Any other relevant information on how to operate, maintain and control the technique</td>
</tr>
<tr>
<td>Applicability</td>
<td>Indication of the type of plants in which the technique may be applied, considering, e.g. plant age (new or existing), plant size (large or small), techniques already installed and type or quality of product</td>
</tr>
<tr>
<td>Economics</td>
<td>Information on costs (both investment and operational) and any possible savings (e.g. reduced raw material or energy consumption, waste charges) or revenues including details on how these costs/savings or revenues have been calculated/estimated</td>
</tr>
<tr>
<td>Driving force for implementation</td>
<td>Local conditions or requirements which lead to, or may stimulate, implementation. Information on reasons other than environmental ones for implementation (e.g. increase in productivity, safety)</td>
</tr>
<tr>
<td>Example plants</td>
<td>Reference to (a) plant(s) in which the technique is applied and from which information has been collected and used in writing the section</td>
</tr>
<tr>
<td>Reference literature</td>
<td>Literature or other reference material (e.g. books, reports, studies, websites) that was used in writing the section and that contains more details on the technique</td>
</tr>
</tbody>
</table>

### 3.3.1 Process optimisation

**Description**
A planned and carefully implemented maintenance practice can ensure that the sinter plant can be operated continuously and without significant disruption to the production of sinter. This is one of the most important of the process-integrated measures to reduce the emissions from sinter plants. Disruption to the smooth progress of the flame front through the sinter bed will result from unplanned stoppages of the strand. This has an adverse effect on the generation of dusts and some organic species.

Research into the formation of PCDD/F emissions in the sintering process [9] has shown that PCDD/F are formed within the sinter bed itself, probably just ahead of the flame front as the hot gases are drawn through the bed and to some extent in the windboxes and wind legs (see Section 3.2.2.1.2.9). It has also been shown that disruptions to flame front propagation, i.e. non-steady state operations, result in higher PCDD/F emissions. The solution therefore has been to operate the sintering process in as consistent a manner as possible in terms of strand speed. In addition, reducing variations in the bed composition (particularly consistent blending of revert materials and minimisation of chloride input) and bed height and, where relevant, maintaining a stable rate of additions such as burnt lime, controlling millscale oil content to a consistent level of <1% (in the raw mix) and keeping the strand, ductwork and dedusting devices air-tight to minimise, as far as possible, the amount of air ingress in the operation, have beneficial effects on the emissions from the sinter strand.
Achieved environmental benefits
Higher than normal levels of particulate emissions can occur during the start-up of a sinter strand after a short stop as a consequence of the bed drying out and the head front becoming dissipated. After longer stops it may be necessary to initiate operation without some of the end-of-pipe abatement equipment in operation, e.g. an ESP and/or bag filter may have to be bypassed to protect the equipment from high moisture levels. Thus minimising stops and short-term fluctuations to the smooth operation of the strand will result in a reduction in the peak emissions of particulates and reduce the visual impact of the plant operations. Other emissions into air are also reduced through consistent operations.

No single technique can be identified that enables relatively low PCDD/F formation, rather, it seems to be a combination of a number of the techniques mentioned above but especially continuous strand operation.

Cross-media effects
Energy usage is minimised by consistency of operations. There are no negative cross-media effects. According to the application of the mentioned techniques there are added advantages in terms of operational performance reflected in increased productivity, reduced energy demand and consistent sinter quality.

Operational data
No data submitted.

Applicability
Can be applied to existing and new plants.

Economics
There are no installation costs. The operational costs for maintenance and labour are balanced by the benefits of higher productivity and constant sinter quality.

Driving force for implementation
No data submitted.

Example plants
The mentioned techniques are usually applied in European plants. All operators endeavour to operate their sinter plants as smoothly as possible, minimising stoppages by ensuring high maintenance standards are upheld.

Reference literature
[9] [301]

3.3.2 Abatement techniques for emissions into air from sinter plants

3.3.2.1 Electrostatic precipitator (ESP)

Description
The most commonly used abatement devices for treating the large volumes of waste gases in sinter plants in the EU are dry electrostatic precipitators with three or four fields arranged in series. These work by generating an electrostatic field across the path of the particulate matter in the air stream. The particles become negatively charged and migrate towards positively charged collection plates. In dry electrostatic precipitators, the collected material is removed by "rappers" which periodically strike or vibrate the collection plates, dislodging the material and allowing it to fall into collection hoppers.

In wet electrostatic precipitators, the collected material is removed by a constant flow of water, which is collected and subsequently treated.
In order to obtain good separation, the specific resistivity of the particulates has to be in the range of $10^4 - 10^9$ $\Omega$m. Usually, most particulates in the waste gas from the sintering process are within this range but compounds with significantly higher specific resistivity, such as alkali chlorides, heavy metal chlorides and calcium oxides (see Figure 3.10) also occur and are difficult to remove with high efficiency.

Other factors that influence the efficiency are: waste gas flowrate; strength of the electric field; particulate loading rate; SO$_3$ concentration; moisture content; and, shape and area of the electrodes.

Performance improvements have been made to ESPs by the use of higher or variably pulsed voltages and rapid reaction voltage and current controls. Operations have been further enhanced through the introduction of systems to improve the rapping forces to a gravitational constant of 200, high energy pulse superimposition and refurbishment with increased plate spacing. Conditioning with SO$_3$ and/or water vapour may also increase dedusting efficiency. As a disadvantage HCl emissions can increase.

Figure 3.13 presents the influence of the alkali input (e.g. Na, K) into the sinter process on dust emissions after the ESP at the sinter plant in Voestalpine Stahl, Donawitz, Austria before the installation of a bag filter. The diagram shows that dust emissions of below 50 mg/Nm$^3$ were achievable only with alkali inputs of below 2.5 kg per tonne sinter.

Three types of ESPs with good reported performance are highlighted below:

1. Use of energy pulse superimposition: The pulse system provides a voltage consisting of negative narrow pulses superimposed on a filtered voltage of negative polarity. These high voltage pulses have a width of 140 $\mu$s and can be repeated at a frequency of up to 200 pulses per second. The peak voltage is higher with pulse energisation, providing a better particle charging and current distribution in the precipitator. One of the most important characteristics of pulse energisation is its capability to cope with high resistivity dust (see Section 3.2.2.1.2.1).

2. Moving Electrode Electrostatic Precipitator (MEEP): in the MEEP several groups of electrode plates move on caterpillar tracks. Rotating brushes continuously clean these plates. Thus, the strongly adhesive dust is easily removed from the plates and the insulating effect of the dust layer is avoided.
3. Electrostatic Space Cleaner Super (ESCS). The ESCS is operated with a higher voltage (70 - 200 kV). This is possible by a larger distance between the electrode plates.

Other techniques to improve the performance of the ESP are control by programmable logic and use of up to five fields.

**Achieved environmental benefits**

ESPs reduce particulate matter concentrations with an efficiency of >95 %. In some cases, an efficiency of over 99 % is achievable. On an annual average basis, ESPs with MEEP fields can achieve emissions in the range of 49 to 56 mg/Nm³ taking into account only normal operating periods and excluding start-ups and shutdowns. Measurements results from 2008 show that with MEEPs daily mean values of below 30 mg/m³ can be achieved [446] (see figure Figure 3.14). For two German sinter plants equipped with an ESP a dust emissions level of 36 mg/Nm³ has been reported (annual averages, based on continuously measured half-hourly average values; at one plant the 5 % and 95 % percentiles were 25 and 65 mg/Nm³ respectively) [407]. ESPs with energy pulse superimposition can achieve 43 to 77 mg/Nm³ on an annual average basis, although in some plants using unique ores, this range can extend to an upper level of 140 - mg/Nm³. Although not operated within the EU, it is reported that ESCS can achieve emissions of <40 mg/Nm³ although the basis of this level is not clear.

![Figure 3.14: Achieved clean gas dust concentrations with ESP for sinter strand off-gas and the impact of reduced chlorine input](446)

Dust emissions of 36 mg/Nm³ (annual average values) have been achieved at sinter plants in Germany, where injection of zeolite and lignite coke in the ESP has been carried out. In one of the plants, partial waste gas recirculation has also been applied.

**Cross-media effects**

A solid waste flow is generated. In some cases, this waste flow can be recycled into the sintering process. Whenever the concentration of heavy metals and/or alkali compounds is too high, recycling may be hampered.

Furthermore, energy consumption is increased. For a sinter plant with a waste gas flow of approximately 1 million Nm³/h, the energy consumption is 300 to 400 kW. At a sinter production rate of 4 Mt/yr, this amounts to 2 to 3 MJ/t sinter (or 0.1 to 0.15 % of the total sinter energy consumption).
Operational data
Electrostatic precipitation is the most common particulate matter abatement device for cleaning sinter plant waste gas and ESPs can usually be applied without problems. Attention needs to be paid to the amount of hydrocarbons in the waste gas in order to avoid the risk of fire. Operators control the mill scale input to avoid hydrocarbons in the waste gas.

Besides the modification and application of advanced ESP techniques, the following techniques are often applied in order to achieve the maximum dedusting efficiency of the ESP:

- careful choice of uncritical recycling materials
- limitation of critical recycling materials, such as oil contaminated mill scale, containing chlorine and alkali dusts and sludges
- preblending and homogenisation of the recycling materials
- deposit of the dust from the last chamber of the ESP, where most of the alkali and chlorine can be found
- adaptation of the sinter operation such as variation in sinter productivity, bed height and stoppages for cleaning of the ESP.

Table 3.16 gives some operational and economic data concerning electrostatic precipitators in use at sinter plants. The data given are emission levels reported and it is not clear in any case what time periods are used to (e.g. daily average, instant value).

Applicability
Electrostatic precipitators can be installed at both new and existing plants. The MEEP can be installed as a last field of an existing electrostatic precipitator, or as a separate unit in its own housing, but the arrangement and possibility of either type of installation will be site-specific.

Economics
The decisive cost factor is the waste gas flow.

Investments for the last generation ESPs cost around EUR 35 million in sinter plants with a 500 - 600 m² sinter strand, and operational costs are about EUR 0.4/t (Reference plants: ArcelorMittal, Fos, France; ArcelorMittal, Dunkerque, France). In this case, more than one ESP is needed.

The following costs for an ESP were reported for 1996:

- investment: EUR 5 to 7.5/(Nm³/h)
- operational: EUR 0.05 to 0.08/1000 Nm³ treated

For a sinter plant with a capacity of 4 Mt/yr, a waste gas flow of 1 million Nm³/h and 8640 operational hours per year, would correspond to the following costs:

  - investment: EUR 5 to 7.5 million
  - operational: EUR 0.11 to 0.16/t sinter.

For all examples the currency was converted into Ecu in 1996 and for the review into EUR.

For a single MEEP filter added to the existing ESP to treat 500000 Nm³/h, a cost of about EUR 1.1 was quoted in 1997.

Driving Force for implementation
The main driving force for the implementation of the techniques described has been stringent emissions standards or other legal requirements.
**Example plants**
Energy pulse superimposition has been installed at many sinter plants, for example on four strands at Kwangyang Works, Posco (South Korea), on two strands at Thyssen Krupp Stahl, Duisburg, Germany and on one strand at ArcelorMittal, Dunkerque, France.
An MEEP has been installed at two sinter plants in Japan, on two strands at in Riva, Taranto, Italy and at one sinter plant in ArcelorMittal, Eisenhüttenstadt, Germany.

An ESCS has been installed at the sinter plant of Nippon Steel Corporation, Yawata Works in Japan.

**Reference literature**
[7] [45] [61] [65] [71] [145] [209] [242] [295] [308] [404] [407] [409] [415] [416] [423] [424] [446]
## Chapter 3

<table>
<thead>
<tr>
<th>Sinter production:</th>
<th>Unit</th>
<th>Nippon Steel Corp. Wakamatsu/Yawata Japan</th>
<th>ArcelorMittal Eisenhüttenstadt Germany</th>
<th>Kobe Steel Ltd. Kakogawa works Japan</th>
<th>Sumitomo Metal Ind. Wakayama Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>• design</td>
<td>t/h</td>
<td>1000</td>
<td>350</td>
<td>n/a</td>
<td>185 n/a</td>
</tr>
<tr>
<td>• actual</td>
<td></td>
<td>600</td>
<td>560</td>
<td>375</td>
<td></td>
</tr>
<tr>
<td>Total waste gas flow:</td>
<td></td>
<td>10^6 Nm³/h</td>
<td>2</td>
<td>0.53</td>
<td>1</td>
</tr>
<tr>
<td>• design</td>
<td></td>
<td></td>
<td></td>
<td>0.52</td>
<td>0.7</td>
</tr>
<tr>
<td>• actual</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.4</td>
</tr>
<tr>
<td>Sinter basicity</td>
<td>CaO/SiO₂</td>
<td>1.92</td>
<td>1.97</td>
<td>1.8</td>
<td>2.2</td>
</tr>
</tbody>
</table>

### Electrostatic precipitator:
- **Type**: ESCS¹
- **Number**: Two parallel
- **Flow per ESP**: 0.5
- **Actual**: n/a

### Particulate matter inlet concentration:
- **Design**: 1000 mg/Nm³
- **Actual**: n/a
- **Max. 1000**: 1000 mg/Nm³
- **Actual**: n/a

### Particulate matter outlet concentration:
- **Design**: 50 mg/Nm³
- **Actual**: 20 - 37 mg/Nm³
- **Actual**: 35 mg/Nm³
- **Actual**: 25 mg/Nm³

### ESP efficiency:
- **Design**: 95%
- **Actual**: n/a
- **Actual**: 95 - 97%
- **Actual**: 96%

### Conditioning ESP and/or pretreatment sinter feed:
- **Non-conditioned**: ESP non-conditioned; Oil content in the raw materials is regulated (no de-oiling)
- **Coke injection**: ESP non-conditioned, lime and lignite coke injection, no special measures to prevent fire hazard
- **Non-conditioned**: ESP non-conditioned; Max. HC⁴ in ESP precipitate: 1%; achieved by max. input mill scale of 3% of feed

### By-product (dust):
- **Amount**: kg/t sinter
- **Processing**: 1 - 2 Recycled to sinter process
- **Exclude filter dust from field three and four**: 1 - 2
- **Actual**: n/a
- **Actual**: 2 n/a

### Energy demand:
- **GJ/t sinter**: 0.00036
- **Operating costs**: 0.0018 - 0.0024 in 1986 (only maintenance)
- **Operational costs**: n/a
- **Operating costs**: 0.11 in 1986 (maint. and depreci. excluded)

### Oxygen content:
- **13.6 %

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¹ ESCS: Electrostatic Space Cleaner Super
² MEEP: Moving Electrode Electrostatic Precipitator
³ For all examples the currency was converted into Ecu in 1996 and for the review into EUR.
⁴ Hydrocarbons

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Table 3.16: Operational and economic data for MEEP and ESCS electrostatic precipitators operated at sinter plants to treat sinter plant waste gas [65] [446]

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3.3.2.1.1 Reduction of PCDD/F by means of ESPs and additives

Description
This technique involves the injection of an activated carbon ahead of the ESP in order to capture especially PCDD/F. At ArcelorMittal, Gent in Belgium, this technique has been in industrial use since 2000 on sinter plants 1 and 2. Activated coal is used as the carbon source and limestone is used as an inert material.

Different carbon sources have been tested in the past for the purpose of absorbing various species in the waste gases of sinter plants. These range between activated coals, through cokes, charcoals and specially prepared carbon absorbents. A future development of the system might come from improvements to the adsorbent. To minimise the risk of glow fires in the electrostatic precipitators and limit the carbon content of the captured dusts, some inert material (e.g. fine crushed limestone, hydrated lime, etc.) can be added to the carbon. (In ArcelorMittal Gent’s experience, the carbon content of the ESP dusts should be less than 25 % but they aim at <20 %.)

The carbon and inert material are dosed separately in one pipe leading to the waste gas ducts, with each duct having its own dosing system. Since the waste gas duct is under suction, the carbon and inert material are sucked into the turbulent gas stream created by a static mixer (an inclined plate) in the duct and the injected materials become rapidly dispersed in the waste gas. In the ducts, the carbon adsorbs a proportion of the PCDD/F (and other species). In the electrostatic precipitators, the carbon, inert material and dusts are collected and recycled to the sinter strand where the PCDD/F are cracked in the sintering zone.

Other techniques to improve the performance of the ESP are control by programmable logic and use of up to five fields.

Achieved environmental benefits
Experience at ArcelorMittal Gent of injecting activated carbon ahead of the ESP shows that a yearly average concentration of PCDD/F of 0.5 ng I-TEQ/Nm³ can be achieved under rigorously controlled conditions that ensure that strictly limited levels of grease, oil and chloride are added to the raw mix in revert materials and electrostatic precipitators in optimal condition. To achieve these results the typical dosing rate of activated coal is 80 mg/Nm³ and 200 mg/Nm³ of limestone. The necessity to add limestone and the dosing level required is dependent upon the ESP inlet gas dust loading.

Another example is ArcelorMittal Eisenhüttenstadt in Germany where 32 kg lignite carbon gets injected and the corresponding PCDD/F concentrations are between 0.074 and 0.170 ng I-TEQ/m³.

Cross-media effects
There are few cross-media effects resulting from the injection of carbon into the waste gas main ahead of an ESP. There are no additional residues because the additional dust arising in the system can be recycled in sinter plants where coal and limestone are used during the sintering process; PCDD/F are cracked in the sintering zone. There may be additional dust to treat if fine dusts are removed from the sinter mix to improve the bed permeability, thereby reducing the possibility for PCDD/F to be produced. In plants where not all the dusts collected in the ESP are recirculated, there may be additional dust requiring treatment. There is no significant increase in energy consumption because there is no additional pressure variation in the off-gas system.
Operational data
When using carbon injection, the off-gas temperature has to be \(\leq 180^\circ C\) in order to minimise the risk of fires. The residence time between the injection point and the gas cleaning device is a sensitive parameter at ArcelorMittal, Gent, Belgium. (At least 3 seconds are required at 150 - 180 °C). The carbon content of the collected dust must be limited to avoid self-ignition as outlined in the description above. The presence of carbon in the waste gas can give rise to a positive change in the resistivity of the dust particles, enhancing the efficiency of the ESP dust collection system resulting in a lowering of the particulate emissions. However, this technique is not applicable at plant start-ups or stops due to temperature considerations.

Applicability
Carbon injection ahead of an ESP is an end-of-pipe technique applicable to existing sinter plants. However a good, well maintained gas cleaning system is required to ensure low particulate emissions (large ESPs with pulse systems).

Economics
At ArcelorMittal, Gent, Belgium, the investment cost for two sinter plants with a total of 1600 kNm\(^3\)/h was ~EUR 2500000 in 2000 (steel structure, bins, dosing equipment, pneumatic transport and static mixer). The variable cost was EUR ~0.15/t sinter for activated coal, limestone and additional energy consumption in 2005.

Driving Force for implementation
The main driving force for the implementation of the technique described has been stringent emission standards or other legal requirements.

Example plants
Injection of carbon into the waste gas main ahead of an ESP has been in use at ArcelorMittal, Gent, Belgium since 2000, at Thyssen Krupp Stahl in Duisburg, Germany since 2003, at Arcelor Mittal, Eisenhüttenstadt, Germany since February 2006 and at Hüttenwerke Krupp Mannesmann, Duisburg, Germany in combination with the LEEP system since December 2001.

Reference literature
[7] [61] [45] [65] [71] [145] [209] [242] [295] [308] [404] [407] [409] [415] [416] [423] [424]

3.3.2.2 Bag filter - combined or integrated reduction of solid and gaseous pollutants

Description
Bag filters are mainly designed and applied to remove particulate matter from the sinter strand waste gas. They are usually applied downstream to an existing electrostatic precipitator or cyclones. Usually, the removal of particulate matter is combined with the removal of acidic waste gas compounds such as HCl, HF and SO\(_X\) by injection of slaked lime or sodium bicarbonate solutions and the removal of persistent organic pollutants such as PCDD/F, PCB, HCB or PAH by injection of adsorbents (mainly powdered lignite coke or activated carbon, and/or sometimes zeolites) (see Figure 3.13). All the particulate matter, the carbon/coke and unreacted desulphurisation reagents as well as the reaction products (gypsum and sodium sulphate) are filtered off by means of the bag filter. Part of the removed dust is recirculated to the waste gas in order to increase the adsorption efficiency and thus reduce the costs for consumables. A significant proportion of the dust and additives is returned to the waste gas stream; the rest is discharged out of the system for disposal. In some cases, the discharged dust and additives are fully returned into the sinter strand where the PCDD/F are cracked in the flame front.
The several steps of this combination of techniques are as follows:

- injection of adsorbents (powdered lignite coke or active carbon and/or zeolites) upstream of the bag filter in the flue-gas duct to reduce the emissions of hazardous compounds
- injection also of sodium bicarbonate or slaked lime into the flue-gas duct to reduce acidic emissions (e.g. SO\textsubscript{2}, HCl, HF) combined with adequate conditioning of the waste gas by moisturisation and temperature adjustment (90 - 100 °C)
- dust capture in a chemical resistant bag filter with an automatic dust removal system (e.g. pulse-jet type)
- recycling of dust back to the flue-gas. In some cases, a large amount of particulates is recirculated
- extraction of flue-gases from the system with a fan.

The injection of alkaline compounds, usually lime, also help to avoid the blinding of the filter material by fine particulates or organic compounds and to avoid corrosion. The lime builds up a layer on the surface of the bag (pre-coating the bag) preventing the formation of an impermeable layer and consequently blinding of the filter material.

In the following paragraphs, more details on the techniques are provided.

For the treatment of the acidic compounds in the waste gas from sinter strands, usually a so-called semi-dry sorption process is used. This means that additional water is applied in order to cool the off-gas temperature to 90 - 100 °C for an efficient desulphurisation and also to avoid potential damage to the downstream fabric filter bags. The water can be sprayed directly into the waste gas flow.

In bag filter systems having dust recirculation (see Figure 3.15) there is generally a mixer for the recirculated dusts and any fresh additives (slaked lime and/or carbon). To facilitate desulphurisation of the waste gas, moisture is added to the dust in the mixer. The amount of water added is dependent upon the waste gas temperature and this can affect the degree of desulphurisation achieved. The desulphurisation rate is determined by the amount of lime added, by the rate of recirculation of the collected dusts and the moisture content of the recirculated dust. Desulphurisation also depends on the quality of hydrated lime.

Usually the filter is divided into several filter lines of similar design, each of which is further subdivided in to several chambers. The predusted waste gas stream is distributed uniformly to the top of each of the filter lines and is sucked to the bottom of each chamber. Within the chamber, the waste gas enters from the outside of the filter tube and particulate matter is collected on the fabric as the gas passes through the bag. The bags are supported by cages and can be mounted vertically (longer bags) or horizontally (shorter bags). During waste gas cleaning, a filter cake builds up on the exterior surface of the bag resulting in an increase in the pressure drop across the bag. Once the pressure drop reaches a set point (usual differential pressure between filter and clean gas chamber of 10 to 20 mbar) the chamber is taken off-line for cleaning by a reverse pulse of compressed air. The dust removed is collected in conical bins below the filter chambers and discharged by screw conveyors. About 98 % of this dust may be recycled back to the waste gas stream as an additive; the rest is discharged out of the system for disposal or optionally sent back to the sinter strand.

A very good example for the combined reduction of solid and gaseous pollutants by bag filter is the so-called MEROS process (Maximised Emission Reduction of Sintering). The full size installation has been in operation at Voestalpine Stahl (Linz, Austria) since August 2007 and replaced the airfine system (Figure 3.15 and Figure 3.16).
Figure 3.15: Basic flow sheet of a bag filter downstream of an existing ESP or cyclone [309]

Figure 3.16: Flow scheme of the SIMETAL MEROS process

Although this technique is different in process layout, the processes mentioned above have in common that the conventional use of additives like activated carbon/activated lignite for heavy metals and PCDD/F removal is accompanied by dust recycling and additional $SO_X$ abatement [467].
To enhance the sinter off-gas cleaning efficiency and to reduce additive costs, most of the dust separated in the bag filter is recycled to the gas stream. This dust consists of primary dust, carbon/coke, non-reacted deSOX reagents or, allowing these non-reacted additives to come once again into contact with the off-gas and thereby decreasing the costs of the additives.

Another advantage is that the highly recirculated dust concentration (1 or 15 g/Nm³ depending on the technique) leads to a rapid collection of dust on the bag filter, which promotes the further removal of heavy metals and PCDD/F. SOX is reduced by hydrated lime for all mentioned techniques, although sodium bicarbonate can also be applied in the MEROS process.

Achieved environmental benefits
A bag filter is highly efficient at reducing dust and simultaneous heavy metals emissions in a waste gas stream. Bag filters enhanced with additives also reduce the emissions of PCDD/F, hydrochloric acid (HCl), hydrofluoric acid (HF) and to a lesser extent, sulphur dioxide (SO₂). In particular, emissions of PCDD/F may be reduced significantly. A significant removal of VOCs and PAHs is also reported.

Table 3.17 shows typical removal efficiencies of European bag filter installations at sinter plants.

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Values 1)</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust</td>
<td>&lt;5 - 10</td>
<td>mg/Nm³</td>
</tr>
<tr>
<td></td>
<td>Up to 99</td>
<td>%</td>
</tr>
<tr>
<td>Heavy metals:</td>
<td>&gt;95</td>
<td>%</td>
</tr>
<tr>
<td>Hg</td>
<td>Up to 95</td>
<td>%</td>
</tr>
<tr>
<td>Pb</td>
<td>Up to 99</td>
<td>%</td>
</tr>
<tr>
<td>PCDD/F</td>
<td>&lt;0.1</td>
<td>ng/Nm³</td>
</tr>
<tr>
<td></td>
<td>Up to 98</td>
<td>%</td>
</tr>
<tr>
<td>Acid gases (HCl/HF):</td>
<td>&gt;90</td>
<td>% (mg/Nm³)</td>
</tr>
<tr>
<td>HCl</td>
<td>Up to 91 (&lt;10)</td>
<td>%</td>
</tr>
<tr>
<td>HF</td>
<td>Up to 92 (&lt;1)</td>
<td>%</td>
</tr>
<tr>
<td>VOC</td>
<td>Up to 99</td>
<td>%</td>
</tr>
<tr>
<td>SOX</td>
<td>&lt;50 - 500</td>
<td>mg/Nm³</td>
</tr>
<tr>
<td></td>
<td>30 - 80 2) (slaked lime)</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>&gt;90 (sodium bicarbonate)</td>
<td>%</td>
</tr>
</tbody>
</table>

Table 3.17: Typical removal efficiency
[217] [294] [295] [298]

Operational data for European sinter plants using bag filters are in the range of 1 to 10 mg/Nm³ particulates expressed on an daily average basis that includes peak periods. The non volatile heavy metals are reduced simultaneously with the dust.

The addition of lime and carbon enables the reduction of dioxin emissions to <0.1 ng TEQ-I/Nm³.

Volatile heavy metals and VOCs are reduced simultaneously by the application of additives and zeolites containing carbon. For example, mercury is reduced by 80 - 95 %.

SO₂ can be reduced by approximately 30 - 80 % with slaked lime and up to 90 % with sodium bicarbonate. This leads to SO₂ emissions of between 100 and 500 mg/Nm³ depending on the amount of lime or sodium bicarbonate that is injected. Depending on the SO₂ input in practice, daily averages for SOX of lower 350 mg/Nm³ have been achieved.

With lime addition, HF emissions concentrations of 0.2 - 1 % mg/Nm³ and HCl emissions concentrations of 1 - 10 % mg/Nm³ (daily average) can be achieved.
The reported achieved environmental levels for these techniques are:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Input (raw gas)</th>
<th>Outputs 1)</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust</td>
<td>80 - &lt;500</td>
<td>0.73 - 10</td>
<td>mg/Nm³</td>
</tr>
<tr>
<td>SO₂</td>
<td>450 - &lt;800</td>
<td>225 - &lt;500</td>
<td>mg/Nm³</td>
</tr>
<tr>
<td>HCl</td>
<td>&lt;60</td>
<td>0.31 - 30</td>
<td>mg/Nm³</td>
</tr>
<tr>
<td>HF</td>
<td>0.34 - 1</td>
<td>mg/Nm³</td>
<td></td>
</tr>
<tr>
<td>PCDD/F</td>
<td>&lt;0.1</td>
<td>mg/Nm³</td>
<td></td>
</tr>
<tr>
<td>Pb</td>
<td>0.17</td>
<td>mg/Nm³</td>
<td></td>
</tr>
<tr>
<td>Sum of Hg, Tl, Cd</td>
<td>0.007</td>
<td>mg/Nm³</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>145</td>
<td>100</td>
<td>°C</td>
</tr>
</tbody>
</table>

1) Some values are guaranteed performances
2) SO₂ removal strongly depends on particulate recirculation in the filter system and on the water addition. Values achieved by injection of lime/activated coke
3) Lower end of the range is achieved by lime injection

Table 3.18: Performance of three installation
[287] [296] [407] [424] [448]

Table 3.19 presents the emissions concentration data for the above-mentioned MEROS process at Voestalpine Stahl (Linz, Austria).

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Emissions level</th>
<th>Percentile</th>
<th>Unit</th>
<th>Reference time period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust</td>
<td>0.9</td>
<td>5%</td>
<td>0.8</td>
<td>1.4</td>
</tr>
<tr>
<td>NOₓ</td>
<td>240</td>
<td>95%</td>
<td>230</td>
<td>260</td>
</tr>
<tr>
<td>SOₓ</td>
<td>263</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HF</td>
<td>0.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HCl</td>
<td>2</td>
<td></td>
<td>&lt;1</td>
<td>2.4</td>
</tr>
<tr>
<td>Cd</td>
<td>&lt;0.002</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ni</td>
<td>&lt;0.002</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hg</td>
<td>0.016</td>
<td></td>
<td>0.01</td>
<td>0.03</td>
</tr>
<tr>
<td>Cr</td>
<td>&lt;0.002</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>0.007</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pb</td>
<td>&lt;0.002</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOC</td>
<td>30</td>
<td></td>
<td>22</td>
<td>33</td>
</tr>
<tr>
<td>CH₄</td>
<td>18.5</td>
<td></td>
<td>15</td>
<td>21</td>
</tr>
<tr>
<td>PCDD/F</td>
<td>0.05</td>
<td></td>
<td>0.044</td>
<td>0.057</td>
</tr>
<tr>
<td>BaP</td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3.19: Performance data from a sinter strand using the MEROS technique (full size installation)
[447]
Cross-media effects
Bag filters generate a solid process residue flow (0.5 to 1 kg/t sinter), which is preferably recycled into the sintering process. In some cases, the captured dust contains unwanted compounds (e.g. zinc, lead, alkalis), hampering its re-use. In this case, some or the entire solid process residues have to be discarded as waste for further treatment or disposal.

At the sinter plant of ArcelorMittal Bremen in Germany that operates without desulphurisation, the separated dust and additives from the bag filter are fully returned to the sinter strand where the PCDD/F are cracked in the flame front. The separated dust at Voestalpine Donawitz, Germany must be disposed of because it contains significant amounts of sulphur, chloride, fluoride and alkalis. The dust separated in the ESP (only used as a prededusting device) is recycled or disposed of depending on the alkali chloride content, which can increase the residual dust content in the treated waste gas when returned to the sinter strand.

Use of a bag filter also increases electricity consumption (from 1.0 to 2.5 kWh/1000 Nm³).

If carbon is used to achieve further reductions of PCDD/F emissions, then special attention has to be paid to the risk of filter fire. Spark detection equipment may be installed and when necessary, the filter is bypassed. Bag filters have to be bypassed during start-up.

With the combination of this technique with the technique described in Section 3.3.2.1.1, sinter waste gas cleaning facilities can handle up to 40% more production and reduce additive consumption per tonne of sinter.

Operational data
The recirculation of particulates inside the system to build up a pre-coating layer at the surface of the bags is sometimes used to improve the dedusting efficiency and to increase the lifetime of bags.

Durable bag filter material is an important aspect of this technique. Different types of filter fabric material with specific qualities can be used to achieve a balance between abatement efficiency, lifetime and costs (see Table 3.23).
Chapter 3

The use of activated carbon or lignite differs in grain size and in their effective adsorption surface area and consequently the amount of injection required. Activated coal has the highest specific free surface and shows a very good adsorptive effect. Activated lignite coke is the more economic alternative to activated coke and the super-milled lignite with diameters of 0.024 mm also shows a very good adsorptive efficiency and leads to half the dosing rates necessary when to standard lignite coke [367]. Sometime inerts have to be added to the injected carbon based materials to avoid ignition. Table 3.20 shows the characteristics of different adsorbents and absorbent materials.

<table>
<thead>
<tr>
<th>Adsorption and absorption materials</th>
<th>Grain size (mm)</th>
<th>Surface area BET 1) (m²/g)</th>
<th>Precipitative pollutants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lime</td>
<td>CaO</td>
<td>12</td>
<td>1 - 3</td>
</tr>
<tr>
<td>Slaked lime</td>
<td>Ca(OH)₂</td>
<td>&lt;8</td>
<td>15 - 45</td>
</tr>
<tr>
<td>Sodium bicarbonate</td>
<td>NaHCO₃</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Standard powdered activated lignite coke</td>
<td>Carbon</td>
<td>0.063</td>
<td>300 - 400</td>
</tr>
<tr>
<td>Super-milled powdered activated lignite coke</td>
<td>Carbon</td>
<td>0.024</td>
<td>1200</td>
</tr>
<tr>
<td>Powdered activated (charcoal) carbon</td>
<td>Carbon</td>
<td>500 - 1600</td>
<td></td>
</tr>
<tr>
<td>Zeolite</td>
<td>Z</td>
<td>4 - 90</td>
<td></td>
</tr>
</tbody>
</table>

1) BET – created from the initials of the family names of the people who developed this theory as a rule for the physical adsorption of gas molecules on a solid surface.

Table 3.20: Characteristics of different adsorbent and absorption materials [498]

To achieve effective adsorption of the PCDD/F, it is necessary to ensure that the carbon additive is distributed rapidly across the duct section. After injection, the absorption and adsorption process starts in the ducts and continues in the filter cake. The carbon additives together with the dust are captured in the bag filter and are removed from the filter in the usual way. A significant proportion of the dust and additives is returned to the waste gas stream; the rest is discharged out of the system for disposal. In some cases, the discharged dust and additives are fully returned into the sinter strand where the PCDD/F are cracked in the flame front.

Table 3.21 shows a comparison between the use of sodium bicarbonate and hydrated lime for use as the desulphurisation agent on the MEROS demonstration plant.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sodium bicarbonate</th>
<th>Slaked lime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stochiometry coefficient</td>
<td>1.1 - 1.4</td>
<td>2 - 4</td>
</tr>
<tr>
<td>Residuals 1)</td>
<td>60 - 70 %</td>
<td>100 %</td>
</tr>
<tr>
<td>Reactant cost 1)</td>
<td>140 - 210 %</td>
<td>100 %</td>
</tr>
<tr>
<td>DeNOₓ (if required)</td>
<td>Less fuel for gas heating</td>
<td>More fuel for gas heating</td>
</tr>
<tr>
<td>Gas temperature at the outlet</td>
<td>Same as inlet</td>
<td>90 - 100 °C</td>
</tr>
</tbody>
</table>

1) Relative values referred to the amount when slaked lime is used.

Table 3.21: Typical operational values when using two different additives [294] [424]

By injection of water, the temperature of the waste gas is reduced and the abatement efficiency of acid pollutants is increased. Modern bag filter techniques have systems which decrease the flue-gas temperature to 120 °C or even down to 80 °C either directly by spraying water into the reactor chamber or indirectly by conditioning the recirculated particles with water. Freshly ground sodium bicarbonate is injected into the flue-gas duct at a temperature above 140 °C. The use of slaked lime needs more energy to reheat the gas.
There is flexibility with the use of additives (e.g. slaked lime, lignite coke, sodium bicarbonate) depending on the environmental needs. Sodium bicarbonate is used when higher desulphurisation or a deNO\textsubscript{X} system is required. Additives are stored in silos and sodium bicarbonate is milled before injection.

In order to enhance the gas cleaning efficiency and to significantly reduce additive costs, most of the separated dust in the bag filter is recycled to the off-gas stream after the conditioning reactor. Unreacted adsorbents once again come into contact with the off-gas, thus increasing the adsorbent efficiency and reducing the costs of consumables.

The reaction products and the dust are usually deposited underground due to their fine grain sizes.

Filters usually get bypassed during start/stop of the sinter strand.

**Applicability**

Bag filter can be regarded as an end-of-pipe technique which can be applied at both at new and existing plants.

**Economics**

In the EU it has been common practice to use ESPs to effect cleaning of the waste gas (see Section 3.3.2) and bag filters have generally been added later. Consequently, bag filters treating sinter plant waste gas are generally installed downstream of an existing ESP, resulting in filters that are generally smaller than they would have to be in the absence of an ESP.

When estimating the costs of bag filter with a flow-injection unit, it should be borne in mind that these installations are not only used for dust separation but also for reducing PCDD/F, heavy metals and acid gases. The investment costs are in the range of EUR 16 to 31/Nm\textsuperscript{3}/h.

Decisive cost factors are pressure drop, the waste gas flow, fabric material and filter loading. The operating cost is around EUR 0.3 - 0.6/t sinter and mostly depends on the costs of supplying activated carbon and limestone, and the extra energy. Examples of costs are shown in Table 3.22.

**Driving force for implementation**

Sinter plants are the major source for dust and dioxin/furan emissions from integrated steelworks. The driving force for implementation is to meet the prescribed emission limit values for dust, heavy metals and PCDD/F, to lower national emissions to meet the national reduction goals according to national and international regulations, environmental reputation and improved economics compared to the airfine system.
<table>
<thead>
<tr>
<th>Sinter plant</th>
<th>Economic characteristics</th>
<th>Cost (EUR)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>ArcelorMittal Bremen, Germany</td>
<td>Investment costs</td>
<td>EUR 6.5 million in 1992 (EUR 3.6/t sinter in 1992)</td>
<td>Additional carbon injection; Waste gas volume 0.4 million Nm³/h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EUR 16.25/Nm³/h</td>
<td></td>
</tr>
<tr>
<td>Voestalpine Donawitz, Austria</td>
<td>Investment costs</td>
<td>Total EUR 9.3 million in 2002 (= EUR 6/t sinter (2002)). Bag filter EUR 6.5 million (= EUR 4.17/t sinter) (in 2002)</td>
<td>Bag filter after ESP; Waste gas volume 0.32 million Nm³/h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EUR 29/Nm³/h</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Operational costs</td>
<td>1.6 to 1.8 EUR/t sinter in 2008</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Waste disposal</td>
<td>0.5 - 0.7 EUR/t sinter in 2008</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Energy demand</td>
<td>0.4 EUR/t sinter in 2008</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Depreciation costs</td>
<td>0.3 EUR/t sinter in 2008</td>
<td></td>
</tr>
<tr>
<td>ArcelorMittal, Fos sur Mer, France</td>
<td>Investment costs</td>
<td>Total EUR 16 million (= EUR 2.4/t sinter considering the total production: EUR 4.8/t sinter considering the size of the installation = 50 % of the flow) EUR 21/Nm³/h.</td>
<td>The project has three parallel bag houses. Waste gas volume 1.4 million Nm³/h. However, only 50 % of the waste gas is treated by bag filter (700000 Nm³/h)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>All data are from 2005</td>
<td></td>
</tr>
<tr>
<td>ArcelorMittal, Dunkerque, France</td>
<td>Investments costs</td>
<td>Around EUR 40 million EUR 31/Nm³/h</td>
<td>Bag filter after ESP; Sinter plant with a 500 - 600 m² sinter strand: appr. 1.3 million Nm³/h</td>
</tr>
<tr>
<td></td>
<td>Operational costs</td>
<td>About EUR 0.6/t</td>
<td></td>
</tr>
<tr>
<td>ROGESA, Dillingen, Germany</td>
<td>Investment costs</td>
<td>Around EUR 22 million EUR 20/Nm³/h</td>
<td>Bag filter with recirculation injection of lime and activated lignite; Waste gas volume 1.1 million Nm³/h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Data are from 2006</td>
<td></td>
</tr>
</tbody>
</table>

Note: In EU countries disposal of filter dusts from sintering can introduce significant additional costs.

Table 3.22: Examples of the cost of bag filters installed in sinter plants [200] [296] [309] [412] [415] [417]

Example plants
Bag filters have been applied to the sinter process for the dedusting of waste gas from the beginning of the 1990s. In Europe, the number of sinter plants treating the waste gases with bag filters has increased since year 2000 and now include the following:

- ArcelorMittal, Bremen, Germany since 1992
- DK Recycling, Duisburg, Germany
- Voestalpine, Donawitz, Austria. Sinter off-gas cleaning plant in operation since 2002 with a capacity of 400000 Nm³/h
- Voestalpine, Linz, Austria. The MEROS full size installation has been in operation since August 2007 and replaced the airfine system
- ArcelorMittal, Fos, France. Industrial operation since 2006. Sinter production 21000 t/day. Bag filter system equipped with slaked lime as the adsorbent at a capacity of 700000 m³/hr sinter off-gas
- Rogesa, Dillingen, Germany. Sinter off-gas cleaning system with a capacity of 600000 Nm³/h with bag filter downstream to an ESP is in full operation since 2009. The system also injects hydrated lime and activated lignite before the bag filter. For the second sinter strand another plant is commissioned for a capacity of 900000 Nm³/h
- At Corus, Ijmuiden, the Netherlands trials with bag filter will be put through in 2009. Depending on the results one of three sinter strand will be equipped with a full scale bag filter in 2010 and the other two sinter strand will be retrofitted with bag filter in 2013
Tyssen Krupp Stahl, Duisburg, Germany announced to retrofit all three sinter plants with bag filters after the existing ESPs till 2011.

Salzgitter AG, Salzgitter, Germany. A sinter off-gas cleaning system with a capacity of 680000 Nm³/h with bag filter downstream to an ESP is commissioned. The plant is scheduled to go into full operation in March 2010.

In the US at least three sinter plants treat the off-gases from sinter strands in bag filter:

- Inland steel, East Chicago, US.
- Warren Consolidated Industries (WCI), Youngstown Sinter Company, Warren, Ohio, US.
- US Steel, Gary Works, Gary, Indiana, US.

**Reference literature**
[217] [294] [295] [298] [407] [415] [424] [447]
### Chapter 3

<table>
<thead>
<tr>
<th>Unit</th>
<th>ArcelorMittal, Bremen, Germany</th>
<th>Voestalpine, Donawitz, Austria</th>
<th>Voestalpine, Linz, Austria</th>
<th>DK Recycling Duisburg, Germany</th>
<th>ArcelorMittal Fos sur Mer, France</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sinter capacity</td>
<td>t sinter/h</td>
<td>325</td>
<td>n/a</td>
<td>177</td>
<td>59</td>
</tr>
<tr>
<td>Waste gas flow</td>
<td>$1 \times 10^6 \text{Nm}^3/\text{h}$</td>
<td>0.58</td>
<td>0.49</td>
<td>n/a</td>
<td>0.32</td>
</tr>
<tr>
<td>Pre-inst. dedusting</td>
<td>Dry ESP (two fields)</td>
<td>Dry ESP (three fields)</td>
<td>Pre-dedusting by ESP, injection of hydrated lime and lignite coke, bag filter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Particulate matter</td>
<td>mg/Nm$^3$</td>
<td>Approx. 211 - 267</td>
<td>150 - 250</td>
<td>&lt;2</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>mg/Nm$^3$</td>
<td>1 - 6</td>
<td>&lt;3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>&gt;98.5</td>
<td>&gt;98.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Approx. 0.64 - 0.91</td>
<td>Approx. 0.4</td>
<td>&lt;0.05</td>
<td>0.23</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td></td>
<td>ng I-TEQ/Nm$^3$</td>
<td>ng I-TEQ/Nm$^3$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dioxin removal</td>
<td>%</td>
<td>0.07 - 0.11</td>
<td>&lt;0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>90</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HCl removal</td>
<td>mg/Nm$^3$</td>
<td>2.6 - 3.6</td>
<td>Max. 100</td>
<td>&lt;1</td>
<td>&lt;0.4 - 1.4</td>
</tr>
<tr>
<td></td>
<td>mg/Nm$^3$</td>
<td></td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>%</td>
<td></td>
<td>Approx. 90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HF removal</td>
<td>mg/Nm$^3$</td>
<td>0.57 - 0.60</td>
<td>7.4</td>
<td>&lt;0.2</td>
<td>&lt;0.40</td>
</tr>
<tr>
<td></td>
<td>mg/Nm$^3$</td>
<td></td>
<td>&lt;0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>%</td>
<td></td>
<td>Approx. 95</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SO$_2$ removal</td>
<td>mg/Nm$^3$</td>
<td>500</td>
<td>263</td>
<td>399.8</td>
<td>450</td>
</tr>
<tr>
<td></td>
<td>mg/Nm$^3$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1)
<table>
<thead>
<tr>
<th>Heavy metal removal efficiency</th>
<th>Unit</th>
<th>ArcelorMittal, Bremen, Germany</th>
<th>Voestalpine, Donawitz, Austria</th>
<th>Voestalpine, Linz, Austria</th>
<th>DK Recycling Duisburg, Germany</th>
<th>ArcelorMittal Fos sur Mer, France</th>
</tr>
</thead>
<tbody>
<tr>
<td>mg/Nm³</td>
<td></td>
<td>after ESP:</td>
<td>after bag filter:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Al: 0.2</td>
<td>Al: 0.04</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>As: 0.009</td>
<td>As: 0.0003</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cd: 0.076</td>
<td>Cd: 0.001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cr: 0.01</td>
<td>Cr: 0.003</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cu: 0.93</td>
<td>Cu: 0.003</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hg: 0.013</td>
<td>Hg: 0.0013</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ni: 0.01</td>
<td>Ni: 0.006</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pb: 13.4</td>
<td>Pb: 0.02</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Zn: 0.41</td>
<td>Zn: 0.12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cd: &lt;0.002</td>
<td>Ni: &lt;0.002</td>
<td>Pb: &lt;0.002</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ni: &lt;0.002</td>
<td>Pb: &lt;0.002</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pb, Cr, Cu, Mn:</td>
<td></td>
<td>n/a</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt;0.02 - &lt;0.05</td>
<td></td>
<td>n/a</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Additives mg/Nm³
- Slaked lime (Ca(OH)₂): approx. 450
- Lignite coke powder: approx. 100

Waste product kg/t sinter
- Approx. 1
- Recycled to sinter plant

Recycled to sinter plant

Type of fabric
- Nomex, Rastex
- Nomex
- PTFE
- Aramid

Type of cleaning
- Pulse jet
- Pulsed air

Pressure drop mm water column
- 150
- ca. 150
- 170

Investments EUR x 10⁶
- Bag filter: 7.3 (in 1993)
- Additive dosage device: 1.1
- Bag filter: 6.5 (in 2002)
- Total system: 9.3

Total system: 10.5

Operational costs EUR/t sinter
- Energy: 0.11 (in 1996)
- Other: strongly dependent on type and operation time of the bag filter

Other: 0.8 - 1.0

3.32

n/a not available

1) Data for 2008

2) For all examples the currency was converted into Ecu in 1996 and for the review into EUR.

Table 3.23: Operational data and economics of bag filters at sinter plants

[65] [164] [309] [407] [449] [447] [448] [455] [458]
Chapter 3

3.3.2.3 Cyclones

Description
Cyclones are only pre treatment devices, or used as shelter for vulnerable downstream equipment (e.g. for spark separation), but never used as stand alone abatement techniques in the sinter process. Cyclones separate out particulate matter by centrifugal action. As they rely on inertia, cyclones are only efficient abatement devices when the particulate matter is relatively coarse. A multicyclone applies the same principle by means of a parallel series of cyclones, thus obtaining greater efficiency. Cyclones are sometimes used in sinter plants as an intermediate gas cleaning device in order to protect equipment (e.g. ducts and fans) from the abrasive effect of the particulate matter present in the waste gas.

Achieved environmental benefits
For particles >10 μm, a removal efficiency of 90 - 95 % achieved by the use of a multicyclone was reported. However, because of the relatively small size of particulate matter in the sinter plant waste gas, 60 to 80 % removal efficiency is assumed here. Thus, outlet concentrations from sinter plants are between 300 and 600 mg/Nm³, depending on the inlet concentration and the particle size distribution.

Cross-media effects
A slight pressure drop (0.5 kPa) increases the energy consumption of the waste gas suction pumps by approximately 200 kW for a sinter plant with a waste gas flow of 1 MNm³/h and a production of 4 Mt sinter per year. This amounts to 1 MJ/t sinter, or less than 0.1 % of the sinter plant's energy consumption. Furthermore, a solid waste flow is generated, which is fully returned to the sinter process.

Operational data
Operates smoothly under abrasive and moist conditions, reducing particulate matter concentrations at sinter plants with an efficiency of approximately 60 to 80 %, depending on the specific weight of the dust. At Corus, Ijmuiden, the Netherlands an outlet concentration of 300 mg/Nm³ was achieved with a multicyclone.

Applicability
Applicable both at new and at existing plants.

Economics
Investments were estimated to be EUR 500 to 750 per 1000 Nm³/h. For a sinter plant with a waste gas flow of 1 million Nm³/h, this amounted to EUR 0.5 million to 0.75 million. Operational costs depend on the pressure drop and thus the energy costs. A figure of EUR 0.007 to 0.015 per 1000 Nm³ treated was mentioned. For the sinter plant mentioned above, this amounted to EUR 60000 to 127000 per year, corresponding to EUR 0.02 to 0.04/t sinter. For all examples the currency was converted into Ecu in 1996 and for the review into EUR.

Driving force for implementation
No data submitted.

Example plants
Many sinter plants in the world use cyclones as a coarse particulate matter abatement device. For example: Corus, Ijmuiden, the Netherlands; Wakamatsu/Yawata Works, Japan.

Reference literature
[65] [310]
3.3.2.4 Fine wet scrubbers

Description
In a scrubber, the particulate matter in the waste gas is abated by using a liquid. The contaminated liquid is removed from the system and it is usually recycled after treatment. The solid matter retained in sludge also undergoes further treatment.

Traditional scrubbers (e.g. venturi scrubbers, spray column scrubbers) are ineffective when applied to sinter plant waste gases due to the relatively fine sizing of the particulate matter and the high concentration of hydrocarbons. Traditional scrubbers are not applied at sinter plants in Europe.

A high performance scrubber has been in operation in Europe since 1993 (manufactured under the name AIRFINE).

The main components of the gas cleaning system include:

- a cyclone or an electrostatic precipitator (ESP) for the removal of coarse dust all of which can be returned to the sinter strand
- a quenching scrubber for waste gas cooling, removal of coarse dust particles and removal of acid components by means of NaOH addition
- a fine scrubber system for fine dust separation and simultaneous gas cleaning
- a water treatment facility for residue/waste processing.

Figure 3.18: Treatment of the waste gas from the sinter plant [311]
Chapter 3

In the quench operation, water dosed with NaOH is sprayed across the surface of the scrubber. In the fine scrubber system, dual flow nozzles jet water and compressed air as a high pressurised mist into the cooled waste gas stream.

The AIRFINE scrubber allows simultaneous removal of the finest dust particles (including alkali and heavy metal chlorides – see Section 3.2.2.1.2.1) and other noxious components of the waste gas. The latter (e.g. PCDD/F, heavy metals) are mainly associated with the fine dust. Compared with dry abatement techniques, this technique can also remove water-soluble compounds, such as alkali chlorides (see Section 3.2.2.1.2.1) and heavy metal chlorides (see Section 3.2.2.1.2.2). When alkalines such as NaOH are added to the scrubbing water, significant removal of acidic components like HF, HCl and SO2 can be achieved. Consequently, the aqueous solution containing alkali and heavy metal salts is treated by precipitation/flocculation.

At Corus, Ijmuiden, the Netherlands the solids were being returned to the sinter plant until 2008. From 2008, the solids are being disposed of in a secured landfill. The overflow is neutralised and passed through several gravel beds before being discharged.

Achieved environmental benefits

Operational data for European sinter plants using wet scrubbers are in the range of 40 to 80 mg/Nm³ expressed as annual averages. Depending on the condition of the unit, dust emission levels lower than this can be achieved on an instantaneous basis. Table 3.24 presents actual operational performance data expressed on an annual average basis for the system at Corus, Ijmuiden, the Netherlands.

<table>
<thead>
<tr>
<th>Component</th>
<th>Corus, Ijmuiden, the Netherlands</th>
<th>Emissions concentrations (mg/Nm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM</td>
<td>32.3</td>
<td></td>
</tr>
<tr>
<td>As</td>
<td>0.0003</td>
<td></td>
</tr>
<tr>
<td>Cd</td>
<td>0.09</td>
<td></td>
</tr>
<tr>
<td>Co</td>
<td>0.025</td>
<td></td>
</tr>
<tr>
<td>Cr</td>
<td>0.032</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>0.0156</td>
<td></td>
</tr>
<tr>
<td>Cu</td>
<td>0.0065</td>
<td></td>
</tr>
<tr>
<td>Hg</td>
<td>3.75</td>
<td></td>
</tr>
<tr>
<td>Ni</td>
<td>0.64</td>
<td></td>
</tr>
<tr>
<td>Pb</td>
<td>0.48</td>
<td></td>
</tr>
<tr>
<td>Sb</td>
<td>0.27</td>
<td></td>
</tr>
<tr>
<td>Se</td>
<td>170</td>
<td></td>
</tr>
<tr>
<td>Tl</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Zn</td>
<td>0.18 ng I-TEQ/Nm³</td>
<td></td>
</tr>
<tr>
<td>HCl</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SO₂</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOₓ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VOC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PAH (EPA 16)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCDD/F</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1) These emission data corresponds to an installation where the solids from the waste gas treatment are returned to the sinter feed.
2) This figure is lower than the range in the text because it is for the Airline scrubber alone. The figure in the text above the table refers to the total operation of the sinter plant (when the Airline scrubber is operated for 95 % of the time). All measurements are continuously monitored.

Table 3.24: Achieved air emission parameters at Corus, Ijmuiden, the Netherlands [200] [311] [409]
The technique is also efficient at removing PCDD/F. Under normal operating conditions, 0.4 ng I-TEQ/Nm³ is guaranteed, 0.18 ng I-TEQ/Nm³ are achievable, corresponding to approximately 95 % efficiency for an inlet of 8 ng I-TEQ/Nm³. This technique is able to reduce the emissions of organic pollutants such as PCDD/F because of the efficient removal of fine dust (at the temperatures of operation, dioxin-like compounds are condensed onto the particulate matter).

No additives (activated carbon) are included to achieve this value. Furthermore, 80 to 95 % of HCl and HF are removed. SO₂ emissions can be removed with high efficiency if a facility with an injection of additives is installed (see Section 3.3.2.7.2). Heavy metal concentrations are also reduced efficiently (>90 %) as a result of their water solubility. Non-polar pollutants such as PAH are also reduced because of the efficient removal of fine dust.

**Cross-media effects**

At Corus Ijmuiden the solids were being returned to the sinter plant until 2008. From 2008, the solids are being disposed of in a secure landfill.

Lead salts in the waste gas have a negative effect on the performance of wet scrubbers (especially at the fine scrubber part). This is typically avoided by maintenance procedures. At Corus, Ijmuiden, the Netherlands the flow of cooling water is 800 m³/h and of waste water 50 m³/h. This contaminated waste water flow must be treated.

The waste water emissions concentrations and emissions factors achieved by a fine scrubber and a dust prefilter and after treatment (precipitation/flocculation) at Corus, Ijmuiden, the Netherlands are given in Table 3.25 (for data from 2007 see Table 6.23).

<table>
<thead>
<tr>
<th>Corus, Ijmuiden</th>
<th>Component</th>
<th>Concentration (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treated waste water flow</td>
<td>50 m³/h</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>9 - 12</td>
<td></td>
</tr>
<tr>
<td>Suspended solids</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>As</td>
<td>0.002 - 0.005</td>
<td></td>
</tr>
<tr>
<td>Cd</td>
<td>0.005 - 0.01</td>
<td></td>
</tr>
<tr>
<td>Cr</td>
<td>0.02 - 0.05</td>
<td></td>
</tr>
<tr>
<td>Cu</td>
<td>0.05 - 0.1</td>
<td></td>
</tr>
<tr>
<td>Hg</td>
<td>0.0001 - 0.0002</td>
<td></td>
</tr>
<tr>
<td>Ni</td>
<td>0.05 - 0.1</td>
<td></td>
</tr>
<tr>
<td>Pb</td>
<td>0.2 - 0.5</td>
<td></td>
</tr>
<tr>
<td>Zn</td>
<td>0.05 - 0.1</td>
<td></td>
</tr>
<tr>
<td>COD</td>
<td>250 - 350</td>
<td></td>
</tr>
<tr>
<td>Total Kjeldahl nitrogen (TKN)</td>
<td>250 - 350</td>
<td></td>
</tr>
</tbody>
</table>

Table 3.25: Achieved emissions concentrations and emissions factors of the treated waste water from waste gas scrubbing and ESP dust filter extraction at Corus, Ijmuiden, the Netherlands in 2004

Data from 2004

1) Annual average

The waste water gets further treated in a biological treatment plant (see Table 6.24, Figure 6.21 and Figure 6.22).

**Operational data**

The actual removal efficiency is related to the energy input (compressed air for atomisation) and the operating efficiency of the quench part.
At the sinter plant of Corus, Ijmuiden, the Netherlands emissions reductions are achieved with the installed high pressure wet scrubber. For instance, emissions of PCDD/F and dust are reduced by approximately 95%, and SO₂ emissions by approximately 85%.

However, due to maintenance, disturbances and start-up/shut-off periods, the scrubbing system was in bypass operation for approximately 500 hours per year. An analysis showed that approximately 50% of this period was as a consequence of maintenance operations, and 50% was due to process disturbances. The emissions from bypass operations therefore are a significant part of the installations yearly emissions (for dust approximately 50%, for SO₂ approximately 15%).

Techniques and ways to reduce bypass operation are:

- it was agreed in the permit of Corus IJmuiden that bypass operation could only be allowed:
  - in case of technically unavoidable stoppages, disturbances, or failures of the high pressure scrubbing system.
  - during 4 hours per start-up/shut-off period. After elapsing of this period sinter strand operation should be stopped.
  - during maintenance of the dual flow nozzles of the high pressure scrubbing system. The nozzles, installed for correct distribution of water and compressed air, are clogged up with lead sulphate. Eventually this clogging process will have an adverse effect on the efficiency of the installation and therefore the nozzles need to be rinsed. It was agreed that the maintenance period for the rinsing process needed to be limited to 32 hours on a yearly basis.

The installation owner has to monitor and register the time, the reason and the duration when bypass operation is performed.

- when the emissions still remain significant one has to consider to install a back-up gas cleaning system.

It is difficult or impossible to predict exactly how much reduction per year is achieved. However, a reduction of the total bypass operation time of 200 h has been estimated which may achieve an emissions reduction of approximately 30 t/yr of dust and 125 t/yr of SO₂, as well as significant amounts of PCDD/F and HF relative to the steel plants total yearly emissions.

**Applicability**

Applicable to both new and existing plants. However, it should be noted that the applicability is site-specific. Residual cleaned waste water has to be extracted out of the water treatment units. Therefore, application of these systems is often dependent on the handling of the residual waste water and subsequently on the location of the sinter plant.
Economics
In Corus, Ijmuiden, the Netherlands the investments and infrastructure costs were approx. EUR 40 million in 1997. The plant has been operational since May 1998 and the waste gas from three sinter strands totalling 630000 Nm$^3$/h has been treated since then. For this examples the currency was converted into Ecu in 1997 and for the review into EUR.

Actual costs will differ widely depending upon the plant and the local requirements for waste water treatment services.

Driving force for implementation
No data submitted.

Example plants
In Europe the airfine scrubber technique was applied at two plants: Voestalpine, Linz, AT, start up in 1993 and at Corus, Ijmuiden, the Netherlands start up in 1998. The airfine scrubber at Voestalpine, Linz, Austria was replaced by a bag filter in August 2007. At Corus Ijmuiden trials with bag filter will be put through in 2009. Depending on the results one of three sinter strand will be equipped with a full scale bag filter in 2010 and the other two sinter strand will be retrofitted with bag filter in 2013. A third unit is operated at BHP, Whyalla, Australia on a pelletisation plant.

Reference literature
[45] [295] [311] [409] [410] [412]

3.3.2.5 Reduction of VOC emissions
3.3.2.5.1 Lowering the content of volatile hydrocarbons in the sinter feed

Description
The input of hydrocarbons can be minimised, especially by the reduction of the oil input. Oil enters the sinter feed mainly by addition of mill scale. The oil content of mill scales can vary significantly, depending on their origin. Sometimes, oil content of up to 10% is found but these are not normally used in sinter plants without prior treatment.

Most of the oil hydrocarbons volatilise from the sinter mixture at temperatures in the 100 to 800 °C range and are emitted from the sinter plant via the waste gas.

Several techniques can be applied to minimise oil input via dusts and mill scale:

1. limiting input of oil by segregating and then selecting only those dusts and mill scale with low oil content
2. the use of ‘good housekeeping’ techniques in the rolling mills can result in a substantial reduction in the contaminant oil content of mill scale
3. de-oiling of mill scale by:
   a) heating the mill scale to approximately 800 °C, the oil hydrocarbons are volatilised and clean mill scale is yielded. The volatilised hydrocarbons can be combusted
   b) extracting oil from the mill scale using a solvent

The use of anthracite as a fuel should be avoided.

Achieved environmental benefits
Non-methane volatile organic compounds (NMVOC) of <20 mg/Nm$^3$ can be achieved (expressed as an annual average). The emissions can be significantly higher if precautionary measures are not taken to reduce the oil content of the sinter feed materials or as a result of the fuel that is used. These higher emissions levels are for plants operating ESP alone as their main end-of-pipe abatement system.
Cross-media effects
When some of the residues/wastes containing iron are rejected as suitable sinter plant feedstock, they are either processed in another way or enter the waste stream and are disposed of. Thus, emissions may, in effect, be transferred to another site.

Whenever mill scale is de-oiled, energy is consumed as it is heated. The volatilised hydrocarbons should be combusted properly (rule of thumb: temperatures >850 °C for >2 seconds at >6 % O₂).

Operational data
Low oil content is preferred in dusts and mill scale residues used at the sinter plant for several reasons; for example, avoidance of fires and scaling in the ESP or blinding in the bag filter. High oil content also could give rise to a higher potential for the formation of PCDD/F (see Section 3.2.2.1.2.8). Lower oil contents typically lead to lower VOC emissions.

Applicability
Can be applied both at new and existing plants.

Economics
No data available regarding de-oiling.

Driving force for implementation
No data submitted.

Example plants
Many plants regulate oil input in the sinter plant via the wastes containing iron, especially those with an ESP or with a bag filter.

A number of plants for de-oiling of mill scales were operated on a trial basis in the late 90s in Germany but these have all ceased to operate. Thus, treatment techniques (3a and 3b above in Description section) are not used commercially in the EU steel industry at present.

Reference literature
[45] [145] [65] [242] [303] [387]

3.3.2.5.2 Top layer sintering

Description
In Section 3.3.4 the recycling of materials containing iron back into the sinter strand is described. With respect to recycled materials containing hydrocarbons, especially oil, in Section 3.2.5.1 techniques are described to lower the oil/hydrocarbon input. There is another possibility to recycle such materials with varying oil contents of up to 3 %. It is called top layer sintering and is claimed to be much cheaper compared to de-oiling techniques. Top layer sintering means that a certain mixture of by-products/residues containing oil/hydrocarbons conditioned to approximately 7 % water content and then deposited with a feeding drum on the main sinter layer. A second ignition hood with an energy output of 25 to 35 % of the energy output of the main burner is used to ignite this second layer. For achieving a high sinter quality from the second sinter layer of by-products/residues containing oil, it is important that a balanced selection of energy carriers is present within this layer in order to satisfy the enthalpy requirements for water and oil evaporation, for the cracking of the inherent organic components as well as for the complete sintering of this layer. In addition to this careful proportion of the sinter feed components, the exact positioning and timing of ignition of the second sintering layer is of critical importance.
Chapter 3

Achieved environmental benefit
The combustion of hydrocarbons (mainly deriving from the oil content of recycled materials) within the sinter layers is optimised in order to protect the ESP (prevention of fires) and to avoid blue haze (which represents incomplete combusted organic compounds). In addition, the emissions of PCDD/F can be reduced; pot grate tests showed a reduction of 60 - 65% but data from sinter strands are not available.

Cross-media effects
Additional fuel for the ignition of the second layer has to be provided.

Operational data
The sinter strand of Voest-Alpine Stahl Donawitz GmbH, Austria has a suction area of 120 m² and a productivity of 35 t/m²/24 h. The productivity did not change after the introduction of top layer sintering in January 1995. The capacity for recycling production residues containing iron is 18 t/h.

Applicability
Limited applicability to existing plants because of missing space for additional storage facilities and for a second feed system as well. New plants would normally go for techniques minimising the hydrocarbon/oil input of the recycled by-products/residues. Flexibility in the selection of raw materials is very limited.

Economics
No data submitted.

Driving force for implementation
No data submitted.

Example plants
In Europe this technique is installed at the sinter plant of Voestalpine, Donawitz, Austria but is currently not used.

Reference literature
[159]

3.3.2.6 Reduction of PCDD/F

3.3.2.6.1 Suppression of PCDD/F formation by addition of nitrogen compounds in the sinter mix or the flue-gas

Description
a) Formation of PCDD/F can be suppressed by the addition of substances which have an inhibiting effect on the formation of PCDD/F assuming that the formation of such substances takes place mainly in the sinter itself. In this case, an effective method for reducing PCDD/F is to add ammonia to the solid sinter mix in order to inhibit catalytic reactions on the surfaces involved. For this reason, urea prills have been added to the sinter feed upstream of the mixer and/or pelletiser. The urea prills are thereby homogeneously distributed throughout the raw sinter mixture prior to feeding it onto the strand.

b) Assuming that a considerable part of the PCDD/F are formed by 'de novo' synthesis in the windboxes downstream of the sinter strand, nitrogen compounds such as triethanolamine (TEA) or monoethanolamine (MEA) are added to the flue-gas to inhibit the formation of PCDD/F. The amines can be dissolved in water and sprayed by nozzles placed in the windboxes.
Chapter 3

Achieved environmental benefits
a) At the Corus Sinter Plant, Port Talbot, United Kingdom, the achieved PCDD/F performance using urea addition was approximately 1 ng TE-I-TEQ/m³ at 17 % residual oxygen. Typically, the dioxin emission concentration is reduced by 40 - 60 % at sinter plants using electrostatic precipitators alone as the end-of-pipe abatement system. There may also be a reduction in emissions of SO₂. The use of urea also minimise hydrogen chloride and hydrogen fluoride emissions.

b) The injection of MEA into the sintering fumes at Sidmar (2 - 4 % of the flying dust) has not reduced the pollutant emissions: the dust and micropollutant emissions actually increased, due to a combination of several factors:

- MEA accumulation due to to ESP dust recycling into the sinter mix, resulting in active coal saturation
- formation of ammonium salts
- sticky dust (less favourable conditions for ESP dust removal during rapping of the collection plates)
- low reactivity of MEA towards micropollutants at around 150 °C.

As far as the researchers know (based on their own long experience and on a review of the available literature), there is not any credible proof of any beneficial effect of MEA on emissions from the sinter plant. The positive results obtained with MEA by Centre de recherches Metallurgiques (CRM) at Sidmar during the period between 1999 and 2001 were only preliminary results obtained over very short periods of time (spot tests) which have never been confirmed on a full scale for a longer period. The laboratory tests carried out at the University of Liège by Xhoue C. do effectively show that one can expect some PCDD/F reduction when subjecting PCDD/F containing dust to high temperatures (325 - 400 °C) for several hours, but it is difficult to know if such an approach could be applied to the sinter plant.

Cross-media effects
a) Urea addition has some distinct disadvantages:

- the exhaust plume from the sinter plant tends to become highly visible, leading to complaints from the public
- the use of urea leads to significant releases of ammonia
- the dust and micropollutant emissions actually increased, owing to a combination of several factors mentioned above.

b) During the trials, most of the MEA was adsorbed on flying dust, abated together with the dust by the ESP and finally recycled into the sinter mix. For this reason, it is possible to assume that the same thing would have happened had MEA been added directly to the sinter mix.

Operational data
a) 40 kg urea/h were added which equates to 0.12 kg/t of graded sinter.

The handling and dispensing of the urea prills can present some problems specific to the material (it is hydroscopic in nature).

b) To achieve the aforementioned inhibition rates for a sinter plant with a production of 230 tonnes sinter per hour 46 kg MEA/h are needed. This equates to 0.2 kg/t of graded sinter.

Applicability
The technique can be applied to existing plants and could be equally incorporated into the designs for a new plant.
Economics
a) There is a relatively low investment cost and low operating costs to applying this technique. The investment cost for a 4 million tonnes/yr sinter plant is approximately EUR 700000 (brick shelter, humidity-controlled storage silo, dosing and control equipment). The operating costs are about EUR 0.08 to 0.14/t of sinter (as per 2004 prices in the UK at 1GBP = EUR 1.44).

An alternative, simpler system has also been installed for a similarly sized plant at a cost of about EUR 145000 and the operational costs here are expected to be about EUR 0.05 to 0.07/t of sinter (as per 2007 prices in the UK at 1GBP = EUR 1.45).

b) An estimation was made that for a full application of the MEA inhibition process to a sinter plant with 230 tonnes sinter per hour the costs for the reagents are EUR 1.49/t sinter and the investment costs are about EUR 0.008/t sinter which equates to a total cost of EUR 0.157 tonnes sinter.

Driving force for implementation
Driving force for implementation of this technique is the reduction of dioxin emissions.

Example plants
Preliminary trials with a temporary dosing system at the former Corus Sinter Plant, Llanwern B, United Kingdom in 1996 - 98 led to a patent application in 1998. Transferability of the technology was demonstrated by further trials at the Corus Sinter Plant, Scunthorpe, United Kingdom in the period 2000 - 2001. A continuous dosing system was installed at Corus Sinter Plant, Port Talbot, United Kingdom from 2003 - 2004 for longer-term continuous dosing trials. The technique will be installed on a permanent basis at both Corus sinter plants, Scunthorpe and Corus, Teesside, United Kingdom in 2007. In addition, tests were carried out from 1999 - 2001 in Sidmar, Gent, Belgium.

Reference literature
[230] [231] [240] [265] [306] [471]

3.3.2.7 Reduction of SO\textsubscript{2}

3.3.2.7.1 Primary measures for reduced SO\textsubscript{2} emissions from the sinter process

Description
The SO\textsubscript{2} emissions from sintering can be reduced in four ways:

- the use of raw materials with low sulphur content
- minimising the fuel consumption, mainly coke breeze
- increasing the sulphur uptake in the sinter
- the use of coarser coke breeze.

Sulphur compounds mainly enter the sintering process with the coke breeze and to a lesser extent amount with the ores. The SO\textsubscript{2} emissions can be reduced by using raw materials with a low sulphur content. A sulphur content of ≤0.8 % S in coke breeze and ≤0.08 % S in iron ores can be regarded as low and will directly correlate with lower SO\textsubscript{2} emissions.

The specific coke breeze consumption has been reduced over the past 30 years by approximately 50 % at EU sinter plants down to a current consumption of 44 - 64 kg/t sinter.

Another important factor is the degree of sulphur uptake in the sinter. The sulphur remains partly in the sinter product (in the order of 13 - 25 %) depending on the sinter basicity. Also the use of coarser coke breeze can reduce SO\textsubscript{2} emissions considerably (see Section 3.2.2.1.2.4).
Achieved environmental benefits
Emission concentrations of 500 mg SO$_2$/Nm$^3$ can be achieved on an average daily basis.

Cross-media effects
The retention of additional sulphur in the sinter could have an adverse effect on the operation of the blast furnace when a low-sulphur iron is required.

Operational data
No specific problems are known. The plants operate smoothly.

Applicability
Minimising sulphur inputs into the sinter feed (use of low sulphur coke breeze and iron ore and minimising specific coke breeze consumption) can be applied both at new and existing plants. However, it should be noted that the availability of low-sulphur breeze and ore might be a constraint.

Economics
No data submitted.

Driving force for implementation
No data submitted.

Example plants
Sinter plants of ArcelorMittal, Gent; Corus sinter plants, United Kingdom and Thyssen Krupp Stahl, Duisburg, Germany. Examples outside the EU also exist.

Reference literature
[7] [304]

3.3.2.7.2 Wet desulphurisation

Description
There are wet and dry desulphurisation processes but only a wet system is considered here. After waste gases are cooled SO$_2$ is absorbed in a spray tower with a solution containing calcium (Ca) or magnesium (Mg). This forms gypsum (CaSO$_4$) or magnesium sulphate (MgSO$_4$), which is removed from the column as a slurry. Several reaction agents may be used:

- steel slag (steel slag desulphurisation (SSD) process). Steel slag, which contains 30 - 40% CaO is pulverised, mixed with water and added as a slurry which contains Ca(OH)$_2$.
- slaked lime (Ca(OH)$_2$)
- calcium chloride (CaCl$_2$) and slaked lime (Ca(OH)$_2$)
- slaked lime (Ca(OH)$_2$) and chalk (CaCO$_3$)
- magnesium hydroxide (Mg(OH)$_2$).

The gypsum is dewatered. Its quality strongly depends on the efficiency of the pre-installed particulate matter abatement device. In some countries, this gypsum can be sold to the cement manufacturing industry.

Water is separated from the gypsum slurry and most of it is recirculated. Because of chloride build-up, there will be a scrubbing water bleed. Thus, both a solid (gypsum) and waste water are generated.
When ammoniumhydroxide (NH$_4$OH) is used as a reaction agent, an Ammoniumhydrogensulfite (NH$_4$HSO$_3$) solution is generated. This solution is processed by wet oxidation in the gas treatment plant of the coke oven producing ammoniumsulphate ((NH$_4$)$_2$SO$_4$).

Wet desulphurisation can be also achieved with fine scrubber systems (see Section 3.3.2.4).

Activated lignite can also be injected into the flue-gas for PCDD/F adsorption. After this reaction the activated lignite is separated by a bag filter.

**Achieved environmental benefits**

Desulphurisation efficiencies of 85 - 90 % can be achieved, although efficiencies of 95 - 99 % have been reported. With these performance values, less than 200 mg/Nm$^3$ of SOX have been reported for input values below 1.5 g/Nm$^3$. Furthermore, HCl, HF and particulate matter are scrubbed from the waste gas. The system does not remove NOX.

**Cross-media effects**

A slurry that contains gypsum is generated. The disposal of the gypsum can create considerable problems. In countries where there is no market for gypsum, the dewatered material has to be disposed of as an active waste, requiring further stabilisation before dumping and thereby generating higher disposal costs. Even where there is a market for gypsum, the contamination of the product with particulate matter makes it less attractive and it may have to be disposed of. Furthermore, additional waste water treatment is necessary when the unit removes particulate matter simultaneously.

In one case, the gypsum is separated in a contaminated part (10 %), which is disposed of, and a "clean" part (90 %), which is sold. This system is no longer in operation.

Most of the scrubbing water can be recirculated, especially when a particulate matter abatement device is used prior to the desulphurisation unit. A bleed is usually needed to avoid the build up of chloride. Bleeds in the range of 5 to 20 m$^3$/h are reported. However, in some cases no bleed occurs, and water is supplemented.

Electricity consumption is estimated at 6.1 - 7.2 MJ/t sinter. Furthermore, the cleaned waste gas has to be reheated before being emitted in order to achieve a sufficient plume rise. In some cases, coke oven gas is used for this purpose and sometimes the CO present in the sinter plant waste gas is catalytically combusted.

Slaked lime consumption depends on the SO$_2$ inlet concentration, the amount of waste gas treated and the desired efficiency. Reported consumption is 3 - 4 kg slaked lime (Ca(OH)$_2$) per m$^3$ SO$_2$ at Wakamatsu Works, NSC, Japan.

**Operational data**

Table 3.29 gives an overview of operational and economic data from five desulphurisation units. All these units have been installed to meet environmental regulations set by the local authorities. No specific operational difficulties have been mentioned.

**Applicability**

Can be applied both at new and existing plants although the requirements of space may be of significance.

**Economics**

The desulphurisation efficiency figures quoted in the Table 3.29 do not take plant downtime into account and so reflect a 24 hour-a-day operation; thus, in practice, the overall efficiency figures would be considerably lower. As noted above, the sale of the resulting gypsum may not be possible in some European countries, thus leaving a disposal problem.
The following costs for wet desulphurisation equipment were reported:
For these examples the currency was converted into Ecu in 1996 and for the review into EUR.

- investments: EUR 50 - 80/(Nm³/h)
- operational: EUR 0.5 - 1.0 per kg SO₂ removed.

For a sinter plant with a capacity of 4 Mt/yr, with a waste gas flow of 1 MNm³/h, 8640 operational hours per year, with untreated SO₂ emissions of 1200 g/t sinter and 90 % desulphurisation efficiency, this would correspond to the following costs:

- investment: EUR 50 - 80 million
- operational: EUR 0.5 - 1.1/t sinter.

Because the investments are relatively high (greater than the cost of a new sinter plant) and depend strongly on the waste gas flow, it may be beneficial to restrict desulphurisation to the waste gas sections with the highest sulphur concentration (see Figure 3.7) and concentrate efforts on lowering the sulphur input to the process (see Section 3.3.2.7.1).

The following Table 3.27 shows the total investment and operational costs for a wet desulphurisation system with simultaneous NOₓ reduction for two different cases. It is a qualitative comparison between dry and wet desulphurisation processes for sinter plants only (see Table 3.33).

<table>
<thead>
<tr>
<th>Abatement efficiency required</th>
<th>De-SO₂: 95 %</th>
<th>De-SO₂: 95 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>De-NOₓ: 40 %</td>
<td>De-NOₓ: 80 %</td>
<td></td>
</tr>
<tr>
<td>Initial cost:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• main facility</td>
<td>110 ¹)</td>
<td>147</td>
</tr>
<tr>
<td>• water treatment plant</td>
<td>85.4</td>
<td>122.6</td>
</tr>
<tr>
<td>• others (piping, electricity and instruments, civil facility, engineering)</td>
<td>7.3</td>
<td>5.9</td>
</tr>
<tr>
<td>• others (piping, electricity and instruments, civil facility, engineering)</td>
<td>17.3</td>
<td>18.5</td>
</tr>
<tr>
<td>Running cost ($476 h/yr):</td>
<td>154.4</td>
<td>197.5</td>
</tr>
<tr>
<td>• electrical power</td>
<td>51.0</td>
<td>56.8</td>
</tr>
<tr>
<td>• coke oven gas</td>
<td>54.5</td>
<td>77.6</td>
</tr>
<tr>
<td>• Mg(OH)₂</td>
<td>29.9</td>
<td>29.9</td>
</tr>
<tr>
<td>• others (Catalyst, NH₃, chemicals for WWTP, Utilities, Steam)</td>
<td>19.0</td>
<td>33.2</td>
</tr>
</tbody>
</table>

Notes: Gas flow rate 1.5 million Nm³/h; gas temperature 120 °C; SO₂ input 140 ppm; NOₓ input 170 ppm.
¹) Total cost of wet system in case 1 is 110 % (this value is referenced to the 100 % shown in Table 3.33 of Section 3.3.2.8.3).

Table 3.27: Cost estimation of wet process together with an SCR system [268]

Driving force for implementation
No data submitted.

Example plants
In Table 3.28 a number of sinter plants, which apply wet desulphurisation, is given
<table>
<thead>
<tr>
<th>Company</th>
<th>Works</th>
<th>Plant no.</th>
<th>Amount of gas treated (design) (1 x10^6 Nm³/h)</th>
<th>Reaction agent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nippon Kokan KK,</td>
<td>Fukuyama Keihin</td>
<td></td>
<td>0.76</td>
<td>Ammonium-hydroxide</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.2 - 1.3</td>
<td></td>
</tr>
<tr>
<td>Kawasaki Steel Corporation,</td>
<td>Chiba Chiba Mizushima</td>
<td>Sinter plant no.4</td>
<td>0.62 - 0.75</td>
<td>Slaked lime</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sinter plant no.3</td>
<td>0.32</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Three sinter plants</td>
<td>0.75; 0.75; 0.9</td>
<td></td>
</tr>
<tr>
<td>Kobe Steel Ltd.</td>
<td>Kakogawa Kobe</td>
<td></td>
<td>1</td>
<td>CAL*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.35</td>
<td></td>
</tr>
<tr>
<td>Sumitomo Metal Industries</td>
<td>Wakayama Kashima Kokura</td>
<td>Sinter plant no.5</td>
<td>0.4</td>
<td>Slaked lime and chalk</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Two sinter plants</td>
<td>0.88; 0.2</td>
<td>Slaked lime and chalk</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.32</td>
<td>Magnesium hydroxide</td>
</tr>
</tbody>
</table>

*CAL: Calcium chloride and slaked lime

Note: In one plant the technique was under operation in the EU until the plant was closed. The reason for this is that the technique was succeeded by a process-integrated measure preventing cross-media effects as waste water and solid waste.

Table 3.28: Wet desulphurisation units at sinter plants
[65] [313]

Reference literature
[65] [268] [295] [313] [412] [413]
<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>Nippon Kokan KK-Keihin</th>
<th>Nippon Steel Corp. Wakamatsu/Yawata</th>
<th>Sumitomo Metal Ind.Wakayama</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sinter production</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• design</td>
<td>t/h</td>
<td>500</td>
<td>1000</td>
<td>185</td>
</tr>
<tr>
<td>• actual</td>
<td>n/a</td>
<td>600</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>Total waste gas flow</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• design</td>
<td>10^6 Nm^3/h</td>
<td>1.2 - 1.3</td>
<td>2</td>
<td>n/a</td>
</tr>
<tr>
<td>• actual</td>
<td>n/a</td>
<td>1</td>
<td>1</td>
<td>0.4</td>
</tr>
<tr>
<td>Sinter basicity</td>
<td></td>
<td></td>
<td>1.8</td>
<td>1.92</td>
</tr>
<tr>
<td>Desulphurisation capacity</td>
<td></td>
<td></td>
<td>1.8</td>
<td>2.2</td>
</tr>
<tr>
<td>• design</td>
<td>10^6 Nm^3/h</td>
<td>1.2 - 1.3</td>
<td>1 (partial deSO_2)</td>
<td>n/a (partial deSO_2)</td>
</tr>
<tr>
<td>• actual</td>
<td>n/a</td>
<td>0.45 - 0.51 (partial deSO_2)</td>
<td>n/a (partial deSO_2)</td>
<td></td>
</tr>
<tr>
<td>Pre-installed dedusting</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• type</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• clean gas</td>
<td>n/a</td>
<td>dry ESP</td>
<td>cyclone</td>
<td>dry ESP</td>
</tr>
<tr>
<td>Reaction agent</td>
<td></td>
<td></td>
<td>NH_4OH</td>
<td>slaked lime</td>
</tr>
<tr>
<td>SO_2 inlet concentration</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• design</td>
<td>mg/Nm^3</td>
<td>n/a</td>
<td>1140</td>
<td>1830</td>
</tr>
<tr>
<td>• actual</td>
<td>560 - 840</td>
<td>513 - 684</td>
<td></td>
<td>730 - 940</td>
</tr>
<tr>
<td>SO_2 outlet concentration</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• design</td>
<td>mg/Nm^3</td>
<td>n/a</td>
<td>&lt;110</td>
<td>370</td>
</tr>
<tr>
<td>• actual</td>
<td>3 - 9</td>
<td>6 - 29</td>
<td></td>
<td>n/a</td>
</tr>
<tr>
<td>Desulphurisation efficiency</td>
<td></td>
<td>%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• design</td>
<td></td>
<td>n/a</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>• actual</td>
<td>&gt;99</td>
<td>95 - 98</td>
<td></td>
<td></td>
</tr>
<tr>
<td>By-product</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• type</td>
<td>kg/t sinter</td>
<td>ammonium sulphate</td>
<td>gypsum</td>
<td>gypsum</td>
</tr>
<tr>
<td>• amount</td>
<td></td>
<td>n/a</td>
<td>1.0 - 1.34</td>
<td>4.5</td>
</tr>
<tr>
<td>• processing</td>
<td></td>
<td>sold</td>
<td>Sold</td>
<td>mainly disposed of</td>
</tr>
<tr>
<td>Energy demand</td>
<td></td>
<td></td>
<td></td>
<td>n/a</td>
</tr>
<tr>
<td>• design</td>
<td>GJ/t sinter</td>
<td>n/a</td>
<td>0.0061 - 0.0072 (electricity)</td>
<td>n/a</td>
</tr>
<tr>
<td>• actual</td>
<td></td>
<td>&lt;0.3 % of tot. energy cons.)</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>Investment</td>
<td></td>
<td>EUR 10^6</td>
<td>n/a</td>
<td>19.4 (in 1976)</td>
</tr>
<tr>
<td>Operational costs</td>
<td></td>
<td>EUR/t sinter</td>
<td>n/a</td>
<td>0.62 (in 1986);</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>without maintenance</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>without depreciation</td>
</tr>
</tbody>
</table>

n/a not available

1) For the example the currency was converted into Ecu in 1996 and for the review into EUR.

Table 3.29: Operational data and economics of sinter plant wet desulphurisation units [65]
3.3.2.8 Reduction of NO\textsubscript{X}

3.3.2.8.1 Primary measures for reduced NO\textsubscript{X} emissions

Use of anthracite may decrease NO\textsubscript{X} emissions taking away the temperature peaks. Low-NO\textsubscript{X} burners can be used for ignition.

3.3.2.8.2 Selective catalytic reduction (SCR)

Description
In this process, NO\textsubscript{X} in the waste gas is catalytically reduced by ammonia (NH\textsubscript{3}) or urea to N\textsubscript{2} and H\textsubscript{2}O. Vanadium pentoxide (V\textsubscript{2}O\textsubscript{5}) or tungsten oxide (WO\textsubscript{3}) on a titanium oxide (TiO\textsubscript{2}) carrier are often used as a catalyst. Other possible catalysts are iron oxide and platinum. Optimal operating temperatures range from 300 to 400 °C.

SCR can be applied as a high dust system, a low dust system and as a clean-gas system; each with its own characteristics. Until now, only clean gas systems have been applied at sinter plants.

Special attention should be paid to the deactivation of the catalyst, the accumulation of explosive ammonium nitrate (NH\textsubscript{4}NO\textsubscript{3}), ammonia slip, and the formation of corrosive SO\textsubscript{3}. Usually, the off-gases have to be reheated before entering the SCR device in order to achieve the required operational temperature.

Achieved environmental benefits
A NO\textsubscript{X} reduction efficiency of about 80 % has been achieved at sinter plants, depending on the catalyst type used, operating temperature and NH\textsubscript{3} addition. Outlet concentration values of between 56 - 108 mg/Nm\textsuperscript{3} (reference O\textsubscript{2}: 15 %) have been reported (input values are between 180 - 600 mg/Nm\textsuperscript{3}). Table 3.30 shows performances achieved during experiments that were carried out at a sinter pilot plant in a co-ordinated research project involving Corus UK Limited, BFI, CENIM and ACERALIA as the main partners.

<table>
<thead>
<tr>
<th>Type of SCR catalyst</th>
<th>NO\textsubscript{X} reduction performance</th>
<th>Temperatures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Packed bed of extruded cylinders</td>
<td>&gt;90 %</td>
<td>above 220 °C</td>
</tr>
<tr>
<td>Monolithic (honeycomb)</td>
<td>&gt;90 %</td>
<td>230 - 250 °C</td>
</tr>
</tbody>
</table>

Table 3.30: Performance of SCRs in a pilot sinter plant [387]

Cross-media effects
Because SCR is a dry technique, there are no emissions to water. The only waste generated is deactivated catalyst, which can be reprocessed by the manufacturer. This technique implies the storage and use of ammonia, but not necessarily as liquid ammonia; urea or ammonia solutions may also be used.

Overall energy consumption increases as the off-gases have to be reheated before coming into contact with the catalyst. This reduces the possibilities for recovery of sensible heat from the sinter process. Furthermore, the SCR device consumes electrical energy.

The use of SCR shows N\textsubscript{2}O emissions lower than 8 ppm. NH\textsubscript{3} slip is reported at two sinter plants to be between <1 - 3 ppm.
Chapter 3

Operational data

1. Sinter Plant, Kawasaki Steel Corporation, Chiba Works, Japan
An SCR was installed at the Kawasaki Steel Corporation, Chiba Works sinter plant in 1975 to reduce NOX emissions. The sinter plant has a capacity of 7000 t sinter/day and a waste gas flow of 620000 to 750000 Nm³/h. The NOX emissions were reduced from 450 mg/Nm³ to 37 mg/Nm³ on a platinum (Pt) catalyst, thus achieving a reduction efficiency of >90 %. The SCR is operated as a clean gas system, which means that the SCR is installed after dedusting and desulphurisation.

The SCR can be operated at either 260 °C or at 400 °C. At 260 °C, the catalyst has to be revitalised several times per year by heat treatment. At this temperature, the 90 % efficiency is only obtained by adding NH3 at 1.2 times above the stoichiometric ratio. In this situation, NH3 slip occurs. After 3 years of operation at 260 °C, a CO converter was installed upstream from the SCR device. In the converter, CO in the waste gas is catalytically combusted and heat is generated. The CO converter increases the gas temperature from approximately 400 °C to 480 °C. NOX removal of approximately 90 % efficiency has been achieved with the addition of NH3 at a stoichiometric ratio of 0.9. No NH3 slip occurs. The pressure drop over the catalyst bed (1 m) is 140 mm (water column).

2. Sinter Plant, Nippon Kokan, Keihin Works, Japan.
At the sinter plant of Nippon Kokan, Keihin Works, an SCR was installed in 1979. This system is operated as a clean gas system after dedusting and desulphurisation. The sinter plant has a capacity of 12000 tonnes sinter per day and a waste gas flow of 1.2 million to 1.3 million Nm³/h.

The SCR uses lump ore (limonite and gasite ores from Asia) as a catalyst. The used catalyst is screened and used as feedstock in the blast furnace or the sinter plant.

The gases enter the SCR after being preheated to a temperature of 340 °C with a NOX concentration of 410 mg/Nm³. The clean gas concentration is 100 - 120 mg/Nm³, equivalent to a SCR efficiency of 70 - 75 %.

The pressure drop over the SCR device is 60 - 70 mm (water column). The heat exchanger has a pressure drop of 80 mm (water column).

NH3 consumption is 120 g/t sinter. Electricity consumption is 0.014 GJ/t sinter, or <1 % of the total sinter energy consumption.

The SCR has operated without any reported problems.

3. COG gas is used for reheating in the operation of the deNOX plant. Sinter plants 1, 3, 4 of China Steel, Taiwan.

- SCR for sinter plants 3 and 4 have been installed in 6/1997, SCR for sinter plant 1 in 6/1999
- NOX emissions have been reduced to 28 - 54 ppm (reference O₂: 15 %). Reduction rates are about 80 %. COG gas is used for reheating in the operation of the deNOX plant.

- sinter plant No. 1: waste gas volume: approx. 464000 Nm³/h
- sinter plant No. 3: waste gas volume: approx. 850000 Nm³/h; catalyst volume: 193.2 m³
- sinter plant No. 4: approx. 1164000 Nm³/h (19400 Nm³/min).

NH3 slip:
Sinter plants No. 1 and No. 3: <1 ppm,
Sinter plant No. 4: between 1.5 and 3 ppm
Applicability
Can be applied as an end-of-pipe technique at both new and existing plants. At sinter plants, only clean gas systems, after dedusting and desulphurisation, have been commissioned. It is essential that the gas is very clean, <40 mg dust/Nm³, and for it to have a minimum temperature of about 300 °C. This requires an energy input.

Economics
1. Sinter plant, Kawasaki Steel Corporation, Chiba Works, Japan
   - investments: EUR 27.3 x10⁶ in 1975
   - maintenance costs: EUR 0.08/t sinter in 1992 (EUR 200000/yr)
   - operational costs: EUR 0.40/t sinter in 1992 (EUR 1000000/yr); including preheating costs.

2. Sinter plant, Nippon Kokan, Keihin Works, Japan
   - investments: EUR 50 x 10⁶ in 1979
   - maintenance costs: EUR 0.57/t sinter in 1992 (EUR 900000/yr)
   - operational costs: EUR 0.75/t sinter in 1992.

[65] reports the following costs for SCR:
   - investment: EUR 25 - 45/(Nm³/h)
   - operational: EUR 0.7 - 0.9/1000 Nm³ treated.

For a sinter plant with a capacity of 4 Mt/yr, a waste gas flow of 1 MNm³/h and 8640 operational hours per year, this would correspond to the following costs:
   - investment: EUR 25 to 45 million
   - operational: EUR 1.5 to 2.0/t sinter.

For the two examples the currency was converted into Ecu in 1996 and for the review into EUR.

In 1997 an estimated cost of about EUR 30 million was quoted for an SCR unit including reheating system at Corus, Ijmuiden, the Netherlands.

Decisive cost factors are the use of catalyst, the ammonia consumption and (if applicable) costs for preheating the waste gas.

No sinter plants in Europe currently operates a deNOₓ system of this type.

Driving force for implementation
Research has shown that neither NOₓ prevention techniques as partial replacement of coke breeze with iron-rich slag, propane, DRI and petroleum coke, nor the use of ammonia solution or ammonium carbonate as blend additives offered a practical solution for reducing NOₓ emissions from sinter plants.

Example plants
1. Sinter Plant, Kawasaki Steel Corporation, Chiba Works, Japan
2. Sinter Plant, Nippon Kokan, Keihin Works, Japan
3. Sinter Plants 3 & 4, China Steel, Taiwan (installed in June 1999 and June 1997).

No new SCR plants have been installed in Japan since 1997. The new installations are located in Taiwan and Korea.
At least one SCR plant is being planned in the EU; however, as of 2008, no SCR installation has become operational in the EU. In 2008/2009, an SCR has been installed for 1/10 of the waste gas in a demonstration plant. The results of the demonstration plant will be used for upscaling, which is scheduled for 2011.

Reference literature
[65] [387] [424]

3.3.2.8.3 Regenerative activated carbon (RAC) process for desulphurisation and reduction of NOx

Description
Dry desulphurisation techniques are based on an adsorption of SO2 on activated carbon. When the SO2 laden activated carbon is regenerated, the process is called regenerative activated carbon (RAC). In this case, a high quality, expensive activated carbon type may be used and sulphuric acid (H2SO4) is yielded as a by-product. The bed is regenerated either with water or thermally. This technique is applied at municipal waste incinerators, refineries, power plants and one sinter plant.

In some cases, lignite-based activated carbon is used. In this case the SO2 laden activated carbon is usually incinerated under controlled conditions. This technique is usually only applied for 'fine-tuning' downstream of an existing desulphurisation unit.

The RAC process (illustrated in Figure 3.19) allows the removal of several components from the waste gas: SO2, HCl, HF, mercury (Hg) and optional NOx. The system can be developed as a 1 stage or a 2 stage process. In the 1 stage process, the waste gases are led through a bed of activated carbon and pollutants are adsorbed by the activated carbon. NOx removal only occurs when ammonia (NH3) is injected into the gas stream before the catalyst bed.

In the 2 stage process, the waste gases are led through two beds of activated carbon. Ammonia can be injected before the bed to reduce NOx emissions.

In the regenerator, PCDD/F are decomposed at temperatures ranging from 400 to 450 °C.

Figure 3.19: Regenerative activated carbon (RAC)
[268] [314]

Achieved environmental benefits
Highly efficient desulphurisation is possible (>95 %). The efficiency in NOx reduction can be as high as 80 - 90 %, depending on operating temperatures, the addition of NH3 and design. These efficiency figures do not consider plant downtime and reflect running 24 hours per day operation. Thus, actual efficiency figures would be considerably lower.
### Table 3.31: Concentration of waste gas components

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste gas flowrate</td>
<td>Nm³/min</td>
<td>14200</td>
</tr>
<tr>
<td>Temperature</td>
<td>K</td>
<td>414 - 415</td>
</tr>
<tr>
<td>Moisture</td>
<td>vol- %</td>
<td>6.9</td>
</tr>
<tr>
<td>O₂</td>
<td>vol- %</td>
<td>14.7</td>
</tr>
<tr>
<td>CO₂</td>
<td>vol- %</td>
<td>7.9</td>
</tr>
<tr>
<td>CO</td>
<td>vol- %</td>
<td>1.2</td>
</tr>
<tr>
<td>NOₓ</td>
<td>mg/Nm³</td>
<td>266 - 322</td>
</tr>
<tr>
<td>SOₓ</td>
<td>ppm</td>
<td>7 - 127</td>
</tr>
<tr>
<td>SO₃</td>
<td>ppm</td>
<td>0.1</td>
</tr>
<tr>
<td>Dust</td>
<td>mg/Nm³</td>
<td>6 - 10</td>
</tr>
</tbody>
</table>

Note: The SOₓ processing plant has a magnesium hydroxylation equipment. If this system is not working, emissions of up to 168 ppm can be reached. The system is composed of a cyclone, an ESP and a dry-desulphurisation system.

### Table 3.32: Achievable performance on sinter plant when applying activated char coal

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Achievable performances</th>
<th>Units</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO₂</td>
<td>95 - &gt; 98 ⁴¹</td>
<td>%</td>
<td>In cases where &gt; 60 % abatement is required, a 2-stage process is needed</td>
</tr>
<tr>
<td></td>
<td>Inlet: 572 - 858</td>
<td>mg/Nm³</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Outlet: 20 - 30</td>
<td>mg/Nm³</td>
<td></td>
</tr>
<tr>
<td>NOₓ</td>
<td>40 - 65 ²¹</td>
<td>%</td>
<td>Inlet &lt;100. Lower performances depends on particle size distribution</td>
</tr>
<tr>
<td></td>
<td>Inlet: 300 - 520</td>
<td>mg/Nm³</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Outlet: 120 - 200</td>
<td>mg/Nm³</td>
<td></td>
</tr>
<tr>
<td>PCDD/F</td>
<td>0.03 - 3</td>
<td>ng-TEQ/Nm³-dry</td>
<td>Inlet 1 - 2</td>
</tr>
<tr>
<td></td>
<td>Inlet: 0.000001 - 0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dust</td>
<td>95 - &gt;99</td>
<td>%</td>
<td>Performance not guaranteed</td>
</tr>
<tr>
<td></td>
<td>Inlet: 10 - 140</td>
<td>µg/Nm³</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Outlet: 2 - 20</td>
<td>µg/Nm³</td>
<td></td>
</tr>
</tbody>
</table>

Notes:
⁴¹ Data based on continuous monitoring during one month at two existing plants show high constant efficiencies
²¹ Data based on continuous monitoring during one month at three existing plants show efficiencies fluctuations between 40 and 60 % for 1-stage system and between 62 - 75 % for a 2 stage system

This technique reduces dust levels from 80 - 100 mg/Nm³ to less than 20. Dioxin emissions are reduced from 3 ng/Nm³ to less than 0.3. PAH emissions are reduced from more than 30 ng/Nm³ to less than 1.

**Cross-media effects**

When the RAC process is applied, the total energy consumption per tonne of sinter increases and a small water flow is generated. In an integrated iron and steel plant, the water flow can be treated in an existing waste water treatment plant if one exists that is or is conveniently located. If not, additional costs would be incurred for a suitable waste water treatment. Sulphuric acid is produced as a by-product.

No solid waste is generated in the RAC process, because the activated carbon is regenerated and partially combusted. Electricity consumption is 1200 kW or 8.6 MJ/t sinter (around 0.4 % of total sinter energy consumption).

When the non-regenerative process is applied, the total energy consumption per tonne of sinter increases and a contaminated solid waste is yielded, which should be properly treated.
Chapter 3

The dust extracted from the gas cleaning process is very fine, and contains heavy metals (radioactive materials may also appear). Therefore, the dust cannot be readily recycled into the ironmaking process in the same way as other iron-bearing dusts.

**Operational data**

Sinter plant No.3, Nagoya Works, Nippon Steel Corporation has a capacity of 12000 tonnes of sinter per day, with a waste gas flow of 900000 Nm$^3$/h. Sinter basicity was 1.72 - 2.1 in 1991. The RAC process was designed as two parallel 1-stage absorption towers, each with a capacity of 450000 Nm$^3$/h. Prior to desulphurisation, particulate matter is removed in a cyclone and subsequently by an ESP (clean gas concentration: 20 - 30 mg/Nm$^3$). SO$_2$ inlet concentrations were 360 mg/Nm$^3$ and the reported desulphurisation efficiency was 97%. This led to an outlet concentration of 11 mg/Nm$^3$. Particulate matter outlet concentrations are 15 - 20 mg/Nm$^3$ (particle size 2 - 4 µm; 60 % carbon).

NO$_X$ reduction with RAC is applied in one of the two adsorption towers only, with NH$_3$ injection. The overall NO$_X$ removal efficiency is low at 15 % (or 30 % on the one adsorption tower with NH$_3$ injection).

The SO$_2$ laden activated carbon is regenerated by thermal treatment at 380 - 430 °C. The carbon is indirectly heated by a coke oven gas fired heater. Nitrogen (N$_2$) is admixed (500 m$^3$/h). The water saturated SO$_2$ rich (15 %) gas is led to the sulphuric acid plant of the coke oven gas treatment. The regenerated carbon is screened and fed back to the adsorption beds. The small size particles are used as sinter plant feedstock. These characteristics are specific to the plant considered and are not generally applicable to other plants. Activated carbon consumption amounts to 150 kg/h. Steam consumption (40 bar) is 600 kg/h and water consumption is 0.08 m$^3$/h.

Special attention has to be paid to the inlet temperature of the waste gas (<140 °C), and to the inlet concentration of dust (max. 50 mg/Nm$^3$). Dust abatement (e.g. ESP or high performance multiple cyclones) should be installed prior to the RAC process to reduce the dust concentration into the system.

**Applicability**

The RAC process can be applied as an end-of-pipe technique both at new and existing plants. The process is usually installed for the simultaneous removal of several components from the off-gas (e.g. SO$_2$, HF, HCl, NO$_X$). Generally the layout of the plant and space requirements are important factors when considering this technique but especially for a site with more than one sinter strand.

The technique can be applied to treat sinter gas flowrates from ~1.0 - 1.7 million of Nm$^3$ per hour.

**Economics**

Investments (excluding the sulphuric acid plant and the waste water treatment plant) in 1987 were approximately EUR 21 million. In 1991 Voestalpine, Linz,Austria were quoted as being approximately EUR 73 million in 1997 for a RAC plant.

Operating costs (excluding maintenance and depreciation) were EUR 0.75 per t sinter in 1991. Maintenance costs are estimated at EUR 0.17 per t sinter (EUR 750000 per year). Note that these data are for an RAC installation for the combined removal of SO$_2$ and NO$_X$.

1) For all examples the currencies was converted into Ecus in 1996 and for the review into EUR.

The following Table 3.33 shows the total investment and operational costs for a dry desulphurisation system with simultaneous NO$_X$ reduction for two different cases. It is a qualitative comparison between dry and wet desulphurisation processes for sinter plants only (see Table 3.33).
### Chapter 3

#### Abatement efficiency required

<table>
<thead>
<tr>
<th>DeSO₂: 95 %</th>
<th>DeSO₂: 95 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>DeNOₓ: 40 %</td>
<td>DeNOₓ: 80 %</td>
</tr>
</tbody>
</table>

#### Initial cost

- **main facility**: 100%
- **initial filling of activated char**: 60.8%
- **by-product facility (H₂SO₄)**: 8.8%
- **others (piping, WWTP, electricity and instruments, civil facility, engineering)**: 8.5%

<table>
<thead>
<tr>
<th>DeSO₂: 95 %</th>
<th>DeSO₂: 95 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>DeNOₓ: 80 %</td>
<td>DeNOₓ: 80 %</td>
</tr>
</tbody>
</table>

#### Running cost (8476 h/yr)

- **activated char**: 57.7%
- **electrical power**: 29.8%
- **NH₃ (for de-NOₓ)**: 10.4%
- **others (COG, utilities, steam, NaOH)**: 13.6%
- **H₂SO₄ (on the market)**: -11.5%

<table>
<thead>
<tr>
<th>DeSO₂: 95 %</th>
<th>DeSO₂: 95 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>DeNOₓ: 80 %</td>
<td>DeNOₓ: 80 %</td>
</tr>
</tbody>
</table>

**Notes:**
- Gas flowrate: 1.5 million Nm³/h; gas temperature: 120 °C; SO₂ input: 140 ppm; NOₓ input: 170 ppm
- Total cost of dry system is 100% (this value is referenced to the 110% shown Table 3.27 of Section 3.3.2.7.2)
- Sulphuric acid produced

#### Table 3.33: Cost estimation of an activated coal system

[268]

Investments for regenerative activated carbon are estimated to be around EUR 60 million in sinter plant with a 500 - 600 m² sinter strand, and operational costs are about EUR 1/t (Arcelor). Investments for RAC were EUR 60 million in 2003 for a 350 m² strand.

**Driving force for implementation**

No data submitted.

**Example plants**

At least eight sinter plants have implemented this technique using activated coal in Japan, Korea and Australia. The RAC process targeting SOₓ has been in operation at sinter plant No.3, Nagoya Works, Nippon Steel Corporation in Japan, since August 1987. In 1999, sinter machines 1 and 2 at Nagoya Steelworks were equipped to target SOₓ, NOₓ and dust for 1.3 million Nm³/h of waste gas. Other plants reported to have installed this system or a variation on the process are:

- BlueScope Steel, Port Kembla Works, Australia, No. 3 sinter machine, to treat 1552000 Nm³/h of waste gas for dust and PCDD/F, (start up June 2003)
- Nippon Steel Corporation, Oita Works, Japan, No 1 sinter plant, to treat 1300000 Nm³/h of waste gas for SOₓ, NOₓ dust and PCDD/F, (start up 2003)
- POSCO, Pohang Steelworks, Korea, Nos. 3 and 4 sinter machines, to treat 1350000 Nm³/h of waste gas for SOₓ, NOₓ dust and PCDD/F, (start up November 2004)
- Nippon Steel Corporation, Kimitsu Steelworks, Japan, No. 3 Sinter plant, to treat 1700000 Nm³/h of waste gas for SOₓ, NOₓ and dust, (start up 2004)
- Kobe Steel Corporation, Kakogawa Steelworks, Japan, No. 1 sinter plant, to treat 1500000 Nm³/h of waste gas for SOₓ, NOₓ dust and PCDD/F, (at planning stage in 2007).

The carbon packed bed filter technology has been tested in one pilot plant installation in Australia (BHP-Steel) and is working in some sinter plants in Japan.

**Reference literature**

[65] [215] [261] [268] [314] [415] [416]
3.3.3 Collection and abatement of dust emissions from secondary sources

Description
Secondary emission sources can be captured by secondary dedusting systems. The expression room dedusting of sinter plants is also used and comprises different sources such as the hearth laying, the strand discharge zone with crushing and sieving and transfer points of the sinter conveyor. The evacuated gases are usually treated in a dedusting device, like an ESP or bag filter. Operations are performed in a closed building to further help the collection of fugitive emissions. At the Voestalpine Stahl Linz, Austria sinter plant a collection and cleaning of one part of the flue-gas (370000 m³/h) is performed with ESPs. Another part of the flue-gas (160000 m³/h) is dedusted in a bag filter.

Achieved environmental benefits
At one sinter plant, the majority of these evacuated gas streams from these sinter plant operations and from transfer points are combined and dedusted in three parallel ESPs. The dust emissions are measured continuously and have a yearly value of 270 t, for a combined gas flow of approx. 815000 m³/h. The dust concentration is approx. 35 mg/Nm³.

Limit values are <10 mg/Nm³ for bag filters (HMW) and <30 mg/Nm³ for ESPs (HMW). Emissions are measured together from both emissions sources and are <20 mg/Nm³ (half hour average). The sinter plant of Voestalpine Donawitz, Austria achieves values of 3 mg/Nm³.

Cross-media effects
No data submitted.

Operational data
At a German plant sinter room dedusting emissions of 3 mg/Nm³ are achieved with bag filters.

Applicability
Secondary dedusting is used for all of the elements of preparatory and support processes which result in emission of pollution to the air including transshipment points, mix or sinter burdening, and sinter cooling, blending, screening and crushing operations.

Economics
For the mentioned example with a gas flow of 815000 m³/h the investments costs for the bag filters were EUR 12 million and the operational yearly costs are EUR 3.25 million.

Driving force for implementation
The various sinter plant operations like blending, crushing, cooling and screening as well as the transport (especially at the transfer points between the conveyor belts) and recycling of the sinter between these different operations are a cause of dust emissions. The dust consists of 75 % PM₁₀ and 35 % PM₂.₅.

Example plants
Corus, Ijmuiden, the Netherlands and Voestalpine, Linz, Austria. At ArcelorMittal, Eisenhüttenstadt, Germany the dedusting of the emissions of the cooling strand and other secondary sources is carried out with ESP).

An installation Thyssen Krupp Stahl, Duisburg, Germany has the particular characteristics of having the sinter cooler situated close to the boundary of the iron and steel works. Measurements have proven that these emissions make a relevant contribution to the dust deposition in the area beyond the boundary of the plant. For this reason, a cooler dedusting system was installed and started up April 2003. The dust created by the transport, handling and cooling of the sinter is collected. The dust laden air from the cooler, hot screens and some other plant areas is separated from the existing plant dedusting facility and fed to a new ESP. Diffuse emissions are considerably reduced from the cooler area by optimising the airflowrates in the...
dedust system at the various extraction points ensuring a relatively high flow (300000 Nm³/h) at the strand discharge area. An installed ESP treat a total waste airflowrate of approx. 1400000 Nm³/h and it was designed to achieve a particulate content of 30 mg/Nm³ at discharge, measured as a half hourly mean value. The dust collected in the ESP is sent by a chain conveyor to a surge bin. After that, it is wetted and sent to the fine ore beds by conveyor belts.

Reference literature
[404] [412] [468]

3.3.4 Use of production residues such as waste and by-products in the sinter plant

Description
The utilisation of residues is an important function of the sinter plant in an integrated steelworks. Residues generated consist mainly of iron scale from the rolling mills and a wide variety of dusts and sludges including those from waste gas treatment devices. Whenever these dusts, sludges and mill scale have a high enough iron or carbon content (or other mineral content, e.g. lime, magnesia), they can be considered for use as a raw material in the sinter plant. Materials with a high lime content, such as steel slag, may also be accepted, reducing the supplementary lime and limestone input. There may be process restrictions on the use of residue materials in the sinter plant other than those associated with the cross-media effects reported below. These restrictions are related to the negative impact that some elements have on the smooth operation of the blast furnace. Therefore, dependent upon the make-up of the blast furnace burden, restrictions may be applied to the zinc, lead and chloride content of the sinter thereby limiting the extent of residue usage at the sinter plant. Currently, nearly all sinter plants in the world utilise some dusts, sludges and mill scale. In most plants these account for 10 - 20 % of the sinter feed. In at least two plants 100 % of the dusts, sludges, slags and additives are used.

Achieved environmental benefits
The amount of raw material saved is equal to the amount of sludges, dusts and mill scale used. Furthermore, disposal of these residues is avoided.

Cross-media effects
Some process residues have a significant oil content, which may lead to higher emissions of some volatile organic compounds (e.g. hydrocarbons, PCDD/F). Using residues containing significant amounts of volatile heavy metals (e.g. Hg, Cd) can lead to an increase in emissions of these metals. The recirculation of certain residues can also contribute to the increase of these metals in the waste gas. Furthermore, undesired components such as alkalis and chlorides may accumulate in the sinter process and as a result may increase waste gas emissions (e.g. increase particulate loadings at the abatement equipment). To avoid these problems, sometimes the abatement equipment is improved (e.g. bag filter or improved/advanced ESP techniques) to cope with the use of the required amounts of waste/residues material [302] [409] [410].

The recycling of precipitated sinter dust may have the effect of increasing the PCDD/F air emissions due to the recycling of dioxine 'de novo' catalysts and chlorine [224] [255]. bag filter/ESP dust contaminated with PCDD/F recycled back to the sinter bed does not increase the concentration of PCDD/F in the subsequently precipitated bag filter/ESP dust [255].

Operational data
No data submitted.

Applicability
This technique can be applied at new and existing plants.
Economics
With the technique described here raw material costs are saved and disposal costs (including pretreatment) are avoided.

Driving Force for Implementation
The most important driving forces for the implementation of this technique are maximisation of residue utilisation in the interest of sustainable consumption, thereby minimising the use of virgin raw materials and in many cases practical disposal options are limited and/or costly [302].

Example plants
Almost all sinter plants around the world utilise sludges, dusts and mill scale arising in the integrated steelworks. The sinter plant at DK Recycling, Duisburg, Germany has been specifically designed to treat production residues from iron and steelmaking operations and is integrated into a blast furnace route to recover the valuable iron units together with the zinc and lead-rich dusts and sludges that can be utilised in the non-ferrous metal industry.

Reference literature
[65] [116] [224] [255] [302] [409] [410] [444]

3.3.5 Heat recovery in the sinter process

3.3.5.1 Heat recovery from sintering and sinter cooling

Description
Two kinds of potentially reusable waste energies are discharged from the sinter plants:

a) the sensible heat from the main exhaust gas from the sintering machines
b) the sensible heat of the cooling air from the sinter cooler.

Concerning item a) under normal operating conditions, the use of a heat exchanger to recover heat from the waste process gases would result in unacceptable condensation and corrosion problems. These constraints have meant that the recovery of heat from the waste gases by means of a heat exchanger has not been practised.

Partial waste gas recirculation is a special case of heat recovery and is dealt with in Section 3.3.5.2. The sensible heat is transferred directly back to the sinter bed by the hot recirculated gases. This is currently the only practical method of recovering heat from the waste gases.

Concerning item b), the sensible heat in the hot air from the sinter cooler is possible to be recovered by one or more of the following ways:

- steam generation in a waste heat boiler for use in the iron and steel works
- hot water generation for district heating
- preheating combustion air in the ignition hood of the sinter plant; see Figure 3.20
- preheating the sinter raw mix
- use of the sinter cooler gases in a waste gas recirculation system.

The amount of waste heat recovered can be influenced by the design of the sinter plant and the heat recovery system.

5 different examples of heat recovery are given below:
Sinter cooler waste heat recovery with conventional sintering
The sensible heat of the sinter cooling hot air gas is used for producing steam in a waste heat boiler and for preheating the combustion air in the ignition hoods.

Achieved environmental benefits
Reported energy recovery amounts to 18 % of the total energy input for the waste heat boiler and 2.2 % of total energy input for recirculation to the ignition hoods [65].

Figure 3.20: Heat recovery from cooling air from the sinter cooler [5]

Operational data
No data submitted.

Sinter cooler and waste gas heat recovery with sectional waste gas recirculation
At Sumitomo Heavy Industries Kokura No. 3 sinter plant, sectional waste gas recirculation is applied. Before recirculation, the waste gases are led through a waste heat boiler. The gases from the sinter cooler are also led through a waste heat boiler.

Achieved environmental benefits
Energy recovery reported at this plant by means of this system is 23.1 % of the energy input.

Operational data
120 kg steam/t sinter was produced at a temperature of 273 °C and at a pressure of 9 bar [123].

Sinter cooler waste heat recovery to the sinter bed with waste gas recirculation
At the Sinter Plant No.5 of voestalpine, Linz, Austria waste heat recovery from the sinter cooler is achieved through the EPOSINT process (see Section 3.3.5.2.1). When a waste gas recirculation system is used, the hot air from the cooler can be used instead of a fresh air addition to raise the oxygen content of the recycled gases returned to the sinter bed. Under these circumstances the heat contained in the sinter cooler gases is recovered in the sintering process. A small proportion of the hot air from the cooler may also be used to preheat the ignition air in the ignition hood.

Achieved environmental benefits
A specific reduction of 2 - 5 kg coke/t sinter was achieved at voestalpine Linz, Austria.

Operational data
No data submitted.
Chapter 3

Strand cooling and waste heat recovery with partial waste gas recirculation
At the Sumitomo Heavy Industries Wakayama No. 4 sinter plant, the sinter cooler is integrated into the sinter strand (strand cooling). At this plant, waste gases from both the sintering and the cooling zone on the grate are led through waste heat boilers and subsequently recirculated to the strand.

Achieved environmental benefits
Recovered heat amounts to 30% of the input heat.

Operational data
Approximately 120 kg steam/t sinter is produced at a pressure of 25 bar and a temperature of 375 °C. The plant is designed for a sinter production of 10000 t/day and has a sinter area of 360 m² [123], but productivity could be adversely affected if the system were applied to an existing plant operating at or near maximum output.

Sinter cooler heat recovery for district heating
At Arcelor Mittal, Dunkerque, France No3 sinter plant, the sinter cooler hot air is collected and sold to a partner who transforms the heat into hot water (105 °C), which is delivered by pipelines to the city for district heating.

Achieved environmental benefits
Approximately 15 kW/t sinter are recovered.

Operational data
No data submitted.

Achieved environmental benefits
CO₂ emissions may be avoided by replacing fossil fuel where the cooler waste gases are used for district heating energy production.

Cross-media effects
In some cases emissions of dust are reduced, due to the pre-installed coarse dust separators. The use of the sinter cooler waste gases in a waste gas recirculation system will result in a reduction in diffuse dust emissions from the sinter cooler.

Applicability
Waste heat recovery from stack or sinter cooling can be applied both at new and existing plants. It is recognised, however, that investment costs are lower for a new plant incorporating heat recovery systems from the planning stage, but at some existing plants, the existing configuration may make costs very high. In 1995, it was reported that 64% of the Japanese sinter plants had heat recovery from sinter cooling and 43% of the Japanese sinter plants applied waste heat recovery from the stack.

Economics
Investments will be site-specific. However, the application of waste heat recovery reduces operational costs.

Driving force for implementation
No data submitted.

Example plants
Heat recovery from sinter cooling is applied frequently in the EU (e.g. at Corus, Ijmuiden, the Netherlands; Riva, Taranto, Italy; Thyssen Krupp Stahl, Duisburg, Germany).
Heat recovery from sinter cooler hot air has been practiced at ArcelorMittal Dunkerque, France, No3 sinter plant since 1991. Three strands at Corus in United Kingdom recover heat from the sinter cooler hot air.

In sinter plant No.5 of Voestalpine, Linz, Austria, waste heat recovery from the sinter cooler has been implemented as part of the EPOSINT process since April 2005.

At least two sinter plants in Europe for technique named b) in the description section.

**Reference literature**

[1] [65] [103] [123] [305] [404]

### 3.3.5.2 Partial recycling of waste gas

In partial recycling of waste gas, some portions of the sinter waste gas is recirculated to the sintering process. The fraction of the waste gas that is recirculated to the strand passes through the hot sinter and the flame front (see Figure 3.3). Various processes have been developed to apply partial waste gas recirculation on an industrial scale. The following techniques are included in this section:

<table>
<thead>
<tr>
<th>Section</th>
<th>Technology commercial name</th>
<th>Example of installation</th>
<th>Schematic diagram (arrows indicate gas flows)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3.5.2.1</td>
<td>Partial recycling of waste gas from the whole strand</td>
<td>Emission Optimised Sintering (EOS)</td>
<td>Corus Ijmuiden, Netherlands</td>
</tr>
<tr>
<td>3.3.5.2.2</td>
<td>Recycling of waste gas from the end sinter strand and heat exchange</td>
<td>Low emission and energy optimised sintering process (LEEP)</td>
<td>HKM, Germany</td>
</tr>
<tr>
<td>3.3.5.2.3</td>
<td>Recycling of waste gas from part of the end sinter strand and use of waste gas from sinter cooler.</td>
<td>Environmental Process Optimised SINTering (EPOSINT)</td>
<td>Voestalpine Linz, Austria</td>
</tr>
<tr>
<td>3.3.5.2.4</td>
<td>Recycling of parts of waste gas to other parts of the sinter strand.</td>
<td>NSC, Tobata No. 2 sinter plant in Japan</td>
<td></td>
</tr>
</tbody>
</table>

Table 3.34: Partial waste gas recirculation techniques

[307]
3.3.5.2.1 Partial recycling of waste gas from the whole strand

Description
The concept of this technique is to recycle a part of the mixed waste gas from the whole strand back to the entire surface of the strand (see Figure 3.21). The recycling rate of the sintering waste gas is of the order of 40 - 45 %, corresponding to a 14 - 15 % oxygen concentration in the wet gas/air mixture in the hood and resulting in a 45 - 50 % decrease of the waste gas flow emitted to the atmosphere.

![Covered sinter strand according to the EOS process](image)

The waste gas is dedusted in a cyclone before being recycled through an additional fan to the hood above the strand. Under these conditions the strand productivity remains unchanged and consumption of coke breeze is reduced by 10 - 15 % compared to conventional practice at Corus Ijmuiden, the Netherlands. The sinter quality, defined as reduction disintegration, appeared constant, the FeO in the sinter increased by 1.5 %, reducibility increased, cold strength decreased slightly and the mean diameter remained approximately 17 mm. The use of the sinter produced in the blast furnace does not show any adverse effects but it should be noted that this sinter only accounts for about 50 % of the charge because of the high percentage of pellets used in blast furnaces at Corus, Ijmuiden, the Netherlands. Elsewhere, the levels of sinter used in the blast furnace burden can be much higher (up to 95 %).
Achieved environmental benefits

This technique was primarily developed to reduce waste gas flow and thus the mass emissions of particulate matter and PCDD/F with the benefit that additional abatement equipment to further treat the waste gas before discharge to the atmosphere would have to treat lower volumes, with implied capital and operational cost savings. Prior to the installation of this system at that plant in Netherlands, the end-of-pipe abatement system was cyclones and it was inevitable that additional abatement equipment would also be required (see Section 3.3.2.4). The results from this particular commercial plant for high basicity sinter ($\geq 1.7 \text{ CaO/SiO}_2$) indicate that successful implementation of this technique is possible (see Table 3.35). The results for sinter with low basicity are similar.

<table>
<thead>
<tr>
<th>Component</th>
<th>Nm$^3$/h</th>
<th>Nm$^3$/h</th>
<th>Nm$^3$/h</th>
<th>Nm$^3$/h</th>
<th>°C</th>
<th>°C</th>
<th>%</th>
<th>%</th>
<th>%</th>
<th>°C</th>
<th>°C</th>
<th>%</th>
<th>%</th>
<th>g/t sinter</th>
<th>g/t sinter</th>
<th>g/t sinter</th>
<th>g/t sinter</th>
<th>g/t sinter</th>
<th>g/t sinter</th>
<th>g/t sinter</th>
<th>g/t sinter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total gas flow</td>
<td>394000</td>
<td>372000</td>
<td>328000</td>
<td>328000</td>
<td>164</td>
<td>114</td>
<td>10</td>
<td>11</td>
<td>15</td>
<td>115</td>
<td>11.5</td>
<td>11.2</td>
<td>7.5</td>
<td>7.0</td>
<td>1430</td>
<td>890</td>
<td>840</td>
<td>680</td>
<td>630</td>
<td>570</td>
<td>300</td>
</tr>
<tr>
<td>Recirculation flow</td>
<td>0</td>
<td>0</td>
<td>153000</td>
<td>120000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>200</td>
<td>145</td>
<td>95</td>
<td>83</td>
<td></td>
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<tr>
<td>Emitted waste gas flow</td>
<td>394000</td>
<td>372000</td>
<td>175000</td>
<td>208000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>500</td>
<td>n.d.</td>
<td>170</td>
<td>n.d.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>46±5</td>
<td>n.d.</td>
<td>71±5</td>
<td>n.d.</td>
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<td></td>
</tr>
<tr>
<td>Percentage of moisture</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>15</td>
<td>15</td>
<td>11.5</td>
<td>12.1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Acid dewpoint</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<td></td>
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<td>7.5</td>
<td>7.0</td>
<td>11.7</td>
<td>11.2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Particulate matter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>1430</td>
<td>890</td>
<td>840</td>
<td>680</td>
<td>630</td>
<td>570</td>
<td>300</td>
<td>410</td>
</tr>
<tr>
<td>SO$_2$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>7.0</td>
<td>11.7</td>
<td>11.2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>CO$_2$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td>840</td>
<td>680</td>
<td>630</td>
<td>570</td>
<td>300</td>
<td>410</td>
</tr>
<tr>
<td>CO</td>
<td></td>
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<td></td>
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<td>7.5</td>
<td>7.0</td>
<td>11.7</td>
<td>11.2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>NO$_x$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td>1430</td>
<td>890</td>
<td>840</td>
<td>680</td>
<td>630</td>
<td>570</td>
<td>300</td>
<td>410</td>
</tr>
<tr>
<td>C$_2$H$_4$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>1430</td>
<td>890</td>
<td>840</td>
<td>680</td>
<td>630</td>
<td>570</td>
<td>300</td>
<td>410</td>
</tr>
<tr>
<td>PCDD/F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>n.d.</td>
<td>0.6</td>
<td>n.d.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3.35: Comparison of characteristics and emission values of conventional sintering and Emission Optimised Sintering (EOS) at a sinter strand at a Corus, Ijmuiden, the Netherlands with a suction area of 132 m$^2$ and a production of 4700 t high basicity sinter/d

[104]
Chapter 3

The emission reductions (by mass) resulting from the application of this technique at Corus Ijmuiden were:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Low basicity sinter</th>
<th>High basicity sinter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste gas flow</td>
<td>40</td>
<td>40 - 50</td>
</tr>
<tr>
<td>Particulate matter</td>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td>Carbon monoxide (CO)</td>
<td>45</td>
<td>50</td>
</tr>
<tr>
<td>SO₂</td>
<td>?</td>
<td>15 - 20</td>
</tr>
<tr>
<td>NOₓ</td>
<td>35</td>
<td>30 - 45</td>
</tr>
<tr>
<td>Hydrocarbons (CₓHᵧ)</td>
<td>n/a</td>
<td>50</td>
</tr>
<tr>
<td>PCDD/F</td>
<td>70</td>
<td>65</td>
</tr>
</tbody>
</table>

1) Emissions reduction is expressed as a mass flow reduction of the component. This does not necessarily imply a reduction in concentration.

Table 3.36: Reported emission reduction (by mass) of Emission Optimised Sintering (EOS) [104]

This technology allowed the consumption of coke breeze to be reduced from 60 kg/t sinter to 48 kg/t sinter. This significant savings in thermal energy in the Dutch plant described above is not necessarily transferable to other plants because they may already be operating at low thermal energy inputs from the solid fuels as a result of the application of process optimisation measures. Data from the European Blast Furnace Committee survey of the operational data for sinter plants (1996), clearly demonstrate that many European plants already operate at significantly lower levels.

The application of EOS requires the installation of extra suction fans. This will result in an additional installed electric capacity of 200 to 400 kW, amounting to an increase in energy consumption by 3 - 8 MJ/t sinter, which is low compared to the overall potential savings.

Cross-media effects
This technique reduces both emissions to air and the energy consumption of the sintering process. The additional suction fans increase electricity consumption, but this increase is negligible compared to the savings in coke breeze. Special attention need to be paid to carbon monoxide (CO) in the recirculated waste gas in order to prevent carbon monoxide poisoning of employees.

Operational data
This technique first came into operation in the EU in May 1994 on sinter strand 31 of the Corus, Ijmuiden, the Netherlands sinter plant. Now, EOS being used at all three sinter strands at the plant. To date, availability of the system has been >95 %. In case of failure, the system is automatically switched to conventional sintering.

Applicability
This technique can be applied to both new and existing plants although it is recognised that investment costs are lower in the case of new plants incorporating the system from the planning stage, than at some existing plants which may have considerably higher costs due to plant design.

Economics
The investment required to implement this technique at the sinter plant at Corus, Ijmuiden, the Netherlands with a total conventional waste gas flow of approximately 1.2 MNm³/h from three sinter strands, was EUR 17 million. Operational costs were decreased compared to conventional sintering due to reduced input of coke breeze. Operational savings are estimated at EUR 2.5 million/yr. This Figure is based on a reduced consumption of coke breeze by 6 kg/t sinter, at a price of EUR 100/t coke breeze and sinter production of 4.2 Mt/yr. These figures may be exceptional and may not be possible to achieve at many other EU sinter plants, particularly
those already operating at significantly lower solid fuel inputs than those quoted for Corus, Ijmuiden, the Netherlands (see above). It should also be stressed that the estimated average price of the coke breeze used at other EU sinter plants is about 40% cheaper, rendering any possible coke breeze savings less economically attractive. However, the smaller volume of waste gases emitted from the sinter strand following the application of waste gas recirculation means the cost of end-of-pipe abatement will be reduced.

For all examples the currencies have been converted into Ecu in 1996 and for the review into EUR.

Implementing gas recirculation costs around EUR 20 million in sinter plant with a 500 - 600 m² sinter strand (Arcelor, Dunkerque, France in 2002). Costs depend on the size of the plant and the number of strands among other particular issues.

Driving force for implementation
The most important driving forces for implementation have been stringent requirements and emission standards laid down by authorities.

Example plants
Corus, Ijmuiden, the Netherlands. All sinter production at this plant is currently performed with this technique and Arcelor, Dunkerque, France. Other examples outside of the EU (such as the US) have also implemented this technique.

Reference literature
[49] [104] [307] [415] [416]

3.3.5.2.2 Recycling of waste gas from the end sinter strand combined with heat exchange

Description
Due to the nature of the sintering process, the concentrations of the various waste gas components show no homogeneous distribution over the length of the sinter strand (see Figure 3.5, Figure 3.7 and Figure 3.12). The first half of the process mainly extracts the water content from the ore mix. In the second half, higher concentrations of sulphur oxides, chlorine compounds and PCDD/F are present. The amounts of carbon monoxide and carbon dioxide as well as oxides of nitrogen are evenly distributed between the two halves of the sinter strand. After the water has been removed half way along the sinter strand, the temperature of the waste gas increases in the second half of the strand until it reaches its maximum level in the area of the hot zone burn-through point.

In contrast to other technique for recycling of waste gas, this technique collects all waste gases of the second half of the strand. These gases are recirculated to the system across the entire length of the sinter strand. The oxygen remaining in the recycled gas provides most of the oxygen required to burn the fuel. When the waste gas is recirculated, the dust content is filtered out in the sintering bed, PCDD/F are partially destroyed, and sulphur oxides as well as chlorine compounds are adsorbed. The oxidation of the carbon monoxide in the recirculated gas in the flame front provides heat to the system, displacing some of the heat derived from the solid fuel addition and allowing the solid fuel rate to be reduced.

Due to the recirculation of the waste gas from the second section of the sinter strand, only the waste gas from the first half with the lower concentrations leaves the process through the stack. This significantly reduces the amount of waste gas and emissions. The emission concentrations are determined by the efficiency of the assimilation of the particulate matter in the sinter bed, the adsorption of species such as chlorides and oxides of sulphur, and the oxidation of some species (e.g. CO, PCCD/F) as the recirculated gas passes through the flame front.
Figure 3.23: The LEEP (Low Emission and Energy optimised sintering Process) process was developed by Hüttenwerke Krupp Mannesmann

Before the two gas streams enter one of the electric precipitators, they flow through a gas/gas heat exchanger. The levelling of the temperatures of the gas stream (before the heat exchanger: 200/65 °C, after the heat exchanger: 150/110 °C) allows the existing exhaust fans to work at the same operating points as in the conventional sintering process. Furthermore, the area where the colder gas of the first strand section reaches dewpoint is restricted to the gas tubes located before the heat exchanger. The temperature levels in all additional gas tubes exceed the acid dewpoint. The cooling of the hot gases that circulate with temperatures of about 150 °C also guarantees that the quality properties of the sinter are maintained.

After the waste gases have passed through the ESPs and the exhaust fans, the recirculating process gas is blown back to the sinter strand via an additional speed-controlled supporting fan. The exhaust from the first strand section is emitted to the atmosphere through the stack.

**Achieved environmental benefits**

With the LEEP technique the following abatements of specific mass emissions (see Table 3.37) can be achieved compared to a conventional sintering process:

<table>
<thead>
<tr>
<th>Emission Type</th>
<th>Reduction in load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decrease of specific waste gas volume per tonne of sinter</td>
<td>About 50% at the stack</td>
</tr>
<tr>
<td>Abatement of dust emissions from the sinter strand</td>
<td>50 - 55%</td>
</tr>
<tr>
<td>Abatement of specific SO(_2) emissions</td>
<td>27 - 35%</td>
</tr>
<tr>
<td>Abatement of specific NO(_x) emissions</td>
<td>25 - 50%</td>
</tr>
<tr>
<td>Abatement of specific CO emissions</td>
<td>50 - 55%</td>
</tr>
<tr>
<td>Abatement of specific HF emissions</td>
<td>50%</td>
</tr>
<tr>
<td>Abatement of specific HCl emissions</td>
<td>50%</td>
</tr>
<tr>
<td>Abatement of specific PCDD/F emissions</td>
<td>about 75 - 85%</td>
</tr>
</tbody>
</table>

The energy contained in the coke breeze saved is equivalent to the energy content of the recycled gas. 10 MJ/t of sinter of electrical energy are required to operate the supporting fan, resulting in a total reduction of the energy requirement of 213 MJ/t of sinter or 12.5%.

Table 3.37: Some environmental benefits achieved

**Cross-media-effects**

There is a slight increase in the use of electrical energy from the additional fan. Special attention must be paid to CO in the recirculated waste gas in order to prevent carbon monoxide poisoning of employees.
Operational data
When this technique was used the first times, a reduction in productivity was observed. Currently the same level of productivity is attained, compared to the conventional sintering. In the future, higher productivity is expected following changes to the ignition furnace, the addition of O₂, the increase in the sinter basicity and by reducing the amount of false air.

The sinter quality data are:

- same level of grain size and strength
- same level of reducibility
- better data for low temperature break down.

The sinter plant of Hüttenwerke Krupp Mannesmann has a suction area of 420 m². The strand has two waste gas mains parallel to the sinter strand. In order to separate the two exhaust zones, a partition has been installed to separate one waste gas main completely from the rear area of the sinter strand, ensuring that this main only extracts the air in the first half of the strand. Shutters separate the windboxes of the front strand section from the second exhaust main, ensuring that this main only collects the exhaust from the rear section of the strand. Since operating conditions can change, four windboxes (from a total of 29) in the middle section of the sinter strand can be optionally integrated either into the circulation or the exhaust gas circuit.

Applicability
This technique can be implemented in new and existing sinter plants. If the existing sinter plant has two separate waste gas mains, there is an advantage as illustrated by Hüttenwerke Krupp Mannesmann where the original main blowers and ESPs were able to be retained.

Economics
With an investment of EUR 14 million, solid fuel consumption is reduced by 5 - 7 kg solid fuel/t sinter (12.5 % of the fuel demand) with corresponding savings in operational cost.

Driving force for implementation
No data submitted.

Example plants
This technique has been in operation since December 2001 at Hüttenwerke Krupp Mannesmann, Duisburg-Huckingen, Germany.

Reference literature
[295] [307] [424]

3.3.5.2.3 Recycling of waste gas from part of the end sinter strand and use of waste gas from the sinter cooler

Description
Selective waste gas recirculation in this process (EPOSINT process: Environmentally Process Optimised SINTering) uses the fact that the release of particulate and other species from the sinter bed tend to be more concentrated in those windboxes towards the discharge end of the sinter strand where the waste gas temperature rise shows a rapid acceleration (see Figure 3.7, for example). Those windboxes are selected for waste gas recycling where the burn-through is at or near the bottom of the bed. It was established that the temperature of the recycled gas should be the same as the gas led to the waste gas stack to avoid corrosion problems in resulting gases at temperatures below the acid dewpoint. At the Voestalpine Stahl sinter plant in Linz, Austria windboxes 11 to 16 of the newly extended strand were found to be the most suited for waste gas recycling. This is shown schematically in Figure 3.24. A second suction fan is installed parallel to the existing process fan to ensure that the suction pressure for sintering can be maintained.
This fan is designed to take the waste gases from the selected windboxes and recycle it via an ESP to the recirculation gas hood.

![Schematic diagram of the EPOSINT gas recycling technique installed at sinter strand No. 5 of Voestalpine, Linz, Austria](image)

[307]

The area in which the temperature increases may vary along the strand length dependent upon the sinter mix and other operational considerations. A feature of this process is the ability to divert the waste gases from the individual windboxes in the range 11 to 16 independently to the stack or to the recirculation hood. This feature gives the process a high degree of flexibility.

To overcome the problem of oxygen deficiency in the recirculated gases, the hot exhaust gases from the sinter cooler are returned to the system via another fan, a gas mixing chamber and the recirculation hood. Not only does this have the effect of boosting the oxygen level in the recirculation hood to help ensure that sinter quality can be maintained, but it also increases the potential to reduce the coke rate by increasing the gas temperature and decreasing the diffuse particulate emissions from the cooler.

The hood structure covers the entire width of the strand and is sealed to the pallet sidewalls through a non-contact, narrow gap labyrinth seal preventing unintentional release of the recirculated gas and dust particles. Since the entire pallet structure is not enclosed, the pallet wheels, etc. are able to operate in a clean atmosphere eliminating wear/failure from dust ingress to the bearings. The seal provides security against the escape of the recirculated gas containing CO and special measures are in place to prevent escapes due to plant or instrument failures. The hood structure does not extend across the whole length of the strand (see Figure 3.24), allowing cold air to be drawn through the sinter bed in the last few windboxes. This helps to ensure that the sinter is appropriately cooled on the strand prior to the cooler and facilitates ease of removal of pallets as necessary from time to time for maintenance purposes.
Some characteristics of this technique are:

- the recirculation of a part of the waste gas is selective from the field of rising temperature, where all relevant emissions are higher than the average values
- the recirculation leads to a reduction in coke breeze consumption and waste gas volume
- the gas recycling hood covers the sinter strand width
- the gas recycling hood does not cover the whole suction area
- due to the low $O_2$ concentration in the recirculated waste gas, in combination with a high efficient sealing system of the hood to minimise false air, additional air from the sinter cooler is used. To ensure that there are no negative effects on sinter production and sinter quality, the minimum $O_2$ concentration in the recirculated gas (i.e. process combustion air) is 13 %.

**Achieved environmental benefits**

Some environmental advantages of this technique are a decrease in energy consumption, up to 40 % reduction in off-gas volume and a decrease in coke consumption. Recirculation of sinter waste gas (also used in the case of techniques described in Sections 3.3.5.2.1 and 3.3.5.2.4) reduces the emissions of NOX and PCDD/F due to their decomposition in the sinter bed. SOX is also absorbed or filtered by the sinter layer and the CO is used as fuel. With this gas recirculation technique not only is a significant reduction of waste gas volume achieved, but particulate and gaseous emissions reductions are also achieved and the abatement of diffuse dust emissions of the sinter cooler is also realised. Table 3.38 shows the benefit from the application of the selective waste gas recirculation technique in percentages for certain parameter.

![Table 3.38: Main environmental benefits](307)

Table 3.39 gives some operational data for the emissions concentrations and emissions factors before and after the application of the selective waste gas recirculation technique for one plant in Austria.
### Cross-media effects

The additional electrical energy due to the additional fan is recouped through higher production and a decrease in the solid fuel requirement of 2 - 5 kg coke/t sinter. Special attention must be paid to carbon monoxide (CO) in the recirculated waste gas in order to prevent carbon monoxide poisoning of employees.

### Operational data

Sinter strand No. 5 of Voestalpine Stahl in Linz has operated with this technique since April 2005. The quality parameters for the product sinter remained the same as before the installation of the technology. The reduction in coke breeze consumption is reported at 2 - 5 kg/t sinter (45 kg/t sinter to 40 kg/t sinter). There have been no reported problems associated specifically with the process. Some operational advantages of this technique are an increased sinter production per Nm$^3$ off-gas and stable sinter quality and the capacity of existing sinter plants can be increased by approx. 40 % (e.g. by lengthening the sinter machine) without any increase of the sinter off-gas volume.

### Applicability

Waste gas recirculation with this technique can be implemented in new and existing sinter plants. In the Linz plant, it was possible to design the system so as to retain the existing waste gas system (i.e. collecting main, gas cleaning system, main fan and stack) that remained unmodified.

### Economics

Investment costs for a suction area of 250 m$^2$ are about EUR 15 million. At the plant cited, the installation was particularly economic because no modifications had to be made to the existing waste gas system. A reduction in operating costs results from a decrease in fuel consumption of about 2 - 5 kg coke/t sinter and a minimisation of costs for waste gas cleaning due to a smaller gas volume, especially when using expensive gas cleaning systems such as fine wet scrubbers or bag filters with addition of adsorbing agents.

The application of this technique lowers the investment and operational costs for modern waste gas cleaning facilities.

### Driving force for implementation

No data submitted.
Example plants
This technique has been in operation since May 2005 at Voestalpine in Linz, Austria on sinter strand No. 5 and has been upgraded from 56 to 74 m.

Reference literature
[217] [295] [307] [424]

3.3.5.2.4 Recycling of parts of waste gas to other parts of the sinter strand

Description
The concept of selective recycling technique is based on a local suction of the sintering waste gas under the strand and its local recycling above the sinter bed. This selective suction and recycling is the main difference between this and the Emission optimised sintering (EOS) process. Figure 3.25 shows a schematic diagram of such a sectional waste gas recirculation implemented at a sinter plant in Japan.

![Schematic diagram of selective waste gas recirculation](image)

In this case, the 480 m² sintering surface is divided into four different zones:

- **zone 1**: gas corresponding to the preheating Section of the raw mix to be recycled in the middle of the strand (high O₂, low H₂O, low temperature) (see Figure 3.5, Figure 3.7 and Table 3.40)
- **zone 2**: gas low in SO₂, to be discharged at the stack after dedusting (low O₂, high H₂O, low temperature) (see Figure 3.5, Figure 3.7 and Table 3.40)
- **zone 3**: gas rich in SO₂, to be discharged at the stack after dedusting and desulphurisation (scrubbing with a magnesium hydroxide solution, in this case) (low O₂, high H₂O, low temperature) (see Figure 3.5, Figure 3.7 and Table 3.40)
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- zone 4: gas rich in SO₂, corresponding to the hot Section around the flame front, to be recycled in the first half of the strand just after the ignition zone (high O₂, low H₂O, very high temperature) (see Figure 3.5, Figure 3.7 and Table 3.40).

In this procedure, the O₂ concentration of the recycled waste gas remains high (19 %) and the moisture low (3.6 %). A recycling rate of 25 % is achieved without a negative impact on sinter quality (the RDI remains practically constant and the SI (Shatter Index) increases by 0.5 %). A solid fuel saving 6 % is also reported.

There are two advantages to this system compared to conventional sintering:

1. The unused oxygen in the waste gas can be used effectively by recirculation.
2. The waste gas from the different sections can be treated separately depending on the composition of the gas. Thus, investments and operational costs of waste gas treatment facilities can be significantly reduced compared to conventional sintering even in comparison with the EOS system.

<table>
<thead>
<tr>
<th>Waste gas flow section</th>
<th>Waste gas composition</th>
<th>Waste gas treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flow kNm³/h</td>
<td>Temp. °C</td>
</tr>
<tr>
<td>Windbox 1 - 3</td>
<td>62</td>
<td>82</td>
</tr>
<tr>
<td>Windbox 4 - 13 + 32</td>
<td>290</td>
<td>99</td>
</tr>
<tr>
<td>Windbox 14 - 25</td>
<td>382</td>
<td>125</td>
</tr>
<tr>
<td>Windbox 26 - 31</td>
<td>142</td>
<td>166</td>
</tr>
<tr>
<td>Stack</td>
<td>672</td>
<td>95</td>
</tr>
</tbody>
</table>

Table 3.40: Characteristics of waste gas flows using sectional waste gas recirculation at Tobata No. 3 sinter plant, NSC’s Yawata works

[119]

Achieved environmental benefits

The following improvements have been achieved in terms of pollution abatement: a substantial decrease in the waste gas released into the atmosphere (about 28 %), in dust emissions (about 56 %). Note that this includes the effect of revamping the electrostatic precipitator, which is equipped with moving electrodes) and in the SO₂ discharge (about 63 %, including the end-of-pipe desulphurisation of the gas arising from zone 3). A slight decrease in the NOₓ emissions (about 3 %) is also reported. Table 3.41 compares emissions before and after the application of sectional waste gas recirculation.
Table 3.41: Comparison of final waste gas composition before and after rebuild to sectional waste gas recirculation

<table>
<thead>
<tr>
<th>Characteristic/Component</th>
<th>Unit</th>
<th>Conventional (with desulphurisation plant)</th>
<th>Sectional waste gas recirculation</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste gas flow</td>
<td>Nm³/h</td>
<td>925000</td>
<td>665000</td>
<td>28 %</td>
</tr>
<tr>
<td>Particulate matter¹</td>
<td>mg/Nm³</td>
<td>50</td>
<td>30²</td>
<td>56 % by mass</td>
</tr>
<tr>
<td>SO₂³</td>
<td>mg/Nm³</td>
<td>26</td>
<td>14</td>
<td>63 % by mass</td>
</tr>
<tr>
<td>NOX</td>
<td>mg/Nm³</td>
<td>408</td>
<td>559</td>
<td>3 % by mass</td>
</tr>
<tr>
<td>Net energy consumption</td>
<td>GJ/t sinter</td>
<td>1.662</td>
<td>1.570</td>
<td>6 %⁴</td>
</tr>
</tbody>
</table>

1) Waste gas treated by electrostatic precipitation
2) Reduction in dust emissions partially achieved by repairing ESP
3) Part of waste gas treated in desulphurisation unit
4) This reduction in net energy consumption has to be considered in relation to the relative productivity and quality requirements in Japan and the EU sinter plants

Cross-media effects
Installing additional fans results in more electricity being consumed. However, this increased energy demand is negligible compared to the decreased coke breeze consumption.

Operational data
A system using sectional waste gas recirculation was installed in the Tobata No.3 sinter plant at Nippon Steel Corporation's Yawata Works in October 1992. The waste gas is divided into four sections, each of which is treated separately. The system operates smoothly and waste gas recycling does not affect the sinter quality. However, this latter point has to be considered in relation to the lower productivity of the cited Japanese plant when compared with many sinter plants in the EU.

Applicability
Sectional waste gas recirculation can be applied at both new and existing plants although it is recognised that investment costs would be lower for a new plant incorporating the system from the planning stage than at some existing plants which may have considerably higher costs due to plant design.

Economics
European investment costs for the gas recycling system were quoted at EUR 8 - 10 million in 1997, excluding the deNOₓ, deSOₓ and other abatement equipment. Operational costs were reported confidentially. A 6 % reduction in coke consumption was reported.

Driving force for implementation
No data submitted.

Example plants
There are five plants in Japan which apply this technique. The data given here refer to Tobata No. 3 sinter plant, Yawata Works, Nippon Steel Corporation.

Reference literature
[65] [119]
3.4 Best available techniques for sinter plants

In understanding this section and its contents, the attention of the reader is drawn back to the Preface of this document and in particular the fifth section of the Preface: ‘How to understand and use this document’. The techniques and associated emission and/or consumption levels, or ranges of levels, presented in this section have been assessed through an iterative process involving the following steps:

- identification of the key environmental issues for sinter plants in the iron and steel industry
- examination of the techniques most relevant to address those key issues
- identification of the best environmental performance levels, on the basis of the available data in the European Union and worldwide
- examination of the conditions under which these performance levels were achieved; such as costs, cross-media effects, main driving forces involved in implementation of these techniques
- selection of the best available techniques (BAT) and the associated emission and/or consumption levels for this sector in a general sense all according to Article 2(12) and Annex IV to the Directive.

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

On the basis of this assessment, best available techniques, and as far as possible emission and consumption levels associated with their use, are presented in this section that are considered to be appropriate to the sinter plants and in many cases reflect current performance of some installations within the sector. Where emission or consumption levels ‘associated with best available techniques’ are presented, this is to be understood as meaning that those levels represent the environmental performance that could be anticipated as a result of the application, for sinter plants, of the techniques described, bearing in mind the balance of costs and advantages inherent within the definition of BAT. However, they are neither emission nor consumption limit values and should not be understood as such. In some cases it may be technically possible to achieve better emission or consumption levels but due to the costs involved or cross-media considerations, they are not considered to be appropriate as BAT for the sinter plants. However, such levels may be considered to be justified in more specific cases where there are special driving forces.

The emission and consumption levels associated with the use of BAT have to be seen together with any specified reference conditions (e.g. averaging periods).

The concept of ‘levels associated with BAT’ described above is to be distinguished from the term ‘achievable level’ used elsewhere in this document. Where a level is described as ‘achievable’ using a particular technique or combination of techniques, this should be understood to mean that the level may be expected to be achieved over a substantial period of time in a well maintained and operated installation or process using those techniques.

Where available, data concerning costs have been given together with the description of the techniques presented in the previous Section 3.3. These give a rough indication about the magnitude of costs involved. However, the actual cost of applying a technique will depend strongly on the specific situation regarding, for example, taxes, fees, subsidies and the technical characteristics of the installation concerned. It is not possible to evaluate such site-specific factors fully in this document. In the absence of data concerning costs, conclusions on economic viability of techniques are drawn from observations on existing installations.
In this section, for sinter plants specific techniques are considered as BAT (including the associated emission and consumption levels). ‘Best Available Techniques’ for a specific installation will usually be the use of one individual techniques or a combination of the techniques and measures listed in this section. Additionally, general BAT elements which can apply for the whole sector, mentioned in Section 2.8, have to be considered.

Where techniques identified individually as BAT can be used in combination, the effects of such combinations should be considered when drawing conclusions on BAT based permit conditions for individual cases.

If not otherwise mentioned, the BAT associated emission levels (BAT-AELs) given in this section are expressed on an annual average basis under standard conditions.

The BAT (including the associated emission and consumption levels) given in this chapter are ‘BAT in a general sense’ (i.e. considered to be appropriate to the sector as a whole). It is intended that they are a reference point against which to judge the current performance of an existing installation or to judge a proposal for a new installation. In this way, they will assist in the determination of appropriate ‘BAT-based’ conditions for the installation or in the establishment of general binding rules under Article 9(8) of the Directive. It is foreseen that new installations can be designed to perform at or even better than the BAT levels presented in this section. It is also considered that existing installations could move towards the BAT levels presented in this section or do better, subject to the technical and economic applicability of the techniques in each case.

While the BAT reference documents do not set legally binding standards, they are meant to give information for the guidance of industry, Member States and the public on achievable emission and consumption levels when using specified techniques. The appropriate permit conditions for any specific case will need to be determined taking into account the objectives of the IPPC Directive and the local considerations.

**Air**

1. **BAT for storage, handling and transport (see Sections 2.6.3 and 2.6.5)**

   **Blending/Mixing**

2. **BAT is to prevent or reduce diffuse dust emissions by applying the following techniques individually or in combination (see Section 2.6.3 and 2.6.5):**
   - I. storage and handling of dusty materials in an enclosed space
   - II. agglomerate fine materials by adjusting the moisture content.

3. **Sinter strand primary emissions**

   3. **BAT is to simultaneously reduce dust and heavy metals emissions from the sinter strand waste gas by applying prededusting (e.g. with ESP, Cyclones) (see Sections 3.3.2.1 and 3.3.2.3) and subsequent fine dust abatement by means of a bag filter (see Section 3.3.2.2).**

   The BAT-AEL for dust is <10 mg/Nm³, determined as a daily mean value

4. **BAT is to prevent or reduce mercury emissions by selecting raw materials with a low mercury content (see Section 2.6.3).**
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Sinter secondary emissions from strand discharge, sinter crushing, cooling, screening and conveyor transfer points

5. BAT for these processes is to achieve an efficient extraction of dust emissions and subsequently to reduce dust emissions by applying the following techniques individually or in combination (see Section 3.3.3):
   I. Hooding
   II. Enclosure
   III. ESP
   IV. bag filter

The BAT-AEL for dust is <20 mg/Nm³, determined as a daily mean value.

Sinter strand waste gas

6. BAT is to reduce SO₂ emissions by lowering the sulphur input by the following techniques individually or in combination (see Section 3.3.2.7):
   I. using coke breeze with a low sulphur content
   II. minimisation of coke breeze consumption
   III. using iron ore with a low sulphur content

The BAT-AEL for these techniques is <500 mg SO₂/Nm³, determined as a daily mean value.

7. BAT is to reduce SO₂ emissions by injection of adequate adsorption agents into the waste gas duct of the sinter strand before dedusting by bag filter (see Section 3.3.2.7.2).

The BAT-AEL is <350 mg SO₂/Nm³, determined as a daily mean value.

8. BAT is to reduce NOₓ emissions by the application of waste gas recirculation (see Section 3.3.5.2).

The BAT-AEL is <500 mg NOₓ/Nm³, determined as a daily mean value.

9. BAT is to achieve NOₓ emissions reduction by applying one of the following techniques (see Section 3.3.2.8.1 and 3.3.2.8.2):
   I. regenerative activated carbon process (RAC)
   II. selective catalytic reduction (SCR)

The BAT-AEL with RAC is <250 and with SCR <120 mg NOₓ/Nm³, determined as a daily mean value.

Due to the high cost waste gas nitrogen oxide reduction is not applied except in circumstances where environmental quality standards are not likely to be met.

10. BAT is to prevent and/or reduce PCDD/F and PCB by applying the following techniques individually or in combination (see Section 3.3.2.2 and 3.3.2.6):
    I. avoidance of raw materials containing PCDD/F and PCB or their precursors as far as possible
    II. application of waste gas recirculation
    III. injection of adequate adsorption agents into the waste gas duct of the sinter strand before dedusting with bag filter

The BAT-AEL for PCDD/F is <0.2 ng I-TEQ/Nm³ for a 6 - 8 hours random sample and steady state conditions.
Chapter 3

Water

Water consumption

11. BAT is to minimise the water consumption by complete recycling of cooling water (see Section 3.2.2.2).

Waste Water treatment and discharge (not cooling water)

12. BAT is to treat the effluent water prior to discharge by applying a combination of the following techniques:
   I. heavy metal precipitation
   II. neutralisation
   III. sand filtration.
   (Relevant only when rinsing water is used or when wet waste gas treatment system is applied.)

The BAT-AELs are:
   - Suspended solids <30 mg/l
   - COD 100 mg/l
   - Heavy metals <0.1 mg/l (Sum of As, Cd, Cr, Cu, Hg, Ni, Pb, and Zn)

The BAT-AELs are based on a qualified random sample or a 24-hour composite sample.

Production residues (wastes and by-products)

13. BAT is to recycle dust, sludge and mill scale containing iron and carbon from the sinter strand and other processes in the integrated steelworks back to the sinter strand, taking into account the respective oil content (see Section 3.3.4).

14. BAT is to lower the hydrocarbon content of the sinter feed by appropriate selection and pretreatment (see Section 3.3.2.5.1).

In all cases, the oil content of the recycled process residues should be <0.1 %.

15. The following techniques are BAT for treating solid wastes and should be applied in descending order of priority (see Section 3.3.4):
   I. effective on-site recycling of solid wastes by a fully closed dust cycle
   II. selective on-site recycling (e.g. exclusion of dust from last ESP field) back to the sinter process by excluding heavy metal, alkali or chloride enriched fine dust fractions
   III. whenever on-site recycling is hampered, external recycling should be considered
   IV. if all recycling is hampered, controlled disposal of solid wastes in combination with the minimisation principle is the only option. For this reason water extraction with subsequent precipitation of heavy metals should be applied in order to minimise the quantity to landfill.

16. BAT for the handling, storage and transport of solid wastes see general Section 2.6.4.

Energy

17. BAT is to reduce thermal energy consumption by applying the following techniques individually or in combination (see Section 3.3.5):
   I. recovering of sensible heat from the sinter cooler waste gas
   II. recovering of sensible heat if feasible from the sintering grate waste gas
   III. maximising the recirculation of waste gases to use sensible heat, if sinter quality and productivity are not significantly affected.

Noise

(see Section 2.6.9)
Chapter 4

4 PELLETISATION PLANTS

As mentioned in Section 3.1.1, the pelletisation and sintering of iron ore are complementary process routes for the preparation of iron oxide raw materials for primary iron and steelmaking. Each has its own specific advantages and drawbacks. These are highly influenced by local conditions such as the availability and type of raw materials. For various reasons, sinter is practically always produced at the steelworks side: it allows solid wastes to be recycled; coke breeze is available at the steelworks for use as a fuel; sinter is prone to degradation during transport and handling. Pellets are formed from the raw materials – fine ore and additives of $<0.05 \text{ mm}$ – into 9 - 16 mm spheres using very high temperatures and this is mainly carried on at the site of the mine or its shipping port. In the EU, there is only one integrated steelworks which includes a pelletisation plant (in the Netherlands). In 2007, Sweden had five standalone pelletisation plants. Pellet production in these six plants in 2007 was about 27 million tonnes/yr. The consumption of pellets in the EU–25 is about 43 million tonnes. This means that compared to the use of sinter, the consumption of pellets is three times lower.

4.1 Applied processes and techniques

Pellets are small crystallised balls of iron ore with a size of 9 - 16 mm. Figure 4.1 shows the balling drum, which is part of a pelletisation plant.

![Figure 4.1: Balling drum as part of a pelletisation plant where the green pellets are formed](image)

The pelletisation process consists of grinding and drying or dewatering, wetting and mixing, balling and induration followed by screening and handling (see Figure 4.2).
4.1.1 Grinding and drying/dewatering

Before being fed into the pelletisation plant, the ore is upgraded by several sorting and benefication steps with intermediate crushing and grinding. The properties of the ore make magnetic separation the predominant means of concentrating.

In the Dutch plant, grinding is carried out at relatively high temperatures (approx. 100 °C) where the material is simultaneously dried with hot air from the induration stage (see Section 4.1.3).

At the Swedish plants, grinding and concentration are wet processes (see Figure 4.3). Additives (olivine, dolomite, quartzite and/or limestone depending on the end-product) are ground and then added to the ore slurry, typically at a level of 3 to 3.5 %, before dewatering.
4.1.2 Green ball preparation

After hot grinding, the material is combined with additives before being rewetted in a separate wetting stage and is mixed with a binder (bentonite or organic binder dependent upon the type of pellet). In both cases, the moisture content is adjusted to 7 - 9%.

The moisture adjusted pellet feed (raw mixture) is then processed in the (green) ball preparation plant. This is typically equipped with four to seven balling circuits consisting of a feed bin, balling drum, roller screens and conveyors for circulating the materials. The balling drum is inclined 6 to 8° to the horizontal plane. To obtain a well defined green ball size, typically in the range of 9 to 16 mm, under- and oversised fractions are screened off and recirculated within the balling stage.
4.1.3 Induration

Induration, which means thermal treatment, consisting of drying, heating and cooling can be carried out in two different systems: in ‘straight grate’ or ‘grate kiln’ systems. During thermal treatment, magnetite is almost completely oxidised to hematite. Swedish ores have a very high magnetite content. Since the oxidation of magnetite is exothermic this reaction can supply up to 60% of the energy needed for pellet induration. Ores processed in the Dutch plants have a lower magnetite content of about 25% (see Table 4.1 energy and fuel demand).

4.1.3.1 The straight grate process

The straight grate process consists of a travelling grate divided into a number of different sections for drying, preheating, firing and cooling the green balls (see Figure 4.4).

![Figure 4.4: Schematic of the straight grate process MK3](image)

Before the green balls are fed onto the grate bars, the bars are covered with a 5 to 10 cm thick hearth layer of fired pellets. The green balls are then charged on top of the hearth layer to form a gas permeable bed with a total depth of 40 - 55 cm. The green balls must be heated to approximately 1250 °C during oxidation and sintering to obtain pellets of a high strength. This can be achieved by means of a row of burners on each side of the travelling grate, usually fired with oil or gas. In integrated steelworks, COG or BOF gas is used and to a small amount coke breeze. At the end of the induration strand, a fraction of indurated pellets is recycled for use as the hearth layer.
4.1.3.2 The grate kiln process

The grate kiln process consists of a travelling grate similar to the straight grate process. The firing takes place in a rotary kiln but the cooling is carried out in a separate annular cooler.

The travelling grate consists of an endless chain of grate plates which are connected with windboxes in a gas-tight manner. The green balls are fed directly onto the grate plates to create a bed of about 20 - 25 cm deep. After pretreatment on the grate, the pellets are charged via a chute to the rotary kiln. The kiln has a single oil- or coal-fired burner at the discharge end, and operates at a temperature of approximately 1250 °C. The annular cooler has a grate bottom which permits cool air to penetrate the pellet layer. Walls divide the cooler into sections so as to provide hot air to the earlier process steps.

When processing magnetite ores, oxidation to hematite and sintering takes place in the upstage preheating parts of the travelling grate, the rotary kiln and the cooling zones.

4.1.4 Screening and handling

At the end of the induration strand, the pellets are collected and screened. Undersise or broken pellets can be recycled, e.g. as hearthlayer (see Figure 4.2). Significant particulate matter emissions may occur.

For the standalone plants in Sweden, the heat treated pellets are kept in covered product bins before charging to open railway wagons for transportation to the harbours at Narvik and Luleå. In connection with ship loading, 2 - 3 % of the material is screened off as undersised, and is sold as sinter feed. As for all blast furnace material (coke, sinter, pellets and lump ore), a final screening takes place at the blast furnace site.

4.2 Current emission and consumption levels

4.2.1 Mass stream overview and input/output-data

Figure 4.7 gives an overview of the input and output mass streams of a pelletisation plant. This overview may be used for the collection of data from single pelletisation plants.
Subsequently, both specific input factors and emission factors have been determined. Values of these factors at various pelletisation plants in the EU are shown in Table 4.1.
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#### 4.2.2 Environmental issues for the pellet making process

The pelletisation plant is primarily a source of particulate matter and gaseous emissions to air. When abatement techniques are applied to reduce emissions, cross-media effects occur. Sections 4.2.2.1 to 4.2.2.5 below describe the most relevant environmental issues for pelletisation plants.

---

<table>
<thead>
<tr>
<th>Input</th>
<th>Product</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw materials</td>
<td>Product</td>
<td>Output</td>
</tr>
<tr>
<td>iron ore kg/t</td>
<td>935 - 965</td>
<td>pellets kg/t</td>
</tr>
<tr>
<td>bentonite kg/t</td>
<td>4.1 - 6.8</td>
<td></td>
</tr>
<tr>
<td>olivine2) kg/t</td>
<td>0 - 27.6</td>
<td>Emissions</td>
</tr>
<tr>
<td>limestone kg/t</td>
<td>0 - 5</td>
<td>waste gas flow Nm³/t</td>
</tr>
<tr>
<td>dolomite1) kg/t</td>
<td>0 - 13.5</td>
<td>dust g/t</td>
</tr>
<tr>
<td>quartzite kg/t</td>
<td>0 - 20</td>
<td>dust mg/Nm³</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cd mg/t</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cr mg/t</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cu mg/t</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hg9) mg/t</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mn mg/t</td>
</tr>
<tr>
<td>Energy</td>
<td></td>
<td>Ni mg/t</td>
</tr>
<tr>
<td>COG/BOF3) MJ/t</td>
<td>306</td>
<td>Pb mg/t</td>
</tr>
<tr>
<td>natural gas3) MJ/t</td>
<td>14</td>
<td>Tl mg/t</td>
</tr>
<tr>
<td>Coke breeze3) MJ/t</td>
<td>342</td>
<td>V mg/t</td>
</tr>
<tr>
<td>Coal4) MJ/t</td>
<td>223</td>
<td>Zn mg/t</td>
</tr>
<tr>
<td>Oil7) MJ/t</td>
<td>43 - 186</td>
<td>HF5), 10) g/t</td>
</tr>
<tr>
<td>electricity MJ/t</td>
<td>54 - 99</td>
<td>HCl5), 10) g/t</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SOX6), 10) g/t</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NOx g/t</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NOx mg/Nm³</td>
</tr>
<tr>
<td>Water m³/t</td>
<td>0.11 - 1.25</td>
<td>CO g/t</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CO₂ kg/t</td>
</tr>
<tr>
<td></td>
<td></td>
<td>VOC7) g/t</td>
</tr>
<tr>
<td>Compressed air Nm³/t</td>
<td>6.2 - 12.8</td>
<td>PAH6) mg/t</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PCDD/F4) ng I-TEQ/ t</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PCDD/F4) ng I TEQ/Nm³</td>
</tr>
<tr>
<td></td>
<td>Production residues (waste/by-products)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dusts kg/t</td>
<td>-</td>
</tr>
</tbody>
</table>

---

1) in the case of pellets production for direct reduction
2) in the case of pellets production for blast furnaces
3) when the pelletisation plant is part of an integrated steelworks (i.e. NL). Data from [200]
4) in the case of standalone pelletisation plants in Sweden (magnetite ores). Data from [200]
5) lower value if techniques for removal of acidic waste gas components are applied
6) lower value if desulphurisation techniques are applied
7) measurement technique is not known
8) information as to whether it is Borneff 6, EPA 16 or benzo(a)pyrene is not available
9) mercury predominately in elemental form. Load depends on ores processed
10) calculated from mass balance

Data are from 2004 and relates to three pellet plant sites that produced almost 13 million tonnes of pellets in 2004 between them, representing around 63 % production in the EU-25

---

Table 4.1: Input/output data from three pellet plant sites in the EU-25 [200] [208] [318]
4.2.2.1 Emissions to air

Particulate matter emissions from grinding
Process discharge gas after the air classifier step contains large quantities of particulate matter. This particulate matter consists mainly of iron (Fe) and reflects the composition of the raw material. Emissions can be abated by means of electrostatic precipitation.

Particulate matter from screening and handling
Screening and handling takes place at the balling stage, which is at the beginning and at the end of the induration strand, where the pellets are collected and screened. Significant particulate matter emissions may occur.

Particulate matter and gaseous emissions from the induration strand
Emissions of gas and particulate matter originate from the firing zone of the induration strand. They occur continuously and have to be removed by efficient ESPs, bag filters or scrubbing.

NOX emissions from induration and drying
Emitted NOX are formed during combustion via two mechanisms. The oxidation of nitrogen compounds in the hydrocarbon fuel generates “fuel NOX”. The other, and most important mechanism, is the formation of NOX in the pelletisation process as a result of the high temperatures involved. These cause airborne nitrogen and oxygen to dissociate and react to form “thermal NOX”. The data shown in Table 4.1 reflect the significant differences in NOX formation. Sometimes the coke breeze is substituted by anthracite which can lead to a reduction of NOX emissions of up to 25%. Another applied way to reduce the NOX emissions is to inject water to lower the peak temperatures.

SO2 emissions from induration
Sulphur dioxide (SO2) is formed during the induration process. The source of sulphur is primarily from the coal and oil and to a lesser extent from the ores. Table 4.1 shows that SO2 emissions are about ten times higher when abatement techniques are not applied.

HCl and HF emissions
The pelletisation plant is also a source of hydrofluoric acid (HF) and hydrochloric acid (HCl). These components are formed during minerals (apatite) induration which are present in the ore and contain fluorine and chlorine. Table 4.1 indicates that emissions of HF and HCl are about ten times higher without application of abatement techniques.

Ores from Sweden are known to contain a high content of fluoride (see Section 3.2.2.1.2.5)

Polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/F)

PCDD and PCDF formation during high temperature processes are generally explained by two different mechanisms:

1. Incomplete destruction of PCDD/F present in raw material/fuel.
2. ‘de novo’ synthesis from carbon and chlorine sources.

During combustion at pelletising plants, ring-structured hydrocarbon species (precursors) are partly formed as intermediate combustion products. In the presence of chlorine, these can react to form PCDD/F. Precursors include dibenzofurans or polycyclic aromatic compounds (PAH) formed through incomplete combustion. Soot is another source of dioxin formation as oxidation can contribute to the formation of non-chloride precursors. Reactions take place in cooling zones, preferably between 300 and 400 °C.
Chapter 4

Table 4.1 indicates significant differences in dioxin formation. Results from direct measurements range from 8.2 to 196 ng I-TEQ/t pellets. The reasons for this range can be explained by the facts that PCDD/F emissions are associated with:

- formation: the fewer precursors present, the less dioxin will be formed. The high oxygen content of flue-gases reduces the possibility of the presence of carbon precursors, so fewer PCDD/F compounds will form
- abatement techniques: if the flue-gas is quenched to low temperatures (<80 °C), the PCDD/F compounds formed will condense on dust particles, so PCDD/F emissions will become congruent to dust emissions
- effective dust abatement at low temperatures will remove PCDD/F effectively.

4.2.2.2 Water flows

Whenever scrubbers are used to remove pollutants, a waste water flow is generated. This waste water needs a bleed, due to the presence of HF. This bleed is relatively small when waste water recycling and NaOH addition are applied. In some cases, this bleed water is treated in an arsenic removal plant.

In addition, waste water is discharged from wet rinsing of the plant and equipment. In the plant at Corus IJmuiden, NL, this water is 100% recycled and this flow is about 0.04 m³/t pellets. Cooling water may derive from the grinding and drying section as well as from the induration strand. For the mentioned Dutch plant, the specific flow is 0.16 m³/t pellets from grinding and drying and 0.05 m³/t pellets from induration respectively.

For the Swedish plant the situation is to some extend special. Parts of the mine water are used as process water for scrubbers and wet ESPs in the refining stages. The process waste water, runoff water and mine water enters through a thickener from where it is further conducted to a tailing pond where pre-settling takes place. From there water is led to a clarification pond where additional sedimentation is achieved.

At the new pellet plant in Malmberget MK3 (Sweden), the pollution of the water is continuously measured. Table 4.2 shows the achievable concentration values for the plants located in Kiruna and Malmberget, Swedish.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Malmberget 2006</th>
<th>Malmberget 2007</th>
<th>Kiruna 2006</th>
<th>Kiruna 2007</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suspended solids</td>
<td>9.12</td>
<td>10.9</td>
<td>4.13</td>
<td>2.33</td>
<td>mg/l</td>
</tr>
<tr>
<td>Total N</td>
<td>39.5</td>
<td>41</td>
<td>19.8</td>
<td>17.5</td>
<td>mg/l</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>41.4</td>
<td>48.7</td>
<td>0.039</td>
<td>0.028</td>
<td>µg/l</td>
</tr>
<tr>
<td>Cadmium</td>
<td>0.018</td>
<td>0.011</td>
<td>0.025</td>
<td>0.014</td>
<td>µg/l</td>
</tr>
<tr>
<td>Cobalt</td>
<td>3.63</td>
<td>6.23</td>
<td>0.35</td>
<td>0.37</td>
<td>µg/l</td>
</tr>
<tr>
<td>Chromium</td>
<td>0.70</td>
<td>0.35</td>
<td>0.05</td>
<td>0.1</td>
<td>µg/l</td>
</tr>
<tr>
<td>Copper</td>
<td>2.30</td>
<td>3.73</td>
<td>2.68</td>
<td>4.03</td>
<td>µg/l</td>
</tr>
<tr>
<td>Mercury</td>
<td>&lt;0.002</td>
<td>&lt;0.002</td>
<td>&lt;0.002</td>
<td>&lt;0.002</td>
<td>µg/l</td>
</tr>
<tr>
<td>Lead</td>
<td>0.20</td>
<td>0.14</td>
<td>0.13</td>
<td>0.24</td>
<td>µg/l</td>
</tr>
<tr>
<td>Zinc</td>
<td>6.87</td>
<td>5.95</td>
<td>0.63</td>
<td>4.56</td>
<td>µg/l</td>
</tr>
<tr>
<td>Nickel</td>
<td>13.7</td>
<td>16</td>
<td>1.83</td>
<td>2.39</td>
<td>µg/l</td>
</tr>
<tr>
<td>Arsenic</td>
<td>3.34</td>
<td>1.47</td>
<td>3.56</td>
<td>0.7</td>
<td>µg/l</td>
</tr>
</tbody>
</table>

Table 4.2: Operational data from the Malmberget and Kiruna water treatment plants [461] [483]
4.2.2.3 Process residues such as wastes and by-products

The pelletisation plant itself is not a primary source of solid waste. However, the sorting and beneficication of raw materials is a source of solid waste. In addition, solid waste is generated whenever emissions of particulate matter are abated and sludge ends up as in the waste water treatment plant.

4.2.2.4 Energy consumption

Specific energy consumption has successively decreased during the last decades. The decrease has been made possible through systematic improvements of the process. In 2008 the specific energy consumption was in the range of 186 to 662 MJ/t of pellets.

There are some differences between the various types of plants both when it comes to the kind of energy used and the kind of energy consumed. The grate kiln process predominantly uses coal while the travelling grate process uses oil or gas.

At most pelletising plants in the world, as is the case in the Netherlands, carbon-bearing additives to the pellets provide part of the heat required for sintering. This case refers to the higher end of the range of external energy consumption, as mentioned above.

The Swedish standalone plants use ores predominantly from magnetite deposits which gives great advantages by magnetite oxidation. In fact, approximately 60% of the thermal energy required is supplied by magnetite oxidation, hence resulting in external thermal energy consumption at the lower end of the above-mentioned range.

To save energy, heat supplied from the oxidation of magnetite and fuel is recovered in the pelletising process. The main part of the surplus heat from the cooling sections of the machines is recirculated to the hot zones, thus reducing the need for external energy input. At some industrial sites waste heat is recovered into the internal heating system. Where it is practically possible, waste heat is also transferred into municipal heating networks.

4.2.2.5 Noise

The grinding drums are filled with 150 t of iron balls and turn with a speed of two revolutions per second. They generate noise emissions of about 85 dB (A).
4.3 Techniques to consider in the determination of BAT for pelletisation plants

This section sets out techniques considered generally to have potential for achieving a high level of environmental protection in the industries within the scope of the document. Management systems, process-integrated techniques and end-of-pipe measures are included, but a certain amount of overlap exists between these three when seeking the optimum results.

Prevention, control, minimisation and recycling procedures are considered as well as the re-use of materials and energy.

Techniques may be presented singly or as combinations to achieve the objectives of the IPPC Directive. Annex IV to this Directive lists a number of general considerations to be taken into account when determining BAT and techniques within this section will address one or more of these considerations. As far as possible, a standard structure is used to outline each technique, to enable comparison of techniques and an objective assessment against the definition of BAT given in the IPPC Directive.

The content of this section is not an exhaustive list of techniques and others may exist or be developed which may be equally valid within the framework of IPPC and BAT.

The standard structure used to outline each technique is shown in Table 4.3.

<table>
<thead>
<tr>
<th>Type of information considered</th>
<th>Type of information included</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Technical description of the technique (including drawings, schematics if necessary)</td>
</tr>
<tr>
<td>Achieved environmental benefits</td>
<td>Main environmental benefits (including energy, water, raw material savings, as well as production yield increases, energy efficiency, etc.) addressed by the technique</td>
</tr>
<tr>
<td>Cross-media effects</td>
<td>Main environmental side effects and disadvantages to other media caused by using the technique. Details of the environmental effects of the technique in comparison with others</td>
</tr>
<tr>
<td>Operational data</td>
<td>Data on consumption and emission levels from operational plants using the technique (including any reference conditions and monitoring methods used). Any other relevant information on how to operate, maintain and control the technique</td>
</tr>
<tr>
<td>Applicability</td>
<td>Indication of the type of plants in which the technique may be applied, considering, e.g. plant age (new or existing), plant size (large or small), techniques already installed and type or quality of product</td>
</tr>
<tr>
<td>Economics</td>
<td>Information on costs (both investment and operational) and any possible savings (e.g. reduced raw material or energy consumption, waste charges) or revenues including details on how these costs/savings or revenues have been calculated/estimated</td>
</tr>
<tr>
<td>Driving force for implementation</td>
<td>Local conditions or requirements which lead to, or may stimulate, implementation. Information on reasons other than environmental ones for implementation (e.g. increase in productivity, safety)</td>
</tr>
<tr>
<td>Example plants</td>
<td>Reference to (a) plant(s) in which the technique is applied and from which information has been collected and used in writing the section</td>
</tr>
<tr>
<td>Reference literature</td>
<td>Literature or other reference material (e.g. books, reports, studies, websites) that was used in writing the section and that contains more details on the technique</td>
</tr>
</tbody>
</table>

Table 4.3: Information breakdown for each technique described in this section
4.3.1 Electrostatic precipitation at the grinding mills (dry grinding)

Description
After grinding, the particles are separated by means of air classification. Coarse particles are recycled to the grinding mills and fine particles are transported to the balling drum, where the green pellets are made. The air used for the air classification contains large amounts of particulate matter. This is basically raw material and has to be captured. The characteristics of the particulate matter are such that emissions are usually abated effectively using electrostatic precipitation. The precipitate can be fed directly to the balling drum as it has the same composition as the raw material (iron ore (62 %) and coke breeze (8.5 %)).

Achieved environmental benefits
The ESP operates more or less as an integrated part of the air classification system. Achieved emissions concentrations are <15 mg/Nm³. Modern design ESPs may achieve lower emissions and hence recover raw materials as well.

Cross-media effects
The precipitate from the ESP is used as raw material in the balling mill. The operation of the ESP consumes energy. At a waste gas flow of 300000 Nm³/h and a production of 4 Mt/yr, the energy consumption is approximately 1 MJ/t pellet.

Operational data
No data submitted.

Applicability
ESPs are applicable for existing as well as for new plants.

Economics
An ESP is an integrated part of the plant design; part of the raw material from the air classification step is recovered by the ESP. However, it can be calculated that a dry ESP for treatment of a waste gas flow of 300000 Nm³/h will require an investment of approximately EUR 2 million (1996 prices). Operational costs can be calculated as EUR 0.03 to 0.05/t pellet (1996 prices) for a pelletisation plant with an annual production of 4 Mt and a drying mill waste gas flow of 300000 Nm³/h.

Driving force for implementation
No data submitted.

Example plants
Pelletisation plant, Corus Ijmuiden, the Netherlands.

Reference literature
[65] [318] [409]

4.3.2 Individual or combined reduction of solid and gaseous pollutants from the drying and induration zone

Description
In pelletisation plants several techniques are used for dust (particulate matter) removal. The main techniques used are mechanical collectors (for coarse particles), multicyclones, wet scrubbers, bag filters and electrostatic precipitators (ESP). ESPs and bag filters provide high cleaning efficiency but can operate only over a limited range of temperature and moisture conditions. Wet scrubbers are therefore also used in pelletisation plants to remove dust. Scrubbers can be highly efficient dust removers. Scrubbing water is collected, and treated by sedimentation (clarifier). The solid matter is recycled back into the process.
Achieved environmental benefits
Dust removal efficiency for the techniques listed above is normally >95 %, and in some cases >99 %. Emissions can be <10 mg/Nm³ (see Table 4.1). For example, at the latest Swedish plant, KK3 in Kiruna, the dust concentrations in the emitted waste gas from the drying and induration zone are below 10 mg/Nm³ and the total dust emissions from the plant as a whole are below 100 g/t pellets, applying scrubber for the abatement of emissions from the drying zone and ESP for the induration zone emissions.

An advantage of wet scrubbers is that SOₓ, HF and HCl can also be removed. Achievable emissions concentrations (wet scrubber with NaOH addition) for SO₂ are <50 mg/Nm³ and for both HF and HCl, <1 mg/Nm³. In addition, fumes and aerosols are also captured. With scrubbers the SO₂ emissions were reduced by approximately more than 95 % at LKAB Kiruna pellet plant in 1995.

Cross-media effects
Normally the collected dust is recycled to the pelletisation process. In the case of scrubbers, some surplus water has to be discharged after appropriate treatment.

The application of bag filters requires the waste gas streams to be reheated after the scrubbers.

Operational data
No specific problems are known.

Applicability
The end-of-pipe techniques described can be applied both at new and existing plants.

Economics
A study has been performed in one installation of a bag filter downstream of the scrubber. Since it is necessary to reheat the waste gas streams after the scrubbers, the investment and operational costs include a provision for the costs of heating. The investment cost for bag filters including reheating equipment is estimated at EUR 25 million. Operational costs are high, EUR 8 million/yr, mainly due to the cost of reheating [412].

Driving force for implementation
No data submitted.

Example plants
KK3 pelletisation plant, LKAB, Kiruna, Sweden, Corus Ijmuiden, the Netherlands.

Reference literature
[65] [208] [318] [409] [412] [413] [529]

4.3.3 Gas suspension absorber (GSA)
Description
The GSA is a semi-dry process. A wet lime slurry is sprayed in the waste gas in a fluidised bed reactor. The water from the lime slurry evaporates and the slaked lime reacts with the impurities (HF, HCl and SO₂). A high concentration of particulate matter in the waste gas enhances the performance of the GSA and as it increases the reaction surface, particulate matter is coated with the slaked lime solution.

After the fluidised bed reactor, the waste gases are led through cyclones. Part of the dry product (reacted lime and particulate matter) is removed here and recirculated into the reactor, in order to maintain a high concentration of particulate matter in the reactor. Final cleaning of the waste gas is performed using electrostatic precipitation.
The rate of injection of slaked lime is proportional to the SO$_2$ concentration in the waste gas.

**Achieved environmental benefits**

The performance data of a GSA at a pelletisation plant are summarised in Table 4.4. These data were provided by the Swedish company LKAB, which operates a GSA to treat the waste gas from the induration strand at their KK3 pelletisation plant. Waste gas from the drying zone of the induration strand is led through venturi scrubbers to remove particulate matter before being emitted to the air.

The values in Table 4.4 show the low overall emissions from this plant.

<table>
<thead>
<tr>
<th>Component</th>
<th>Before GSA (mg/Nm$^3$)</th>
<th>After GSA (mg/Nm$^3$)</th>
<th>Removal efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulphur oxides (SO$_2$)</td>
<td>300</td>
<td>9.6</td>
<td>96.8</td>
</tr>
<tr>
<td>Hydrofluoric acid (HF)</td>
<td>78</td>
<td>&lt;0.1</td>
<td>99.9</td>
</tr>
<tr>
<td>Hydrochloric acid (HCl)</td>
<td>133</td>
<td>0.6</td>
<td>99.5</td>
</tr>
<tr>
<td>Particulate matter</td>
<td>1400</td>
<td>2</td>
<td>99.9</td>
</tr>
</tbody>
</table>

Notes: KK3 pelletisation plant of LKAB, Kiruna in 1995

Table 4.4: Performance data of the Gas Suspension Absorber (GSA) [200]

The following data can be given for this plant: the plant was commissioned in January 1995 and has an annual production capacity of 4.5 Mt. Actual production in 1995 was 2.8 Mt pellet. The plant is equipped with two burners: one burner in the firing zone of the induration strand and one burner to increase the temperature of the off-gas from the second cooling section, which is used as preheating air in the first preheating zone.

**Cross-media effects**

A GSA is a semi-dry device, with an electrostatic precipitator (ESP) as the last cleaning stage. The dry precipitate from the ESP contains particulate matter, CaSO$_3$, CaCl$_2$, and CaF$_2$ and some unreacted lime (CaO). The dry precipitate is deposited.

Slaked lime consumption is 264 kg/h (design) and water consumption is 10.6 m$^3$/h (design). Furthermore, pressurised air (7 bar) is used: 690 kg/h (design). Energy consumption is about 0.64 MJ/t pellet (design).

**Operational data**

No specific problems are known.

**Applicability**

A GSA is an end-of-pipe measure that can be applied to both new and existing plants.

**Economics**

No data submitted.

**Driving force for implementation**

No data submitted.

**Example plants**

KK3 pelletisation plant, LKAB, Kiruna, Sweden.

**Reference literature**

[200] [409] [410]
4.3.4 Process-integrated NO\(_X\) abatement

**Description**

The primary sources for NO\(_X\) formation in a pelletisation plant are "thermal", "fuel" and "prompt" NO\(_X\). NO\(_X\) that is formed in the pellet bed mainly consists of "fuel" NO\(_X\) and "prompt" NO\(_X\). Both are formed by reactions between hydrocarbons in the coke breeze, nitrogen in the coke breeze and oxygen and nitrogen in the air. The main factors for "thermal" NO\(_X\) formation are the high temperatures (1300 - 1400 °C) in the induration strand and the high availability of oxygen in the burner zone. It is not possible to distinguish between the various forms of NO\(_X\) after they have formed, there being no difference in chemical composition. For pelletisation plants, it can be assumed that the overall NO\(_X\) emissions are dominated by "thermal NO\(_X\)".

The most important measure aims to reduce the formation of thermal NO\(_X\). This can be achieved by lowering the (peak) temperature in the burners and reducing the excess oxygen in the combustion air. Additionally lower NO\(_X\) emissions can be achieved by a combination of low energy use, low-Nitrogen content in the fuel (coal and oil) and limiting the excess oxygen.

**Achieved environmental benefits**

At the KK3 pelletisation plant of the company LKAB, Kiruna (Sweden) NO\(_X\) emissions from the firing zone are 175 - 196 g/t pellets or (with 2400 Nm\(^3\)/t pellets) 73 - 82 mg/Nm\(^3\). This plant was commissioned in January 1996 and no end-of-pipe techniques are used to reduce NO\(_X\) emissions. The low-NO\(_X\) emissions were achieved by a combination of low energy use, low nitrogen content in the fuel (coal and oil) and limiting the excess oxygen. The plant uses two large burners in the induration strand.

At the KK2 pelletising plant of the company LKAB, Kiruna (SE), the indirect coal firing technique is used. The NO\(_X\) emissions from this plant are 150 g/t pellets. The “indirect coal” means that the coal is milled, filtered and is stored before it is used in the burner. The technique makes it possible to finely adjust energy use and the amount of transport air is small which means that one of the requirements for the formation of thermal NO\(_X\) is minimised.

The situation at the Corus Ijmuiden, the Netherlands pelletisation plant is somewhat different. The plant uses 56 long burners (of which 44 are operated simultaneously). NO\(_X\) emissions from the induration strand are approx. 550 g/t pellet or (with 1940 Nm\(^3\)/t pellets) 283 mg/Nm\(^3\). Process-integrated measures at this plant are complicated and were tailor made for it.

The new pellet plant in Malmberget MK3, Sweden is equipped with extra burners in the recuperation hood to allow for lower flame temperatures in the burner hoods. This is expected that NO\(_X\) formation can be reduced. Furthermore, the burner chambers are designed to allow shaping and varying the geometry of the flame. In addition, long-term work has recently started on the development of new burner techniques for pelletising plants to reduce NO\(_X\).

**Cross-media effects**

No cross-media effects occur.

**Operational data**

No data submitted

**Applicability**

When building a new plant, process-integrated measures for reducing the generation of NO\(_X\) can be considered at the design stage. In the case of existing plants, process-integrated NO\(_X\) abatement techniques are preferable. Non design related measures can be considered for both new and existing plants.

**Economics**

Part of plant design in new plants.
Chapter 4

Driving force for implementation
The driving force is to lower national emissions to meet the national reduction goals according to national and international regulations, environmental reputation and improved economics.

Example plants
KK2 and KK3 pelletisation plants, LKAB, Kiruna, Sweden, Malmberget MK3, Sweden and Corus Ijmuiden, the Netherlands.

Reference literature
[200] [208] [318] [460]

4.3.5 Selective catalytic reactor (SCR)

Description
See Section 3.3.2.8.1.

Achieved environmental benefits
Reduction of NOX emissions.

Cross-media effects
See Section 3.3.2.8.1.

Operational data
The fact that the SCR might be successfully installed in a new pellet plant does not automatically mean that the installation would give the required effects at reasonable costs in existing plants. LKAB has already investigated the possibilities of end-of-pipe techniques for existing plants. Generally, the temperatures are too low to optimise the abatement of NOX. Therefore, the gas flow must be preheated in this kind of installation, which involves negative effects like increased fuel use and consequently higher emissions and costs.

Applicability
For the existing plants, both straight grate and grate kiln systems, it is difficult to obtain the operating conditions necessary to suit an SCR reactor. For a new pelletising plant, however, the plant and the SCR system can be correctly designed with respect to the required temperature of the reactor and moderate gas flows.

Economics
No data submitted.

Driving force for implementation
The driving force is to lower national emissions to meet the national reduction goals according to national and international regulations.

Example plants
LKAB will be involved in an extensive research programme on NOX abatement until 2010. In this respect it has been decided that the new pellet plant KK4 in Kiruna, Sweden, will be equipped with a deNOX facility.

The Alstom selective catalytic reduction reactor (SCR) was installed in KK4 for a full scale pilot test. The test started in spring 2008 and the result will be reported by the end of 2009. This installation will be the first in the world on a grate kiln pelletising plant and the aim is to evaluate an SCR reactor in a new plant, under circumstances where the working conditions for this technique can be optimised.
Laboratory tests concerning the life span for an SCR were performed on a small scale and so far these have given positive results. Many uncertainties still remain, however, regarding the functioning of an SCR reactor in pelletising plants.

Reference literature
[318]

4.3.6 Pellet plant water treatment

Description
The waste water from scrubbers undergoes neutralisation before it enters a circulation basin. From there it is further processed to settling tanks. The sedimentation properties of the sludge are very often improved by dosage of flocculation agents. A part of the waste water from the settler is re-used as scrubbing water. At Corus Ijmuiden, the Netherlands another part is directed as a bleed to the arsenic removal plant to be further precipitated (see Section 4.3.7).

Achieved environmental benefits
Precleaning of process water and separation of sludge enables the recycling of water in the scrubber.

Cross-media effects
Sludge needs to be recycled or disposed of and this may contain heavy metals such as Ni, Cr, and Cd.

Operational data
No specific problems are known.

Applicability
No data submitted.

Economics
No data submitted.

Driving force for implementation
No data submitted.

Example plants
Corus Ijmuiden, the Netherlands

Reference literature
[462]

4.3.7 Arsenic removal plant

Description
The waste water from the water treatment plant at the Corus Ijmuiden, the Netherlands, pellet plant contains dissolved arsenate (As\textsuperscript{5+}) and arsenite (As\textsuperscript{3+}). Arsenic compounds are present in some iron ores. The arsenite is converted to arsenate by means of Fenton’s reagent (combination of Fe(II) chloride and peroxide) at pH 7, after which the arsenate is precipitated. After dewatering, the filter cake containing arsenic can be recycled or disposed of. After sedimentation, the waste water passes two sand filters in order to remove residual suspended solids, and three ion exchangers to control the level of other heavy metals, e.g. Cd, Cr, Cu, Ni. See Figure 4.6.
Achieved environmental benefits
The operational data from the arsenic removal plant are shown in Table 4.5.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suspendid solids</td>
<td>&lt;10 - 95</td>
<td>mg/l</td>
</tr>
<tr>
<td>COD</td>
<td>56 - 81</td>
<td>mg/l</td>
</tr>
<tr>
<td>Total Kjeldahl-N</td>
<td>8.1 - 15</td>
<td>mg/l</td>
</tr>
<tr>
<td>Fluorides</td>
<td>1300 - 2000</td>
<td>mg/l</td>
</tr>
<tr>
<td>Cd</td>
<td>&lt;1 - 1.7</td>
<td>µg/l</td>
</tr>
<tr>
<td>Hg</td>
<td>0.25 - 2</td>
<td>µg/l</td>
</tr>
<tr>
<td>As</td>
<td>10 - 27</td>
<td>µg/l</td>
</tr>
<tr>
<td>Cr</td>
<td>13 - 18</td>
<td>µg/l</td>
</tr>
<tr>
<td>Pb</td>
<td>10 - 83</td>
<td>µg/l</td>
</tr>
<tr>
<td>Zn</td>
<td>43 - 95</td>
<td>µg/l</td>
</tr>
<tr>
<td>Ni</td>
<td>44 - 64</td>
<td>µg/l</td>
</tr>
<tr>
<td>Cu</td>
<td>&lt;1 - 19</td>
<td>µg/l</td>
</tr>
</tbody>
</table>

Table 4.5: Operational data from the arsenic removal plant (2007)

Cross-media effects
An arsenic sludge needs to be recycled or disposed of and this may contain heavy metals such as Ni, Cr, and Cd.

Operational data
No specific problems are known. Consumption of chemicals has not been reported.

Applicability
The removal of arsenite and arsenate can be implemented as an end-of-pipe solution after all types of new and existing water treatment plants.
Economics
The investment cost for an arsenic removal plant with a capacity of 55 m$^3$/h was EUR 2.6 million in 2004. These costs also depend on the effluent limits of arsenic and the heavy metals.

Driving force for implementation
The Corus plant in Ijmuiden, the Netherlands is being optimised in order to comply with legal limits and to reduce operating costs.

Example plants
Corus, Ijmuiden, the Netherlands pellet plant has been operational since August 2004.

Reference literature
[318]

4.3.8 Recovery of sensible heat from induration strand

Description
A pelletisation plant is designed in such a way that the sensible heat in gas flows in the induration strand is re-used efficiently. For example, the hot air from the primary cooling section is used as secondary combustion air in the firing section. In turn, the heat from the firing section is used in the drying section of the induration strand. Heat from the secondary cooling section is also used in the drying section.

For a pelletisation plant in an integrated steelworks, the cooling section generates more sensible heat than can be used in the induration strand. Formerly, this heat was not used, but since the mid 1980s, this sensible heat has been used in the drying chambers of the drying and grinding unit. The hot air is transported through an insulated pipeline called a "hot air recirculation duct".

The "hot air recirculation duct" transports approximately 150000 m$^3$/h hot air (250 °C) from the cooling section of the induration strand to the mills in the drying and grinding section. In the drying section, hot air (600 - 800 °C) is used to dry the concentrates and fines before grinding. By using the hot air from the cooling section, considerably less firing is needed in the drying chamber.

Achieved environmental benefits
Gross energy consumption of the above-mentioned pelletisation plant is approximately 1.8 GJ/t pellet (compared to standalone plants, this consumption is significantly higher - see Table 4.1). About 0.7 GJ/t pellet is supplied by means of heat recuperation, whereas approximately 1.1 GJ/t pellet is introduced by means of fuel. The 'hot air recirculation duct' is included in this calculation and accounts for an energy recovery of approximately 67.5 MJ/t pellet (approx. 4 % of gross energy consumption).

Cross-media effects
The use of hot air from the cooling zone in the firing zone of the induration strand may give rise to higher flame temperatures in the burner(s) and thus to higher NO$X$ emissions.

Operational data
No data submitted.

Applicability
Recovery of sensible heat is a process-integrated part of pelletisation plants. New plants can be expected to have a more efficient design than existing ones. The "hot air recirculation duct" can be applied at existing plants with a comparable design and a sufficient supply of sensible heat.
Chapter 4

Economics
Heat recuperation in the induration strand is an integrated part of the plant design and does not require additional investment. The 'hot air recirculation duct' was commissioned in 1984. The estimated investment was EUR 5 million. Savings in energy costs total EUR 2.8 million per year.

Driving force for implementation
No data submitted.

Example plants
Pelletisation plant, Corus, IJmuiden, the Netherlands.

Reference literature
[65] [318]
4.4 Best available techniques for pelletisation plants

In understanding this section and its contents, the attention of the reader is drawn back to the Preface of this document and in particular the fifth section of the Preface: ‘How to understand and use this document’. The techniques and associated emission and/or consumption levels, or ranges of levels, presented in this section have been assessed through an iterative process involving the following steps:

- identification of the key environmental issues for pelletisation plants in the iron and steel industry
- examination of the techniques most relevant to address those key issues
- identification of the best environmental performance levels, on the basis of the available data in the European Union and worldwide
- examination of the conditions under which these performance levels were achieved; such as costs, cross-media effects, main driving forces involved in implementation of these techniques
- selection of the best available techniques (BAT) and the associated emission and/or consumption levels for this sector in a general sense all according to Article 2(12) and Annex IV to the Directive.

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

On the basis of this assessment, best available techniques, and as far as possible emission and consumption levels associated with their use, are presented in this section that are considered appropriate to the pelletisation plants and in many cases reflect current performance of some installations within the sector. Where emission or consumption levels ‘associated with best available techniques’ are presented, this is to be understood as meaning that those levels represent the environmental performance that could be anticipated as a result of the application, for pelletisation plants, of the techniques described, bearing in mind the balance of costs and advantages inherent within the definition of BAT. However, they are neither emission nor consumption limit values and should not be understood as such. In some cases it may be technically possible to achieve better emission or consumption levels but due to the costs involved or cross-media considerations, they are not considered to be appropriate as BAT for the pelletisation plants. However, such levels may be considered to be justified in more specific cases where there are special driving forces.

The emission and consumption levels associated with the use of BAT have to be seen together with any specified reference conditions (e.g. averaging periods).

The concept of ‘levels associated with BAT’ described above is to be distinguished from the term ‘achievable level’ used elsewhere in this document. Where a level is described as ‘achievable’ using a particular technique or combination of techniques, this should be understood to mean that the level may be expected to be achieved over a substantial period of time in a well maintained and operated installation or process using those techniques.

Where available, data concerning costs have been given together with the description of the techniques presented in the previous Section 4.3. These give a rough indication about the magnitude of costs involved. However, the actual cost of applying a technique will depend strongly on the specific situation regarding, for example, taxes, fees, subsidies and the technical characteristics of the installation concerned. It is not possible to evaluate such site-specific factors fully in this document. In the absence of data concerning costs, conclusions on economic viability of techniques are drawn from observations on existing installations.
In this section for pelletisation plants, specific techniques are considered as BAT (including the associated emission and consumption levels). ‘Best Available Techniques’ for a specific installation will usually be the use of one individual techniques or a combination of the techniques and measures listed in this section. Additionally, general BAT elements which can apply for the whole sector, mentioned in Section 2.8, have to be considered.

Where techniques identified individually as BAT can be used in combination, the effects of such combinations should be considered when drawing conclusions on BAT based permit conditions for individual cases.

If not otherwise mentioned, the BAT associated emission levels (BAT-AELs) given in this section are expressed on an annual average basis under standard conditions.

The BAT (including the associated emission and consumption levels) given in this chapter are ‘BAT in a general sense’ (i.e. considered to be appropriate to the sector as a whole). It is intended that they are a reference point against which to judge the current performance of an existing installation or to judge a proposal for a new installation. In this way, they will assist in the determination of appropriate ‘BAT-based’ conditions for the installation or in the establishment of general binding rules under Article 9(8) of the Directive. It is foreseen that new installations can be designed to perform at or even better than the BAT levels presented in this section. It is also considered that existing installations could move towards the BAT levels presented in this section or do better, subject to the technical and economic applicability of the techniques in each case.

While the BAT reference documents do not set legally binding standards, they are meant to give information for the guidance of industry, Member States and the public on achievable emission and consumption levels when using specified techniques. The appropriate permit conditions for any specific case will need to be determined taking into account the objectives of the IPPC Directive and the local considerations.

### Air

1. **BAT for the storage, handling and transport (see Sections 2.6.3 and 2.6.5)**

   *Pretreatment, drying and grinding, balling; the induration strand (heat treatment), handling and screening of the waste gases*

2. **BAT is to reduce the dust emissions in the waste gases from the crushing, grinding and drying, wetting and mixing, and the balling of raw materials; the waste gases from the induration strand and from handling and screening of products by applying one of the following techniques (see Sections 4.3.1 and 4.3.2):**
   
   - I. ESP
   - II. Bag filter
   - III. Any other device with the same efficiency.

   The BAT-AEL for dust is <20 mg dust/Nm$^3$ for the crushing, grinding and drying and <10 mg dust/Nm$^3$ for all other process steps (see Sections 4.3.1 and 4.3.2).

   These BAT-AELs are determined as daily mean values.

3. **BAT is to reduce the SO$_2$, HCl and HF emissions from the induration strand waste gas by one of the following techniques (see Sections 4.3.2 and 4.3.3):**
   
   - I. Scrubbing
   - II. Semi-dry absorption and subsequent dedusting system
   - III. Any other device with the same efficiency.
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The **BAT-AELs** for these compounds are:

- for SO$_2$ < 20 mg/Nm$^3$
- for HF < 1 mg/Nm$^3$
- for HCl < 1 mg/Nm$^3$.

All of these BAT-AELs are determined as daily mean values.

4. BAT is to reduce NO$_X$ emissions from the drying and grinding section and induration strand waste gases by applying process-integrated techniques (see Section 4.3.4).

Plant design should be optimised for low-NO$_X$ emissions from all firing sections. Solutions have to be tailor-made and the possible NO$_X$ emissions level might vary from site to site.

5. BAT for new plants is to reduce NO$_X$ emissions by applying one of the following techniques (see Section 4.3.5):
   I. end-of-pipe techniques applying selective catalytic reduction (SCR)
   II. any other technique with a NO$_X$ reduction efficiency of at least 80%.

Due to high costs, the end-of-pipe nitrogen oxide reduction of waste gas should only be considered in circumstances where environmental quality standards are otherwise not likely to be met.

**Water**

**Water consumption**

6. BAT is to minimise the water consumption and discharge of scrubbing, wet rinsing and cooling water and re-use as much as possible (see Sections 4.2.2.2, 4.3.6 and 2.6.6).

**Waste water treatment and discharge**

7. BAT is to treat the effluent water prior to discharge by applying a combination of the following techniques (see Sections 4.3.6 and 4.3.7)
   I. neutralisation
   II. flocculation
   III. sedimentation
   IV. sand filtration
   V. heavy metal precipitation.

The BAT-AELs are:

- suspended solids < 25 - 50 mg/l
- COD < 150 mg/l
- Kjeldahl nitrogen < 10 mg/l
- heavy metals < 0.1 mg/l (Sum of As, Cd, Cr, Cu, Hg, Ni, Pb, Zn)

The BAT-AELs are based on a qualified random sample or a 24-hour composite sample.

Where local considerations make it necessary, BAT is to remove heavy metals by using ion exchangers.
Production residues (wastes or by-products)

8. BAT for solid wastes are the following techniques which should be applied in descending order of priority:
   I. Prevention of waste generation by effective on-site recycling or re-use of residues (i.e. undersised green and heat treated pellets) (see Sections 4.1.2 and 4.1.4)
   II. Controlled disposal of unavoidable wastes or by-products, i.e. sludge from waste water treatment (see Sections 4.3.6 and 4.3.7)

9. BAT for the handling, storage and transport of solid wastes, see general Section 2.6.4.

Energy

10. BAT is to reduce/minimise thermal energy consumption by applying the following techniques individually or in combination (see Section 4.3.8).
   I. Process-integrated re-use of sensible heat as far as possible from the different sections of the induration strand (pelletisation plants usually recover energy to a large extent; for further improvements tailor-made solutions are necessary)
   II. Using surplus waste heat for internal or external heating networks if there is demand from a third party (The co-operation and agreement of a third party may not be within the control of the operator, and therefore may not be within the scope of an IPPC permit).

Noise

(see Section 2.6.9)
5 COKE OVEN PLANTS

Coal pyrolysis means the heating of coal in an oxygen free atmosphere to produce coke (solid), gases, liquids and a solid residue (char). Coal pyrolysis at high temperature is called carbonisation. In this process, the temperature of the flue-gases from underfiring is normally 1150 - 1350 °C indirectly heating the coal up to 1000 - 1100 °C for 14 - 24 hours. The most important reducing agent in hot metal production is coke which removes the oxygen either indirectly by forming carbon dioxide or directly using its inherent carbon content. The gasification of the coke also serves to supply the heat necessary for the reduction process. Coke functions both as a support material and as a matrix through which gas circulates in the stock column. Coke cannot be wholly replaced by coal or other fuels. This produces blast furnace and foundry coke.

Only certain coals, for example coking or bituminous coals, with the right plastic properties, can be converted to coke and, as with ores, several types may be blended to improve blast furnace productivity and extend coke battery life. Other materials containing carbon can also be applied in small quantities (e.g. petroleum (petrolcoke) coke, used crushed rubber tyres) under the precondition that there is no negative influence on the environment. Oil or oil residues are added to give a better compaction of the coal.

5.1 Applied processes and techniques

By the 1940s, the basic design of modern coke ovens had been developed. The ovens were about 12 m long, 4 m high and 0.5 m wide, and were equipped with doors on both sides. The air supply was preheated by the hot exit gas; waste heat recovery enabled higher temperatures and increased coking rates. Since the 1940s, the process has been mechanised and the materials used in the construction of the ovens have been improved without significant design modifications. Batteries may contain up to 70 ovens as large as 14 m long and 6 m high. Because of heat transfer considerations, widths have remained at between 0.3 and 0.6 m. Each oven in the battery holds up to 30 tonnes of coal. Figure 5.1 shows such a battery. Some recently constructed coke oven plants have increased dimensions further. For instance, the chambers of the coke oven plant used in Schwelgern in Duisburg, Germany (see Figure 5.1), which was put into operation in 2003, are approximately 20 m long, 8.3 m high and 0.59 m wide, and each chamber has a capacity of approx. 70 tonnes of coal.

Figure 5.1: Photograph of the Schwelgern coke oven plant in Duisburg, Germany
Chapter 5

Developments in recent years have also been particularly aimed at minimising emissions from the processes and at improving working conditions for operators.

The coke making process can be subdivided into:

- coal handling and preparation  
- battery operation (coal charging, heating/firing, coking, coke pushing, coke quenching)  
- coke handling (discharge, storage, conveyance) and preparation  
- coke oven gas treatment:  
  - collection and treatment of coke oven gas (COG) with recovery of by-products  
  - heat recovery coking without recovery of by-products

In order to make the description of waste water treatment clearer, the water flows in the coking process are also described here.

Figure 5.2 shows a simplified scheme of the whole sequence of operations and processes required to produce coke (showing emissions sources). The main steps mentioned above are described in more detail below.
Figure 5.2: Typical flow diagram of a coke oven plant showing emissions sources [148]
Chapter 5

5.1.1 Coal handling and preparation

Coal handling and preparation comprises the following steps:

- discharge of coal: the coal is discharged from ships or trains onto a transportation system or for storage. Usually large cranes with grabs are used. Wind and handling operations may cause coal dust emissions.
- coal storage: coke oven plants are normally associated with large coal stocking areas. Wind may cause coal dust emissions. Attention has to be paid to treatment (sedimentation) of runoff water from rain and water spraying.
- coal transport: coal transport by conveyor, possible transfer points outside buildings and transportation by road has to be taken into consideration.
- coal preparation: this comprises crushing and bed or bunker blending, which may lead to dust emissions. Coal is prepared for coking by pulverising in a way that 80 - 90% of the coal passes through a 3.2 mm screen. During blending, recycled substances such as tar may be added, which may lead to emissions of volatile compounds.
- charging of the coal tower (coal dust emissions may occur).
- charging of the charging car (coal dust emissions may occur).
- operation of two blending beds which can be filled and emptied alternatively. While one bed is filled, the other delivers the coal to the coal tower by scratching devices. Water sprayers prevent dust emissions and a continuous water spraying and height control of the feeder takes place.

5.1.2 Coke oven battery operations

The operation of a coke oven battery comprises:

- coal charging.
- heating/firing of the chambers.
- coking.
- coke pushing.
- coke quenching.

These operations dominate the emissions from a coke oven plant. They are therefore described in more detail here, together with information about emissions sources. Figure 5.3 shows the layout of the battery and shows the main emissions sources.
5.1.2.1 Coal charging

There are a number of techniques for charging coke ovens with pulverised coal (80 - 90 % of the pulverised coal is <3.2 mm) through the charging holes. The most common technique is gravity charging by charging cars (see Figure 5.4). The charging process starts with lifting the first charging hole lid and finishes with closing the last charging hole. The whole procedure takes about 2 to 3 minutes whereas the charging process itself takes about 45 to 60 seconds depending on the size of the chamber. This can be simultaneous, sequential or stage charging by speed controlled horizontal screw feeders or turntables. Other systems like pipeline charging or stamp charging are also applied.

In stamp charging system charging is realised at the machine side through door opening of the coke oven battery. Two systems of the stamp charging technique are applied in coke oven plants as follows:

- in the classical stamp charging technique, the charging machine consists of a coal bunker and a charging box which moves after every charging. The coal blend demand necessary for one coke oven chamber filling is loaded by feeder to charging box. In the charging box, the blend is compacting and is then loaded into the coke oven chamber
- a new way of coal stamping is so-called “stationary stamping”. Rammer units are installed under the coal tower and they compact and deliver the charge to the charge box of the charging machine. A charging machine is a mobile element and its main task is to load compacted charge into the coke oven chamber.
The advantage of stamp charging is that even with low quality coal high quality coke can be produced. Stamping of coal in the charging machine takes 4 to 17 minutes. The density of the charge is 20 - 50% higher than the density of the coal in gravity charging systems. Additionally, “stationary stamping” allows better efficiency operation of the rammers unit and the charging machine is smaller and lighter in comparison to classical charging machines.

Regardless of the system, the flow of the coal must be kept under control. General measures are given for all these systems. The aim of these measures is to achieve “smokeless” charging (charging with reduced emissions).

![Diagram of coal charging of a coke oven chamber using a charging car showing the emissions points (indicated by arrows)](image)

**Figure 5.4:** Diagram of coal charging of a coke oven chamber using a charging car showing the emissions points (indicated by arrows) [200]

### 5.1.2.2 Heating/firing of the chambers [223] [320]

The individual coke oven chambers are separated by heating walls. All of the chambers are lined with refractory (silica) bricks. These heating walls consist of a number of heating flues with nozzles for fuel supply and with one or more air inlet boxes, depending on the height of the coke oven wall. The average nozzle brick temperature, characterising heating flue operation, is usually set at between 1150 and 1350 °C. Usually, cleaned coke oven gas is used as a fuel, but other gases such as (enriched) blast furnace gas can be used. The cleaned coke oven gas has a caloric value of about 17540 kJ/m³ and the mixed fuel gases have about 4200 kJ/m³.

In order to improve energy efficiency, regenerators are located directly under the ovens, exchanging heat from flue-gases with combustion air and/or process gases. Figure 5.5 shows a schematic diagram of a coke oven heating system together with the emissions points. If the heating walls are not completely gas-tight because of cracks, coke oven gas, produced during coking, will reach the flue-gas and will cause incomplete combustion, resulting in emissions at the stack.

For the mechanisms and products of sooting resulting from an incomplete combustion of benzene see [213] and [214].
The design shown Figure 5.5 is for a single stage combustion whereas today most modern plants have multi-stage combustion; crude coke oven gas (COG) used as a fuel is normally desulphurised beforehand.

The most difficult task during the commissioning and start-up of coke ovens is the heating-up of the batteries (e.g. each battery of the Schwelgern coke plant in Germany contains 43000 tonnes of refractory material) [204].

5.1.2.3 Coking

The coking process starts immediately after coal charging. The moisture driven off accounts for about 8 - 15 % of the charged coal. In addition to the moisture, carbonisation gas is produced. The total amount of volatiles is about 25 % [320]. This crude coke oven gas (COG) is exhausted via ascension pipes into the collecting main. The high calorific content of this gas means that after purification it can be used as a fuel (e.g. for battery heating). The coal is heated by the heating/firing system described above and remains in the coke oven until the centre of the coal has reached a temperature of 1000 - 1100 °C.

Depending on oven width and heating conditions the coking process takes around 14 - 24 hours to complete [207] [223]. The coking time is determined by the coal mixture, moisture content, rate of underfiring and the desired properties of the coke (e.g. foundry coke requires more time than blast furnace coke). When the coking time is not correct, ‘green’ coke is produced. Green coke is a bad quality coke that is not preferable to coke producers [223].

Figure 5.6 shows the main emissions sources during coking. Due to the positive pressure (10 - 15 mm H₂O column at 5 - 7 m tall ovens) within coke oven chambers, there may be door emissions, emissions from charging holes and ascension pipes and also, where there are wall cracks, emissions of incompletely combusted COG (see Section 5.1.2.2) [320].
1000 kg of coal yields between 750 and 800 kg coke and approximately 325 m$^3$ COG corresponding to approximately 187 kg COG. However it should be noted that coke yield and COG production and composition depend, to a large extent, on coal composition and coking time.

5.1.2.4 Coke pushing

Fully carbonised coke is pushed out of the oven into a container by the ram of the pusher machine usually in less than one minute (see Figure 5.7) through a coke guide car (transfer machine) into a so-called 'coke quenching car'. Contact with atmospheric oxygen causes the coke to start burning instantaneously.

5.1.2.5 Coke quenching

The coke quenching car transports the hot coke to a quenching tower. Basically there are two ways of quenching the red hot coke from the coke oven: wet quenching and dry quenching [320] [334]. Wet quenching consumes large volumes of water. The temperature of the coke is reduced from 1100 to 80 °C to avoid ignition [223]. The water fraction that does not evaporate can be collected and is used in the next batch, thus reducing water consumption [320].
5.1.3 Coke handling and preparation

After quenching, the coke can be stored in stock piles from where it is transported by conveyors (with transfer points), road, rail or any combination of these to a separate building for crushing and screening. At the bottom of the wet quench tower, a small fraction (coke breeze) settles and is conveyed directly to the sinter strand or set aside for the sinter process [227]. Large fractions (20 - 70 mm) are used in the blast furnace or sold to the market [320] [321]. Small fractions (<20 mm) are used for the sinter process. According to the specific requirements for the sinter process and the blast furnace process these fractions undergo further crushing in order to meet the required size.

5.1.4 Coke oven gas treatment

In principle there are two options for dealing with the huge amount of generated coke oven gas:

- in the first case, the coke oven gas is fully collected and further processed by the cleaning and recovery of by-products. The cleaned coke oven gas (after removal of economically valuable by-products) is internally or externally used by other steelworks consumers as a fuel in coke oven batteries, hot blast stove (cowper), blast furnaces, for the heating of ignition furnaces in sinter plants, for pusher-type heating furnaces in rolling mills and for electric power generation in power plants
- in the second case, the heat recovery process, the raw coke oven gas is burnt directly at its source in the coking reactor by a prudent air supply and no further recovery steps are necessary. The heat produced is partly used for the coking process. The excess energy is subsequently converted to steam and/or electricity. The heat recovery coking process has been operating successfully in the US since 1998.
The first case is described in more detail below as it is the commonly applied technique in Europe.

Another possibility is to use the cleaned coke oven gas as a raw material in the chemical synthesis of methanol or to hydrogen separation. In China approx. 10 methanol production installations with capacities of 70 - 200000 Mg/yr each are in use. An example is the installation in Shanxi Hancheng Heimao Coking Company. Methanol synthesis from coke oven gas after deep desulphurisation with a fixed bed reactor in one step by Second Design Institute of Chemical Industry (SE Din) technique has been in operation since 2006.

5.1.4.1 Collection and treatment of coke oven gas (COG) with recovery of by-products

Raw COG has a relatively high calorific content due to the presence of hydrogen, methane, carbon monoxide and hydrocarbons. Furthermore, the raw coke oven gas contains valuable products such as tar, light oil (mainly consisting of BTX (benzene, toluene and xylene)), sulphur and ammonia. Table 5.1 shows the composition of raw coke oven gas. For several reasons, the coke oven gas must be treated before use as a fuel.

<table>
<thead>
<tr>
<th>Raw gas</th>
<th>Values</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>yield</td>
<td>280 - 600</td>
<td>m³/t coal</td>
</tr>
<tr>
<td>density</td>
<td>0.42 - 0.65</td>
<td>kg/Nm³</td>
</tr>
<tr>
<td>Net calorific value</td>
<td>17.4 - 20</td>
<td>MJ/Nm³</td>
</tr>
<tr>
<td>H₂</td>
<td>39 - 65</td>
<td>vol- %</td>
</tr>
<tr>
<td>CH₄</td>
<td>20 - 42</td>
<td>vol- %</td>
</tr>
<tr>
<td>C₆H₆</td>
<td>2.0 - 8.5</td>
<td>vol- %</td>
</tr>
<tr>
<td>CO</td>
<td>4.0 - 7.0</td>
<td>vol- %</td>
</tr>
<tr>
<td>H₂S</td>
<td>4 - 12</td>
<td>g/Nm³</td>
</tr>
<tr>
<td>CO₂</td>
<td>1 - 3</td>
<td>vol- %</td>
</tr>
<tr>
<td>BTX</td>
<td>20 - 30</td>
<td>g/Nm³</td>
</tr>
<tr>
<td>NH₃</td>
<td>6 - 8</td>
<td>g/m³</td>
</tr>
<tr>
<td>PAH</td>
<td>n/a</td>
<td>mg/Nm³</td>
</tr>
</tbody>
</table>

Legend: n/a = not available.
CₓHᵧ is mainly ethylene and ethane. Others are cyclopentadiene, propane, butane, propylene, butane, acetylene and pentene. Tar oil, tar acids (CₓHᵧOH), tar bases (CₓHᵧN), heavy hydrocarbons, and crude light oil are removed as liquid products during cooling. Oxygen, nitrogen and water vapour also appear in the composition of raw coke oven gas. PAH (e.g. naphthalene, phenanthrene, benzo pyrenes), nitrogen compounds (e.g. pyridine, HCN, (CN)₂ and NO₂) and other sulphur compounds (e.g. COS, CS₂, thiophenes) also appear.

Table 5.1: Raw coke oven gas yield and composition
[65] [206] [223] [320] [322] [423]

The composition of coke oven gas depends on coking time and coal composition. The data given refer to water- and ash-free coal. Tar and naphthalene in the raw gas may foul the piping and the equipment and should be removed first. For each tonne of coke produced, approximately 25 to 45 kg of tar may be recovered [223]. Several products can be recovered from the tar, e.g. pitch, anthracene oil, wash oil, naphthalene oil, carbolic oil (phenol) and light oil [320].

Sulphur compounds and ammonia would cause corrosion of the piping and equipment and the sulphur compounds would cause emissions of SO₂ if raw uncleaned coke oven gas would be used as a fuel. For each tonne of coke produced, approximately 3 kg of ammonia and 2.5 kg of H₂S are generated.
In some cases BTX is recovered from the raw coke oven gas as a valuable by-product. Up to 15 kg of light oil may be recovered per tonne of coke produced. This oil contains benzene, toluene, xylenes, non-aromatics, homologous aromatics, phenol, pyridine bases and other organic compounds such as polycyclic aromatic hydrocarbons (PAH).
Figure 5.8 shows a typical COG treatment plant. The main steps in the process are described below.

![Diagram of a typical COG treatment plant with recovery of by-products]

**Figure 5.8:** Typical scheme of a COG treatment plant with recovery of by-products

[200]
### 5.1.4.2 Gas cooling

Hot crude oven gas enters the ascension pipes at a temperature of approximately 800 °C. In the goose neck it is directly cooled by an ammonia liquor spray to a steam saturation temperature of around 80 °C. This requires 2 - 4 m³ of ammonia liquor for each tonne of coal carbonised (see Figure 5.9).

The liquid phase build by the used ammonia liquor and the condensate of the coal moisture and chemical water, is fed to the tar/water separator, whilst the gas phase is led to the primary coolers. It used to be common for primary coolers to be operated as open systems. Nowadays, indirect cooling with closed cooling systems is more frequent. When sufficient cooling water of the right temperature is available, the gas can be cooled to below 20 °C, given a moderate ambient temperature. Under these conditions, most of the higher boiling point compounds and the water from the steam fraction of the gas will condense [320].

Droplets and particles are precipitated in the downstream electrostatic tar precipitators before the gas is drawn into the washing facilities by exhausters (suction fans). Occasionally electrostatic tar precipitators are installed downstream of the exhausters. The precipitate from the electrostatic tar precipitator is also led to the tar/water separator.

The suction fans cause compression of the gas, and even if the fans are such that this is only slight, the associated temperature increase cannot be tolerated in view of the downstream processing conditions. This makes it essential to use so-called 'final coolers'.

Final coolers may be indirect or direct. When direct cooling is applied the cooling water absorbs the impurities from the COG. Subsequently at the end of the cooling cycle, during return-flow cooling using natural draught or fan coolers, emissions are inevitably generated. Closed systems are therefore usually preferred for final cooling, though open circuits are still operated at some plants [320].

![Diagram](image-url)  
**Figure 5.9:** Schematic diagram of example water flows in a coke oven plant
5.1.4.3 Tar recovery from the coke oven gas

Most of the water and the high boiling point hydrocarbons are condensed during coke oven gas cooling. The condensate from the pipes and the electrostatic tar precipitator is led to the tar/water separator, where the tar is recovered. The water phase is separated off as so-called ‘coal water’ and led to the ammonia liquor storage tank. From there the surplus water goes to the ammonia stripper/still or to the H₂S washers.

Sometimes scrapers are installed to remove coal tar from the condensate. This coal tar contains reasonable amounts of PAH and is usually fed back to the coal feed [320].

5.1.4.4 Desulphurisation of coke oven gas

Coke oven gas contains hydrogen sulphide (H₂S) and various organosulphur compounds (carbon disulphide (CS₂), carbon oxisulphide (COS), mercaptans, etc.). All wet desulphurisation techniques in use are highly efficient at removing H₂S. They are less efficient at removing organosulphur compounds. Commercial coke oven gas desulphurisation processes can be divided into two categories:

- processes using wet oxidation to produce elemental sulphur (S⁰)
- processes which absorb and strip H₂S for subsequent conversion into sulphuric acid (H₂SO₄) or elemental sulphur (S⁰).

All wet oxidation processes utilise a reduction oxidation catalyst to facilitate the wet oxidation of hydrogen sulphide to elemental sulphur (S⁰) or sulphate. All these processes are characterised by very efficient removal of hydrogen sulphide (efficiency of > 99.9 % for achieving residual H₂S concentrations as low as 1 - 10 mg/Nm³, depending on the inlet concentration), but have the disadvantage of producing highly contaminated waste water and/or air, which make elaborate treatment facilities a necessary part of the process [153] [320].

Absorption/stripping processes are characterised by generally lower H₂S removal (efficiency of > 95 % for achieving residual H₂S concentrations as low as 50 to 500 mg/Nm³, depending on the inlet concentration) but, since air is not included in the regenerating system and no toxic catalysts are used, emissions to air and water of process related chemicals are minimised or eliminated. The processes can be operated to produce sulphuric acid (sulphuric acid plants), or a very high-purity elemental sulphur (Claus plants).

A common process combination is NH₃/H₂S circuit scrubbing in the low pressure stage and potassium carbonate scrubbing (vacuum carbonate process) in the high pressure stage, combined with a BTX washer either at a low or at an enhanced pressure. Potassium carbonate scrubbing at both pressure stages, combined with a BTX washer is also common.
5.1.4.5 Recovery of ammonia from the coke oven gas

The ammonia formed during coking appears in both the coke oven gas and the condensate (weak liquor) from the gas. Typically 20 - 30 % of the ammonia is found in the weak liquor.

The following processes are applied commercially to remove ammonia from the coke oven gas:

- the NH3/H2S scrubbing circuit. In this process, the ammonia is scrubbed from the coke oven gas in an ammonia scrubber using water or dilute liquor wash as a scrubbing liquid. The effluent from the ammonia scrubber is used as a scrubbing liquor in the H2S scrubber. The effluent from the H2S scrubber contains H2S and NH3 and is led to the ammonia stripper and the still. This process is also known as the Carl Still, Diamex or Ammoniumsulphide Kreislaufwäschter (ASK) process. Some scrubbers use packed columns for the scrubbing system [204] [320].
- direct recovery as ammonium sulphate ((NH4)2SO4). Two processes can be used:
  - the Otto-type absorber and the Wilputte low differential controlled crystallisation process. In both systems the COG is sprayed with a dilute sulphuric acid solution and ammonium sulphate is yielded
  - direct recovery as anhydrous ammonia (NH3). The recovery of ammonia from the gas as anhydrous ammonia was developed by the United States Steel Corporation under the name USS PHOSAM. In this process, ammonia is scrubbed from the coke oven gas by countercurrent contact with an ammonia-lean phosphate solution (phosphoric acid). Ammonia removal efficiency is 98 - 99 % [153].

5.1.4.6 Recovery of light oil from coke oven gas

The gas leaving the ammonia absorbers contains light oil, a clear yellow-brown oil with a specific gravity of 0.88. It is a mixture of COG products with boiling points mostly between 0 and 200 °C, containing well over a hundred constituents. Most of these are present in such low concentrations that their recovery is seldom practicable. The light oil is usually referred to as BTX. The principal usable constituents are benzene (60 - 80 %), toluene (6 - 17 %), xylene (1 - 7 %) and solvent naphtha (0.5 - 3 %). Four main methods are used for the recovery of light oil [153]:

- refrigeration and compression to temperatures below -70 °C and pressures of 10 hPa.
- adsorption by solid adsorbents, in which the light oil is removed from the gas by passing the latter through a bed of activated carbon and recovering the light oil from the carbon by heating with indirect or direct steam [320]
- absorption by solvents, consisting of washing the COG with a petroleum wash oil, a coal tar fraction or other absorbent, followed by steam distillation of the enriched absorbent to recover the light oil
- the distilled wash oil is recirculated to the scrubber [204].

5.1.5 Water flows from coke oven and by-product plants

Figure 5.9 shows an example of possible water flows in a coke oven plant. However, many other alternative layouts exist.

The main water flows to be drained from the coke oven results from the steam or ammonia liquor used in the goosenecks for the suction and direct cooling of the charging gases, the coal moisture and so-called "chemical water" (which is formed during the coking process).

Additionally condensates from the coke oven gas treatment in the by-product plant from cooling (in case of direct cooling), the electrostatic precipitator and scrubbing units originates.
The condensed water and tar from the collecting main (downstream the goose neck), the coolers and the electrostatic precipitator are led to the tar/water separator.

Primary cooling can be conducted by direct, or more usually, by indirect cooling. In the case of indirect cooling the water is circulated in a close cycle and will not influence the waste water quantity. In the case of direct gas cooling, the cooling water is considered to be a washing liquor and is eventually drained via the still.

Water losses occur during recooling of cooling waters and condensates by evaporation of the cooling waters.

The water from the tar/water separator so called "coal water" contains high concentrations of ammonia and is led to the ammonia liquor storage tank.

The ammonia liquor storage tank provides water for the gooseneck spray equipment. The surplus water from the ammonia liquor storage tank is led to the ammonia stripper/still [320] or to the H₂S washers [457]. Together with parts of the steam used in the ammonia stripper/still, scrubbing liquor from the NH₃/H₂S scrubbing circuit this water corresponds to the waste water referred to in Table 5.2.

It should be noted that usually all water flows, except for water from indirect cooling systems and wet oxidative desulphurisation systems, are eventually drained from the ammonia still and led to a waste water treatment plant.

High concentrations of NH₃ are present in the ammonia still. There are several reasons for decreasing the ammonia concentration before discharging the water to a waste water treatment plant or to the environment:

- the ammonia can be recovered as a valuable energy source (in a sulphuric acid plant) or as a valuable by-product (as ammonium sulphate or anhydrous ammonia)
- free ammonia is highly toxic for aquatic ecosystems (including biological waste water treatment plants)
- ammonia has a very high specific oxygen demand (it requires 4.5 times its own weight of oxygen for oxidation to nitrates). Thus, there is a risk of oxygen depletion of the waste water treatment plant or the recipient water.

These reasons have led to ammonia strippers being installed in virtually all coke oven plants. This device strips H₂S and NH₃ from the liquid by steam and alkaline additions. The vapours are subsequently led to the crude gas or to the NH₃/H₂S scrubbing circuit (to improve H₂S scrubbing efficiency) or to a sulphuric acid plant, where NH₃ and H₂S are incinerated together. Sometimes the NH₃ is removed from these vapours in saturators, producing ammonium sulphate [320].

The most commonly used alkali is caustic soda (NaOH). Formerly, slaked lime (CaOH₂) was often used.

Some possible water flows that were not indicated in Figure 5.9 include:

- waste water from BTX recovery which is led to the tar/water separator
- phenol (concentration ≥3 g/l) which may be recovered from the coal water by a solvent extraction process, before the coal water is led to the ammonia liquor storage tank
- waste water from oxidative desulphurisation processes which is usually discharged separately after pretreatment
- chemical water from the (optional) sulphuric acid plant which is usually led to the still
- chemical water from the (optional) Claus process which will usually not be condensed but discharged to the atmosphere via a stack [21]. An alternative is to inject this water into the raw gas before treatment
indirect gas cooling water which is recirculated and will not influence the waste water quantity. In the case of direct gas cooling, the cooling water is considered to be a washing liquor and is eventually drained via the still.

### 5.2 Current emission and consumption levels

#### 5.2.1 Mass stream overview and input and output data

Figure 5.10 shows an overview of the input and output mass streams of a coke oven treatment plant. This overview might be used for the collection of data from single coke oven plants.

![Mass stream overview of a coke oven plant](image-url)
Chapter 5

Subsequently, specific input factors and emission factors have both been determined. Values of these factors at various pelletisation plants in the EU are shown in Table 5.2.

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Raw materials</strong></td>
<td><strong>Products</strong></td>
</tr>
<tr>
<td>Coal (dry) kg/t coke</td>
<td>COG Nm³/t coke</td>
</tr>
<tr>
<td>1220 - 1350</td>
<td>360 - 518</td>
</tr>
<tr>
<td>NetCV of COG MJ/Nm³</td>
<td>17412 - 20000</td>
</tr>
<tr>
<td>Energy GJ</td>
<td>7200 - 9000</td>
</tr>
<tr>
<td>Steam MJ/t coke</td>
<td>20000 - 27000</td>
</tr>
<tr>
<td><strong>Energy</strong></td>
<td><strong>Air emissions</strong></td>
</tr>
<tr>
<td>BF gas + COG MJ/t coke</td>
<td>2700 - 3900</td>
</tr>
<tr>
<td>Electric Nm³/t coke 20 – 230¹⁷</td>
<td>SO₂²⁶ g/t coke</td>
</tr>
<tr>
<td>20 – 230¹⁷</td>
<td>80 - 900 (2820²⁷)</td>
</tr>
<tr>
<td>NOx g/t coke</td>
<td>336 – 1783³¹</td>
</tr>
<tr>
<td>NH₃ g/t coke</td>
<td>0.5 – 24.7</td>
</tr>
<tr>
<td>H₂SO₄ g/t coke</td>
<td>2¹⁶</td>
</tr>
<tr>
<td>Steam MJ/t coke</td>
<td>60 – 800¹³</td>
</tr>
<tr>
<td>CO₂ kg/t coke</td>
<td>15.7 – 298¹¹</td>
</tr>
<tr>
<td>CO₂ g/t coke</td>
<td>160 – 860¹⁷</td>
</tr>
<tr>
<td>CH₄ g/t coke</td>
<td>1 – 15</td>
</tr>
<tr>
<td>CH₄ g/t coke</td>
<td>15 – 80</td>
</tr>
<tr>
<td>H₂S g/t coke</td>
<td>12 – 100</td>
</tr>
<tr>
<td>H₂S g/t coke</td>
<td>12 – 100</td>
</tr>
<tr>
<td>HCN g/t coke</td>
<td>0.05 – 1.87</td>
</tr>
<tr>
<td>HCN g/t coke</td>
<td>1500 – 2500</td>
</tr>
<tr>
<td>Benzene g/t coke</td>
<td>0.1⁷ – 45</td>
</tr>
<tr>
<td>Benzene g/t coke</td>
<td>0.17</td>
</tr>
<tr>
<td>PAH¹⁰ mg/t coke</td>
<td>135 – 109¹¹</td>
</tr>
<tr>
<td>PAH⁴¹ mg/t coke</td>
<td>135 – 109¹¹</td>
</tr>
<tr>
<td>Process water m³/t coke</td>
<td>0.24 – 1.5</td>
</tr>
<tr>
<td>PCDD/F ng TEQ/Nm³</td>
<td>&lt;0.1¹³</td>
</tr>
<tr>
<td>Production residues (waste/by-products)</td>
<td></td>
</tr>
<tr>
<td>Benzene kg/t coke</td>
<td>5.3 – 14</td>
</tr>
<tr>
<td>Light oil (BTX)²³</td>
<td>9.1 – 14</td>
</tr>
<tr>
<td>H₂SO₄²⁶ g/t coke</td>
<td>4 – 9</td>
</tr>
<tr>
<td>Tar kg/t coke</td>
<td>26 – 48</td>
</tr>
<tr>
<td>(NH₄)²SO₄ as SO₄²⁻³ kg/t coke</td>
<td>28 – 48</td>
</tr>
<tr>
<td>Sulphur¹³ kg/t coke</td>
<td>0.9 – 2</td>
</tr>
<tr>
<td>Sodium phenolate kg/t coke</td>
<td>1.4</td>
</tr>
<tr>
<td>Waste water m³/t coke</td>
<td>0.1 – 0.5</td>
</tr>
</tbody>
</table>

Legend: VOC = volatile organic carbon; PAH = polycyclic aromatic hydrocarbons

¹ High value for old plants with cracks in the oven walls (older than 20 years)
² Old Plants older than 20 years can have a steam consumption of 1200 MJ/t coke.
³ Values up to 983 g/t coke produced have been reported but they are not considered to be representative of the EU coke ovens [460].
⁴ High values in cases of coke dry quenching (with heat recovery in the form of steam); value of 270 MJ/t coke from two plants which have been in operation for 14 and 15 years respectively; value 1500 MJ/t coke from a plant which has been in operation for about 7 years.
⁵ The higher value of this range indicates no or insufficient desulphurisation.
⁶ To cases of SO₂ absorption to H₂SO₄ as the final by-product.
⁷ Only data from one plant available.
⁸ The H₂S content of coke oven gas is analysed and a sulphur balance is made. The emissions include heating with coke oven gas, burning raw gas, quenching and when the catalytic cracker and Claus plant is out of operation and the old combustion chamber is used.
⁹ Low value for one modern plant (about 5 years old).
¹⁰ PAH = EPA 16 (sum of following 16 PAH: \[\text{FLU+PYR+TRI+CPP+BaA+CHR+BNT+BeP+BbF+BkF+DbhaA+BghiP+INP+ANT+COR}\]). Calculated from measurements taken from pushing, quenching and emissions from the stack of the battery.
¹¹ Only data from two plants available. Values up to 10 and 29 g/t coke produced have been reported but they are not considered to be representative of EU coke ovens [226] [210].
¹² To cases of SO₂ absorption with ammonia liquor.
¹³ To cases of SO₂ absorption and sulphur recovery as elemental sulphur.
¹⁴ Water losses due to evaporation.
¹⁵ Data from one installation in Germany.
¹⁶ Some nitrogen is consumed from bottles.
¹⁷ Depending on the kind of fuel gases.
¹⁸ Off-gas flow is usually 2000 to 2300 m³/t coke depending on the combustion air demand for the different fuel gases.

Table 5.2: Input and output data from coke oven plants in different EU Member States from 2005 complemented by other references [206] [210] [218] [223] [225] [226] [227] [228] [237] [320] [324] [403] [460]
It should be noted that Table 5.2 is not applicable for proper calculations, e.g. benchmarking purposes, since it comprises the performances of old and new plants all over Europe which results in very wide ranges of emission factors. Furthermore it should be pointed out that not all operators provided information. Table 5.2 only includes the emissions from stacks and quenching towers. Stack emissions occur from the underfiring and the cleaning of the collected emissions during charging and pushing if applied. It does not include non captured diffuse or fugitive sources caused by battery operation or by the by-products. The emissions data represent the emissions after abatement, they do not comprise emissions from coal and coke handling because of missing information but these emissions are of less significance. Information about the determination of the data such as sampling methods, analysis methods, time intervals, computation methods and reference conditions is not available.

Table 5.3 gives the emission factors for specific compounds and must be seen as a complement to Table 5.2.

<table>
<thead>
<tr>
<th>Location</th>
<th>Benzo(a)pyrene</th>
<th>Pyridine</th>
<th>Toluene</th>
<th>Xylene</th>
<th>Phenol</th>
<th>CS₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Directed emissions sources</td>
<td>0.012</td>
<td>2.35</td>
<td>0.74</td>
<td>0.69</td>
<td>5.67</td>
<td>0.30</td>
</tr>
</tbody>
</table>

Table 5.3: 2004 output data from a Polish coke oven plants 2004 as a complement to Table 5.2

[403]

5.2.2 Environmental issues for the coke making process

The coke oven plant is primarily a source of particulate matter and gaseous emissions to air. When abatement techniques are applied to reduce emissions, cross-media effects occur. Generally, the information given in Section 5.2.2.1 to 5.2.2.5 below describe the most relevant environmental issues for coke ovens plants

5.2.2.1 Emissions to air

It should be noted that coke oven plants have a relatively large number of emission sources. However, it is necessary to distinguish between:

a. directed emissions sources, like stacks for the off-gas from battery heating or from the various dedusting facilities, are transported by pipes and leave via the stack. They can be treated and minimised reasonably easily. They can be measured without any problems in most cases (e.g. according to the rules of the Verein Deutscher Ingenieure VDI)
b. diffuse emissions occur during regular operation such as, e.g. coal and coke handling, transport of coal and coke, coal blending beds, ascension pipes, coke pushing, coke quenching. If these are not captured they can be released through the roof, roof-hatch, windows or from stored material. Minimisation is possible only by prevention and/or further treatment after transferring them into ducted emissions (i.e. by capturing them)
c. fugitive emissions which occur during irregular operation from leakages at the battery, e.g. because of leakage from vessels, oven doors, flanges, or at the by-product plant. For minimisation the first option is prevention by good maintenance. PAH compounds, like benzo(a)pyrene (BaP), and benzene play an important role with regard to fugitive emissions [320] [324].

Diffuse and fugitive emissions are difficult to quantify.

In many cases, the emissions from the different sources vary considerably with time (e.g. semi-continuous emissions from doors, lids, ascension pipes and discontinuous emissions from pushing and quenching).
Comparison of emission factors between plants also needs to take account of plant specific parameters. For instance, specific door emissions vary widely depending upon the type of doors, the size of ovens and the quality of maintenance. Maintenance can be a determining factor. Indeed, examples of good results with traditional (knife edged) doors on well-maintained small ovens and bad results with modern flexible sealing doors on badly maintained large ovens can be found. This should be borne in mind when assessing the information on individual emission sources to air given in Table 5.4. The wide range of values for emissions factors can primarily be explained by the maintenance programme, the degree of care taken in its performance (enabling smooth and stable operation conditions) and the abatement techniques applied [320] [324].

Because of the high expenditure for at leakage monitoring there are only very few actual data available for non-captured emissions caused by battery operation as shown in Table 5.4, where the situation of coke plants in the EU is described by the emission factors given. The results are supported by by measurements from various plants in Europe, which differ in age, state of repair as well as in the emissions control techniques applied. The monitoring were carried out by capulation of the leakages when a sample from the formed space was taken. While the lower level of the given range represents emissions from modern plants in a good state of repair, the higher emissions relate to older plants with poorer emissions control techniques and/or in a worse state of repair. Comparison of figures in Table 5.4 shows that emissions from door leakages represent the largest portion of all fugitive emissions from the battery. The correctness of these emissions factors, especially for BaP emissions, could be confirmed by reverse dispersion calculations, and by single emissions measurements from 7 m doors which gave specific emissions of BaP only up to 10 mg/t (coke). However, measurements taken at doors with the most modern sealing systems showed that emissions of down to below 1 mg/t (coke) could be achieved [320] [324].

As there are still plants in Europe in bad conditions, the emission situation for all European coke plants can best be described by the complete range of factors given in Table 5.2. In case of temporary failure, the actual emissions can exceed the range quoted.

The values for CO are usually reported to be higher than those indicated in Table 5.4. The emissions concentration is very much relative to the design, the age and the maintenance of the combustion chambers. High CO values indicate incomplete combustion resulting in high CO stack emissions. Usually the emissions concentrations for CO are about or below 1000 g/t coke.

**Coal handling and preparation**
Diffuse dust emissions are associated with material handling operations. These operations consist of unloading, storing, crushing and screening of coal. No information about emissions caused by these operations have been submitted.

**Coal charging**
During coal charging of pulverised coal, not only do particular dust emissions occur, but also organic compounds such as Benzene and BaP from coal decomposition and SO₂, H₂S and NH₃ are emitted [223] [320], [324].

The charging concept and the geometry and proper sealing of the charging holes and systems are very important elements in the reduction of charging emissions.

While charging, a distinction can be made between:

- emissions near the charging holes during the charging process itself
- evacuation and cleaning of the charging gases
- leveller door emissions during levelling the coal with the leveller bar
- fugitive emissions from material spilled on the oven deck.

Some figures for diffuse or fugitive emissions to air from charging are given in Table 5.4.
Chapter 5

<table>
<thead>
<tr>
<th>Operation</th>
<th>Dust (g/t)</th>
<th>CO (g/t)</th>
<th>SO₂ (g/t)</th>
<th>H₂S (g/t)</th>
<th>NH₃ (g/t)</th>
<th>Benzene (mg/t)</th>
<th>BaP (mg/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charging</td>
<td>0.3 - 10</td>
<td>0.1 - 71</td>
<td>0.01 - 1</td>
<td>&lt;0.3</td>
<td>10 - 1200</td>
<td>0.02 - 4.5</td>
<td></td>
</tr>
<tr>
<td>Coking:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Doors</td>
<td>0.3 - 6</td>
<td>1.5 - 30</td>
<td>0.1 - 1.5</td>
<td>0.02 - 1</td>
<td>0.1 - 1.5</td>
<td>200 - 14000</td>
<td>4.5 - 45</td>
</tr>
<tr>
<td>• Lids</td>
<td>0.2 - 1</td>
<td>1.5 - 9</td>
<td>0.1 - 1</td>
<td>&lt;0.01</td>
<td>0.1 - 0.3</td>
<td>800 - 8000</td>
<td>9 - 15</td>
</tr>
<tr>
<td>Ascension pipes</td>
<td>&lt;0.2</td>
<td>0.003 - 0.3</td>
<td>0.01 - 0.1</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>10 - 100</td>
<td>0.3 - 3</td>
</tr>
</tbody>
</table>

Table 5.4: Factors for emissions to air from diffuse or fugitive emissions caused by battery operation of coke oven plants

Coke oven undergrate heating and firing

Directed emissions from the stacks occur during the combustion of fuel gases used to heat coke ovens. Sulphur dioxide emissions may be present if coke oven gas is not completely desulphurised. COG contains aromatic components (mainly BTX as shown in Table 5.1). If COG is used without scrubbing, these aromatic compounds have the tendency to form soot (containing PAHs) [213] [214].

One source of fugitive emissions from the coke ovens that causes public concern is the black emissions from the battery combustion stacks of the coke ovens. Black emissions are caused by incomplete combustion of the fuel gases used to heat the ovens, or when leakage occurs from the ovens to the heating walls. In this case coal fines and coking decomposition products may leak from the coke oven into combustion exhaust gases.

Table 5.2 shows emissions factors of between 336 and 1783 g/t coke for NOₓ. For existing plants without process-integrated deNOₓ measures, such as staged air combustion, achievable levels for NOₓ are in the higher range of 1300 to 1783 g/t coke (concentrations: 600 - 800 mg/Nm³ at 5 % O₂).

The following Table 5.5 provides some emission data from German and Czech coke oven plants.

<table>
<thead>
<tr>
<th>Location</th>
<th>Dust (g/t)</th>
<th>CO (g/t)</th>
<th>NOₓ (mg/Nm³)</th>
<th>SOₓ (mg/Nm³)</th>
<th>PCDD/PCDF (ng/Nm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coke oven undergrate firing 1)</td>
<td>0.8 - 4.8</td>
<td>20</td>
<td>322 - 414</td>
<td>111 - 157</td>
<td>0.001</td>
</tr>
<tr>
<td>Coke pushing</td>
<td>0.9</td>
<td>30 3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coke grading plant</td>
<td>0.5 - 4.5</td>
<td>100 3)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: All data are annual averages. Reference oxygen content for particulates, NOₓ and SOₓ is 5 %.
1) Data from mixed gas, coke gas or desulphurised coke gas.
2) Values after coke gas desulphurisation.
3) Czech data [451].

Table 5.5: Directed emissions concentrations from installations in Germany and the Czech Republic

Emissions from flaring off or bypassing COG

On rare occasions, the production of COG exceeds demand. In these cases, and for safety reasons, the excess COG must be flared off. The flaring of coke oven gas generates some emissions quantified as 2.4 kg CO/t, 390 kg CO₂/t, 0.05 kg H₂S/t, 0.85 kg heavy hydrocarbons/t and 6.5 kgSO₂/t [223]. Bypassing can also be necessary due to maintenance of the sulphuric acid plant. During these periods, the raw coke oven gas is used as a fuel for coke oven firing leading to increased SO₂ emissions.
Chapter 5

Coking
The coking process starts immediately after coal charging. In addition to the coal moisture, carbonisation gas is produced. The total amount of volatiles is about 25% [320]. This crude coke oven gas (COG) is exhausted via ascension pipes into the collecting main. Due to the positive pressure (10 - 15 mm H2O column 5 - 7 m tall ovens) within coke oven chambers, there may be diffuse and fugitive door emissions, emissions from charging holes and ascension pipes and also, where there are wall cracks, emissions of incompletely combusted COG via the heating gases. Figure 5.6 shows the main emissions sources during coking. Table 5.4 gives some ranges for the corresponding emissions factors for some pollutants during the coking process.

Estimation method of emissions from coke oven leaks
Fugitive emissions occur from the ascension pipe and charging hole sealings and from the oven doors and frame seals during coking. Different methods for estimating these fugitive emissions from coke ovens are in use and all these methods have one thing in common: experienced or certified observers visually determines the visual emissions.

From these results achieved emission levels are expressed as a frequency of leaking percentage of the total number of ascension pipes and charging holes showing visible leaks) or mass/time depend on the monitoring method. For example the EPA 303 methode enables the results from the observation procedure to be expressed in percentages of leakage.

However the DMT (Deutsche Montan Technologie GmbH) methodology, which is to a large extent consistant to the EPA method, allows emissions per day based on basic measurements to be calculated, assigning four different degrees of strength to the emissions and taking the duration of the visible emissions during the observation into consideration. Another method was developed by BCRA (British Carbonization Research Association). In contrast to the DMT method, the visable emissions are assigned five different degrees of strength. Another method which is used at Corus IJmuiden in the Netherlands is described in Section 5.3.3.

Coke pushing
Prior to pushing, the oven doors are automatically taken away. Eventually the fully carbonised coke is pushed out of the oven by a coke guide car (the coke transfer maschine) into a so-called 'coke quenching car'. The coke transfer maschine is equipped with hoods. Emissions during pushing are collected by an adequate extraction flow. Subsequently the off-gas is treated in a dust abatement device.

In cases where bag filters are applied sparks needs to be precipitated prior to the filter. As an annual average after a bag filter the dust emissions concentration have been observed to be below 1 mg/Nm³ in one plant [407].

Coke quenching
Quenching hot coke with cold water creates thermal shock, releasing particulates from hot coke. Water vapour from water heated during contact with hot coke rises from quenched coke and entrains particulate matter from the coke mass. In addition, dissolved solids from the quench water may also become entrained in the steam plume rising from the tower. For the quenching process, the main components of the emissions are dust, CO, NH₃ and H₂S. Additionally traces of different organic compounds can be emitted particularly when the coal is is not fully coked. The emissions from quenching are considered to be in the ranges given in Table 5.6. Quenching towers can be equipped with a spraying system for dust abatement.
<table>
<thead>
<tr>
<th>Location</th>
<th>Dust</th>
<th>CO</th>
<th>H₂S</th>
<th>NH₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coke quenching</td>
<td>10 - 50</td>
<td>100 - 2000</td>
<td>25 - 150</td>
<td>1 - 8</td>
</tr>
</tbody>
</table>

1) The values for dust depend very much on the kind of dust sampling. Isokinetic sampling results in higher emissions values.

Table 5.6: Emissions factors for directed emissions from coke quenching towers

Coke handling
Usually after quenching, the coke is conveyed to a separate building for crushing and screening. This generates particulate emissions which need to be extracted and this requires further abatement. The use of cyclones can reduce the emissions to 3 g/t coke. The dust emission concentration as an annual mean after a bag filter has been observed to be 0.5 and 4.5 mg/Nm³ respectively in two plants [407]. The handling of dry quenched coke causes more dust emissions than the handling of wet quenched coke [320] [321] [423].

COG treatment and by-product processing
Emissions from by-product processing like light oil, tar, naphthalene, phenol and ammonia are mainly organic compounds. Usually the by-product plant installations consists of closed processes. Fugitive emissions occur from leakages of, e.g. pumps, valves, exhausters, pressure relief devices and losses during transfers. Only a few data can be found for estimations of fugitive emissions from coke oven by-product plants based on measurements (see Table 5.7).

<table>
<thead>
<tr>
<th>Location</th>
<th>Benzene</th>
<th>BaP</th>
<th>PAH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mg/t coke</td>
<td>mg/t coke</td>
<td></td>
</tr>
<tr>
<td>By-product plant</td>
<td>100 - 24000</td>
<td>0.06 - 0.09</td>
<td>1.5 - 4.5</td>
</tr>
<tr>
<td></td>
<td>4000 - 26000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1) The higher values are for plants without a gas balancing pipe system
2) Data from US by-product plants referring to tables C54-C57 from [237]

Table 5.7: Emissions factors for fugitive emissions from by-product plants

One method for describing procedures for the measurement of volatile organic compounds fugitive emissions is the EPA method 21. A complete methodology for a comprehensive inventory of the leaks and the further management of fugitive emissions is described in [216].

5.2.2.2 Water usage and waste water
Figure 5.9 shows an example of possible water flows in a coke oven plant. However, many other alternative layouts exist.

Use of water
A wide variety of processes and variants are used for the downstream processing of coke oven gas. The amount of waste water originated by gas treatment plants depends on the water demand, for instance steam, fresh water addition to the washing liquids, diluting water, etc.

A substantial proportion of water to be drained from the coking process is the coal moisture from the coke oven. The average moisture content of coal is about 8 - 15 %, i.e. 0.08 - 0.15 m³/t coal. Thus, a representative coke yield of 780 kg coke/t coal produces a water flow of about 0.1 to 0.17 m³/t coke.
Thermal decomposition of coal generates additional water. Depending on the rank of coal 3 to 5 % by weight of so-called 'chemical water' is produced which means 0.03 - 0.05 m³/t coal corresponding to 0.04 - 0.06 m³/t coke.

If steam injection is used for aspiration (cooling and suction of charging gases) condensation of this steam will result in further water being produced in the primary coolers. The condensate is then also part of the waste water from the coke oven plant.

The condensed water and tar from the collecting main (downstream the goose neck), the coolers and the electrostatic precipitator are led to the tar/water separator where the so-called 'coal water' is separated off [21]. This water is led to the ammonia liquor storage tank. The ammonia liquor storage tank provides water for the gooseneck spray equipment. The surplus water from the ammonia liquor storage tank is led to the ammonia stripper/still [320] or to the H₂S washers [457]. Together with parts of the steam used in the ammonia stripper/still this water corresponds to the process water referred to in Table 5.2.

**Cooling water**

[320]

Cooling by the use of water takes place at:

- direct cooling of the hot crude COG with ammonia liquor
- further primary cooling of the crude COG (indirect or direct)
- further cooling (indirect)
- recooling of the condensates or the waters from indirect cooling.

For direct cooling of COG in the goose neck between 6 and 10 m³ ammonia liquor/t coke are normally used and kept in a closed circuit. In the case of a coke plant capacity of 100 to 300 t/h this equates to 600 up to 3000 m³ ammonia liquor per hour.

Normally most cooling water is used for indirect cooling. In this case of indirect primary cooling in coke oven gas (COG) treatment the water is recirculated in a close loop and will not influence the waste water quantity. In the case of direct gas cooling, the cooling water has to be considered to be a washing liquor and it is eventually drained via the still.

Water losses occur during recooling of cooling waters and condensates by evaporation of cooling waters e.g. in cooling towers. The amount of fresh water to replace evaporation and drainage losses from recooling is of around 6 - 10 m³/h, which equates to 1 - 2 % of the used water.

Cooling water management in a coke oven plant primarily depends on the local conditions, above all on the availability of fresh water and on legal requirements. Legal constraints of the local authorities in some countries demand the avoidance of plumes or the formation of industrial snow and ice during the winter period from recooling towers, which prevents further cooling water recycling. In such cases of a once-through cooling system, the cooling water demand is about 17 m³/t coke.

**Waste water from the coke oven plant**

[227]

The ammonia liquor storage tank provides water for the gooseneck spray equipment. The surplus water from the ammonia liquor storage tank is led to the ammonia stripper/still [320] or to the H₂S washers [457]. Together with parts of the steam used in the ammonia stripper/still and scrubbing liquor from the NH₃/H₂S scrubbing circuit this water corresponds to the waste water effluent referred to in Table 5.2. The specific amount of waste water for the plants mentioned in Table 5.8 is 0.31 to 0.69 m³/t coke.
After ammonia removal by distillation (see ‘still effluent’ in Figure 5.9) the waste water effluent contains various organic (such as phenols) and inorganic compounds (such as residual ammonia and cyanides). These compounds have a negative impact on the recipient water when directly discharged. The still effluent is therefore usually treated in a waste water treatment plant before discharge.

Data concerning the composition of the amounts and composition of waste water before treatment can differ considerably from one plant to another, both in terms of concentration and load per tonne of coke produced. The main reason for the wide variations lies in the gas treatment systems, the type of charging processes and the type of coal at the individual coke oven plants. For coals used for stamp charging a higher moisture content is preferred since they show better characteristic during compaction prior to charging.

In cases where water sealing of ascension pipes is applied, a small water consumption occurs due to evaporation losses. To guarantee gas tightness the sealing have always to be filled with water. During filling the seals a small water overflow occurs. Compared to the ammonia liquor from direct cooling this water is comparably clean and usually treated separately. In figure 5.9. this water is led to the ammonia liquor storage tank.

Additional waste water flows can be generated from condensed steam in the ammonia stripper/still, collected rainwater and runoff water, bleed from cooling and recooling circuits and filter backwash water from water treatment which can lead to a dilution of the surplus coal water flow.
### Table 5.8: Influent and effluent concentrations and some aspects of waste water treatment systems with the pre-DN/N system

<table>
<thead>
<tr>
<th>Aspect/component</th>
<th>Unit</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coke production</td>
<td>Mt/yr</td>
<td>0.63 - 1.25</td>
</tr>
<tr>
<td>Coal water flow (= surplus water)</td>
<td>m³/h</td>
<td>16 - 80</td>
</tr>
<tr>
<td>Dilution by other waste waters</td>
<td>m³/h</td>
<td>0 - 40</td>
</tr>
<tr>
<td>Total effluent flow</td>
<td>m³/h</td>
<td>22 - 86</td>
</tr>
<tr>
<td>Specific effluent flow (specific waste water amount)</td>
<td>m³/t coke</td>
<td>0.31 - 0.69</td>
</tr>
</tbody>
</table>

**Influent**

| pH | - | 8.5 - 9.5 |
| Suspended solids | mg/l | 30 - 40 |
| COD (x±s) | mg/l | 200 - 6500 |
| TOC (x±s) | mg/l | 835 - 1215 |
| BOD₅ | mg/l | 800 - 3000 |
| Phenol | mg/l | 500 - 1500 |
| SCN | mg/l | 150 - 380 |
| N-Kjeldahl | mg/l | 300 |
| Ammonia (x±s) | mg/l | 50 - 200 |
| Nitrite | mg/l | n/a |
| Nitrate | mg/l | n/a |
| Oil and tar | mg/l | 40 |
| PAH (6 Borneff) | µg/l | 200 |

**Effluent**

| pH | - | 7.6 - 8.0 |
| Suspended solids | mg/l | 42 - 75 |
| COD (x±s) | mg/l | 45 - 800 |
| TOC (x±s) | mg/l | 30 - 60 |
| BOD₅ (x±s) | mg/l | <20 |
| Phenol | mg/l | 0.1 - <2 |
| SCN | mg/l | <4.0 |
| N-Kjeldahl | mg/l | 3 - 10 |
| TNb | mg/l | 3 - 30 |
| Ammonia (x±s) | mg/l | 0.6 - 80 |
| Nitrite | mg/l | <1.3 |
| Nitrate | mg/l | 0* - 27 |
| Oil and tar | mg/l | 5 - 15 |
| PAH (6 Borneff) | µg/l | 0.2 - <50 |

n/a not available; Ranges reflect the maximum and minimum of daily averages over two years (2004 - 2005) except for BOD, BTX and PAH that refer to fewer samples. TNb Total nitrogen bound

* Lorfonte reports this value, although in theory it is impossible; but high residual ammonia content and a negligible nitrate concentration indicate nitrification inhibition.

The COD as a sum parameter comprises a large variety of different organic chemical compounds such as phenol (1000 - 2000 mg/l) organic nitrogen compounds (Kjeldahl-N: 250 - 500 mg/l) and polycyclic aromatic hydrocarbons (PAH) (up to 30 mg/l). In addition to ammonia other compounds containing inorganic nitrogen are also present, such as thiocyanides (150 - 350 mg/l) [65].

The levels of concentration of the monocyclic hydrocarbon aromatics are rather low. The PAHs are essentially present in an adsorbed state on solid particles. Benzo(a)pyrene has also been detected [202] [201].

**Waste water from wet oxidation desulphurisation processes**

Waste water from wet oxidative desulphurisation processes is usually treated separately owing to the presence of compounds that have a detrimental effect on the biological waste water treatment plant.
Table 5.9 shows the waste water composition of two wet oxidative desulphurisation processes. The application of one of the other wet oxidative techniques may lead to water emissions of arsenic compounds (Thylox process), 1.4-naphthoquinone-2-sulphonic acid (Takahax), picric acid and thiocyanides (Fumaks/phodacs process).

<table>
<thead>
<tr>
<th>Component</th>
<th>Stretford desulphurisation (g/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NH₃ (free)</td>
<td>0.1</td>
</tr>
<tr>
<td>Na₂CO₃</td>
<td>5.7 - 65</td>
</tr>
<tr>
<td>SCN⁻</td>
<td>80 - 300</td>
</tr>
<tr>
<td>S₂O₃²⁻</td>
<td>50</td>
</tr>
<tr>
<td>SO₄²⁻</td>
<td>12.2</td>
</tr>
<tr>
<td>Vanadate (VO₃⁻)</td>
<td>1.2</td>
</tr>
<tr>
<td>Anthraquinodisulphonate (ADS)</td>
<td>1.9</td>
</tr>
</tbody>
</table>

Table 5.9: Composition of waste water from two wet oxidative desulphurisation processes [21] [320] [327]

**Wet coke quenching**

Usually no waste water results from wet quenching. The consumption of quenching water depends on the quenching process itself and can be considered to be between 1 - 3 m³/t coke. When quenching is operated correctly, the excess water is collected. Solids can be separated in settling chambers or sand filters prior to use for the next batch. Evaporation losses are between 0.5 and 1 m³/t coke and is replaced with fresh water.

**5.2.2.3 Process residues from coke oven plants**

<table>
<thead>
<tr>
<th>Waste/residue</th>
<th>Amount (kg/t of coke)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal tar recovery</td>
<td>0.1</td>
</tr>
<tr>
<td>Tar decanter</td>
<td>0.2</td>
</tr>
<tr>
<td>Tar storage</td>
<td>0.4</td>
</tr>
<tr>
<td>Light oil processing</td>
<td>0.2</td>
</tr>
<tr>
<td>Waste water treatment</td>
<td>0.1</td>
</tr>
<tr>
<td>Naphthalene collection and recovery</td>
<td>0.02</td>
</tr>
<tr>
<td>Tar distillation</td>
<td>0.01</td>
</tr>
<tr>
<td>Sludges from biological waste water treatment</td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>1.03</strong></td>
</tr>
</tbody>
</table>

Table 5.10: Main waste/residues from coke oven plants [227]

Coke production facilities generate process solid wastes other than coke breeze and biosludges of about 1 kg/t of coke as shown in Table 5.10. Most of the solid wastes contain hazardous components such as benzene and PAHs. All process wastes are usually recycled to the coke ovens. Waste water sludges should be dewatered. Dewatered sludges can also be charged to the coke ovens or disposed of in a secure landfill or an appropriate combustion unit.
5.2.2.4 Energy demand

Notes: Values in MJ/t coke (dry) and correspond to an annual production of 1.4 Mt

Figure 5.11 details the information on the energy input in a typical coke oven plant including consideration of COG treatment. The figure also gives information on the energy output. The COG produced by coke oven plants means that this plays an important role in energy supply and management in integrated steelworks (see Section 2.1.1) [320].

The expression 'rest of balance refers to losses.

Figure 5.11: Example for the annual energy demand/balance of a coke oven plant in an integrated iron and steel works [320]

5.2.2.5 Soil pollution

In the coke oven gas treatment plant, tar and other organic compounds (e.g. BTX) are recovered from the coke oven gas. Spillage or leakage of these compounds may cause a soil pollution hazard, depending on local soil conditions. Furthermore, spillage or leakage of coal water may also cause a soil pollution hazard. Only a brief description of possible measures will be given here:

- minimising the number of flanges and appendages
- pipes and flanges must be inspectable as much as possible (e.g. placed above ground or in mantle pipes), unless the age and design of the plant makes this impossible
- storage and transport of substances which are potentially a soil pollution hazard should be done in such a way that precautions are taken to avoid spillage to soil occurring
- groundwater precipitation if necessery (see Table 6.23).
5.3 Techniques to consider in the determination of BAT

This section sets out techniques considered generally to have potential for achieving a high level of environmental protection in the industries within the scope of the document. Management systems, process-integrated techniques and end-of-pipe measures are included, but a certain amount of overlap exists between these three when seeking the optimum results.

Prevention, control, minimisation and recycling procedures are considered as well as the re-use of materials and energy.

Techniques may be presented singly or as combinations to achieve the objectives of the IPPC Directive. Annex IV to this Directive lists a number of general considerations to be taken into account when determining BAT and techniques within this section will address one or more of these considerations. As far as possible, a standard structure is used to outline each technique, to enable comparison of techniques and an objective assessment against the definition of BAT given in the IPPC Directive.

The content of this section is not an exhaustive list of techniques and others may exist or be developed which may be equally valid within the framework of IPPC and BAT.

The standard structure used to outline each technique is shown in Table 5.11.

<table>
<thead>
<tr>
<th>Type of information considered</th>
<th>Type of information included</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Technical description of the technique (including drawings, schematics if necessary)</td>
</tr>
<tr>
<td>Achieved environmental benefits</td>
<td>Main environmental benefits (including energy, water, raw material savings, as well as production yield increases, energy efficiency, etc.) addressed by the technique</td>
</tr>
<tr>
<td>Cross-media effects</td>
<td>Main environmental side effects and disadvantages to other media caused by using the technique. Details of the environmental effects of the technique in comparison with others</td>
</tr>
<tr>
<td>Operational data</td>
<td>Data on consumption and emission levels from operational plants using the technique (including any reference conditions and monitoring methods used). Any other relevant information on how to operate, maintain and control the technique</td>
</tr>
<tr>
<td>Applicability</td>
<td>Indication of the type of plants in which the technique may be applied, considering, e.g. plant age (new or existing), plant size (large or small), techniques already installed and type or quality of product</td>
</tr>
<tr>
<td>Economics</td>
<td>Information on costs (both investment and operational) and any possible savings (e.g. reduced raw material or energy consumption, waste charges) or revenues including details on how these costs/savings or revenues have been calculated/estimated</td>
</tr>
<tr>
<td>Driving force for implementation</td>
<td>Local conditions or requirements which lead to, or may stimulate, implementation. Information on reasons other than environmental ones for implementation (e.g. increase in productivity, safety)</td>
</tr>
<tr>
<td>Example plants</td>
<td>Reference to (a) plant(s) in which the technique is applied and from which information has been collected and used in writing the section</td>
</tr>
<tr>
<td>Reference literature</td>
<td>Literature or other reference material (e.g. books, reports, studies, websites) that was used in writing the section and that contains more details on the technique</td>
</tr>
</tbody>
</table>

Table 5.11: Information breakdown for each technique described in this section
5.3.1 Coal preparation

Description
A prerequisite for good operation of a coke oven plant as described in Section 5.3.4 is optimised coal handling. The purchased coal can be preprocessed by beneficiation (preferably at the coal mine) and blending processes that improve the quality of coal feed to produce coke of desired quality together with reduced emissions of sulphur oxides and other pollutants.

The optimal operation of a coke oven plant requires a coal blend, which is as homogenous as possible. A modern coal pretreatment plant consists of two mixing hoppers, a crushing/screening plant, transporting equipment, dedusting equipment, conveyor belts in a closed building and possibly additional processes such as coal drying or addition of coal additives.

These crushing and screening processes are usually carried out in buildings. All relevant devices should be enclosed. The emissions from these devices and material transfer points should be extracted and abated by cyclones, rotoclones, building enclosures of primary coal pulverisers, secondary coal pulverisers with building enclosures, scrubbers, wet ESPs and bag filters.

For the transport of the coal enclosed or covered conveyors are used. For the storage of the coal sprinklers and plastic emulsions can be used to suppress dust formation. Windbreak fences or upwind mounds can be applied to lower the wind velocity. If prerequisite enclosed storage shall be applied. The free fall height of the materials should be less than 0.5 m.

Achieved environmental benefits
For the directed extracted emissions values of <10 - 20 mg/Nm³ can be achieved.

Cross-media effects
No data submitted.

Operational data
No data submitted.

Applicability
No data submitted.

Economics
No data submitted.

Driving force for implementation
No data submitted.

Example plants
No data submitted.

Reference literature
[223] [227] [435]
5.3.2 Minimising oven charging emissions

Description
Oven charging is most commonly performed by gravity charging with charging cars. Three basic techniques are used to reduce the emissions during charging in this way:

1. "Smokeless" charging. This system uses gas-tight connections between the coke oven and the charging car. The chambers are rapidly filled through four or five charging holes. Suction is generated by steam or water injection in the goose neck of the ascension pipe.

2. Sequential charging or stage charging. In this process, the charging holes are charged one after the other. This type of charging takes a relatively long time. Suction is generated on both sides of the oven, either by the use of two ascension pipes (when present) or the use of the ascension pipe and a jumper pipe to the adjacent oven. The connections between the charging car and the oven are not gas-tight, but due to the suction, virtually no emissions occur when only one opening to the atmosphere is present.

3. Charging with telescope sleeves also known as “Japanese charging”; this kind of charging is done by simultaneous charging through the (usually) four charging holes. The connections between the charging car and the coke oven are not gas tight, but are enclosed by "telescope sleeves" from which the gases are extracted and led to a collecting main via a connection between the collecting main and the charging car. The extracted gases are combusted and subsequently led through a particulate matter arresting device, which is stationed on the ground. In some cases, the charging cars are equipped with dedusting devices for the treatment of the extracted gases.

Additionally dust from coal charging can be evacuated by the use of jumper-pipe systems and steam injection into the ascension pipe or controlled by bag filters or scrubbers.

Among others, by levelling already during charging, a free gas space should be created in the top of the oven resulting in an undisturbed gas suction during charging, as well as during coking. Thus, charging emissions can be reduced. The effect of this technique depends greatly on the oven design and subsequently on the method of levelling and charging.

Achieved environmental benefits
Charging emissions can be very low in all of these systems. The main determining factor is the over pressure in the oven chamber and the charging telescopes.

Emissions from charging are difficult to quantify but <30 seconds of visible emissions per charge is generally achievable. Emissions of less than 10 seconds are achievable under optimum conditions. The standard in force in the US according to EPA method 303 for all by-product coke oven batteries is 12 seconds of visible emissions per charge.

Reported particulate matter emissions from charging with telescope sleeves with a dust collecting unit on the charging car are less than 5 g/t coke (concentration <50 mg/Nm³). In this case, the evacuated gas is burnt before discharge.

Cross-media effects
No data submitted.

Operational data
Some of the systems are more vulnerable to operational problems than others.

Applicability
Can be applied both to new and existing plants.

Economics
No data submitted.
Driving force for implementation
No data submitted.

Example plants
Emissions-minimised charging is applied at many plants all over the world. Table 5.12 gives some examples:

<table>
<thead>
<tr>
<th>Charging technique</th>
<th>Example plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Smokeless&quot;</td>
<td>Coke oven 2, Corus, Ijmuiden, the Netherlands</td>
</tr>
<tr>
<td></td>
<td>Coke oven plant ArcelorMittal, Gent, Belgium</td>
</tr>
<tr>
<td></td>
<td>Coke oven plant ArcelorMittal, Dunkerque, France</td>
</tr>
<tr>
<td></td>
<td>Coke oven plant ArcelorMittal, Fos, France</td>
</tr>
<tr>
<td></td>
<td>Coke oven plant Gijón, Spain</td>
</tr>
<tr>
<td>Sequential/stage</td>
<td>Many plants in the US;</td>
</tr>
<tr>
<td></td>
<td>Coke oven Hüttenwerke Krupp Mannesmann, Duisburg-Hucking, Germany</td>
</tr>
<tr>
<td></td>
<td>Coke oven Prosper, Bottrop, Germany</td>
</tr>
<tr>
<td>&quot;Japanese&quot;</td>
<td>Coke oven 1, Kawasaki Steel Corporation, Chiba Works, Japan</td>
</tr>
<tr>
<td></td>
<td>Coke oven, Nippon Steel Corporation, Kimitsu Works, Japan</td>
</tr>
<tr>
<td></td>
<td>Coke oven, Sumitomo Metal Industries, Wakayama Works, Japan</td>
</tr>
<tr>
<td></td>
<td>Coke oven 1, Corus, Ijmuiden, the Netherlands</td>
</tr>
<tr>
<td></td>
<td>Coke oven plant ArcelorMittal, Seremange, France</td>
</tr>
<tr>
<td></td>
<td>BHP Steel, Australia</td>
</tr>
</tbody>
</table>

Table 5.12: Example plants

Reference literature:
[33] [215] [223] [227] [320] [337]

5.3.3 Sealing of ascension pipes and charging holes

Description
During the coking period, diffuse emissions from coke oven openings can be minimised by sealing these openings efficiently after the pushing and charging operation. However, such measures can only be successful when accompanied by careful maintenance and cleaning.

Water-sealed ascension pipes are standard equipment at most coke oven plants (see Figure 5.12).
Additionally, many older plants are also fitted with water-sealed ascension pipes. The water sealing can be very effective, providing that the water supply and runoff pipes are kept free of obstructions.

The best way to keep the charging holes leak-proof is to lute them carefully with a clay-type material or similar product.

The performance of the ascension pipe and charging hole sealings should be monitored. Different methods for estimating the fugitive emissions from coke ovens are in use. The achieved emission levels expressed as a frequency of leaking percentage of the total number of ascension pipes and charging holes showing visible leaks) or mass/time depend on the monitoring method. The EPA 303 method for example enables the results from the observation procedure to be expressed in percentages of leakage. However the DMT methodology, which is according to the EPA method, allows emissions per day based on basic measurements to be calculated, assigning four different degrees of strength to the emissions and taking the duration of the visible emissions during the observation into consideration.

The following monitoring method is used at one example plant:

- visible leaks of the ascension pipes and charging holes are determined on the oven deck at a distance of 2 m from the ascension pipes and charging holes. Visible leaks of the ascension pipes are also determined from the collecting main
- ascension pipes and charging holes are observed once a day (random check)
- visible emissions due to normal operations (coal charging, coke pushing) are not counted as leaks
- a weekly average of the frequency of leaking is determined.
Achieved environmental benefits
Water sealed ascension pipes and charging holes with luted lids will significantly reduce particulate matter emissions, CO and hydrocarbons (see also Table 5.2).

For a 30 days average with luted lids, a maximum of 1% of charging holes showing visible leaks is achievable. For the apparatus which provides a passage from the coke oven battery to the collecting main, including ascension pipe, gooseneck and stationary jumper pipes also 1% is also achievable.

Cross-media effects
Water sealed ascension pipes generate a waste water flow. However, this waste water can in some cases, be recycled to the ammonia liquor tank or led to the ammonia stripper/still. Electricity is consumed by the pumps to circulate the water.

Luting of charging holes causes no significant cross-media effects.

Operational data
No data submitted.

Applicability
Applicable both at new and existing plants. In new plants the design of the ascension pipes and the charging holes can be optimised in order to reduce fugitive emissions.

Economics
No data submitted.

Driving force for implementation
No data submitted.

Reference plants
Many plants in the world have water sealed ascension pipes. Furthermore, almost all plants lute the charging holes, either automatically or manually.

Reference literature
[33] [320] [412]

5.3.4 Smooth and undisturbed operation of the coke oven plant

Description
Together with the maintenance regime and cleaning operations, smooth and undisturbed operation of the coke oven is one of the most important process-integrated measures for emissions control. Failure to do so leads to severe temperature fluctuations and increased chances of coke sticking during pushing. This has an adverse effect on the refractory and on the coke oven itself and may lead to increased leakage and an increase in abnormal operation conditions.

A prerequisite for smooth and undisturbed operation is good reliability of the oven machinery and installations. This also leads to higher productivity.

A disturbance free operation of the by-product plant will also have a positive influence on the emissions from the batteries.

By controlling the temperature of the heating surface (measuring device at the ram bar) it is possible to determine the temperature distribution in the chamber which allows conclusions on the efficiency of the heating system.
Based on these results, actions to repair or to optimise it can be taken.

Checking and ensuring that the coke mass is fully coked can prevent emissions of VOC or emissions from spontaneous combustion of residual coke gases when the door is opened.

Automation of the coke making enables a coke oven plant to be operated at optimum efficiency. Some examples of control types are:

- an infrared measuring system of the surface temperature of the two heating walls
- an infrared pyrometer with an integral data memory for taking manual measurements at the heating flues
- plumes, which occur when pushing green coke, are a source of dust emissions. Four main causes of plumes are: battery conception, coke cake components, mechanical reasons (clogging) and hood system quality. The technique first consists of implementing a system to register plumes (for example, an infrared thermal camera system) which allows all abnormal events to be recorded. Then the records are analysed and linked with the main identified cause among the four possible causes mentioned above. Finally defect correction (charging height and heating adjustments, charge quality modifications, cleaning operations, etc) allows the number of further plumes to be reduced
- a set of strategically located video cameras can be used to monitor air emissions from the coke ovens. Some can be mounted within the coke oven plant and others can be mounted at certain distances to provide an overview of the operations. The cameras transmit images to the control room operators and these images can be recorded and archived for analytical purposes
- a computer system to calculate the amount of heat required in each battery
- a system to automatically push and charge, to assist operating crews
- a system to control gas treatment plants.

**Achieved environmental benefits**

A significant part of the coke oven plants emissions is caused by leakage through cracks between the heating chamber and the oven chamber and as a result of deformed doors, door frames, buck-stays, etc. These emissions can be avoided, to a large extent, by a more smooth and undisturbed operation of the coke oven plant. Furthermore, this technique may significantly increase the duration of the life of the coke oven plant.

The recorded images can be used to investigate and identify emissions and to clarify exactly where they came from and what was happening at the plant at the time. This analysis provides valuable information for the prevention of future abnormal incidents.

The dust emissions from plumes are avoided in a large extent.

**Cross-media effects**

No significant cross-media effects are known.

**Operational data**

No data submitted.

**Applicability**

Can be applied both at new and existing plants. Because of the modular design of a coke oven, the design of coke making automation equipment allows for tailor-made solutions according to the customer's specific requirements.

**Economics**

In general, the avoidance of green coke improves the productivity of the coke plant.

**Driving force for implementation**

No data submitted.
Example plants
All operators in the world are trained to operate their coke oven plant as smoothly as possible. However, economic incentives may induce higher production levels and increase the chances of less stable plant operation.
One example for the technique described in bullet point 3 is the coke oven plant, Arcelor Dunkerque, France.
One example for the technique described in bullet point 4 is BHP steel in Australia.

Reference literature
[65] [215] [223] [227] [253] [320] [415]

5.3.5 Maintenance of coke ovens

Description
The maintenance of coke ovens is one of the most important process-integrated measures and is a decisive factor for smooth and undisturbed operation.

The maintenance can be performed in campaigns or continuously. No fixed or minimum period of maintenance can be set. Maintenance should follow a systematic programme and be carried out by specially trained maintenance personnel (e.g. during two shifts).

The maintenance programme at ArcelorMittal, Gent, Belgium is described below as an example. There, each oven receives a complete overhaul after, on average, five years, depending on the state of the ovens. This entails leaving the oven empty for a week when the following operations are carried out:

- periodic inspection of the ovens (e.g. one oven per day)
- degraphitising of all deposits within the chamber (walls, ceiling, ascension pipes)
- oxythermic welding of cracks, holes and surface damage of the refractory brickwork
- repair of the oven chamber floor by flooding with cement
- airborne dust is injected into the fine cracks
- overhaul of the sealing surface of the door frame by readjustment of the doorframe in the oven
- complete overhaul of the doors; complete dismantling of all individual parts, cleaning and reassembling; readjustment of the sealing elements. Damaged door bricks are replaced; in many cases, the door is completely rebricked.

In addition to this overhaul, the bracing system of the ovens (springs, anchoring, etc.) is regularly checked and adjusted.

Other programmes include, for example:

- frequently cleaning goosenecks and the main collecting passages to prevent obstructions
- cleaning of lids
- development of coke oven chamber wall diagnosing-repairing apparatus
- monitoring the pushing force to discover cracks in walls.

Achieved environmental benefits
Good maintenance prevents cracks in the refractory brickwork and minimises leakage and consequently emissions of incompletely combusted underfiring gas. This prevents black smoke being visible at the stacks discharging flue-gas from coke oven firing. In addition, the maintenance, readjustment and overhaul of the doors and frames prevents leaks. Well maintained goosenecks and collecting mains also prevent emissions from charging.
Cross-media effects
No significant cross-media effects are known.

Operational data
The maintenance programme described has been applied in general by all operators (e.g. ArcelorMittal, Gent (BE) since 1986), with considerable success.

Applicability
Maintenance programmes as campaigns or continuously actioned, can be applied both at new and existing plants.

Economics
Personnel costs for skilled workers carrying out the maintenance programme are considerable (about EUR 2/t coke in the case of ArcelorMittal, Gent, Belguim) but as part of the measures of smooth and undisturbed operation better skilled operators contribute to higher productivity, thus compensating the costs.

Driving force for implementation
The intention to operate the coke oven plant as smoothly as possible with optimised productivity and minimised emissions.

Example plants
ArcelorMittal coke oven plant, Gent, Belguim. This is a common technique carried out by all coke operators.

Reference literature
[200] [223] [225] [242] [253] [320] [330] [416] [423]

5.3.6 Larger coke oven chambers

Description
The development of wider and taller coke oven chambers is inspired by two main principles:

- better environmental performance by reducing the number of ovens pushed per day and reducing of the length of the sealing faces
- lower investment and production costs because only one set of machines is needed.

The main characteristics of the tall or wide chamber coke ovens is the large oven volume compared to conventional ovens. Thus for a given output, the door seal is decreased in length and the frequency of pushing is reduced. However, special attention has to be paid to the sealing because it is more difficult to keep such ovens gas-tight, especially at the top and bottom ends.

Achieved environmental benefits
When properly maintained and when spring-loaded flexible sealing doors are used under comparable operational circumstances, the total (fugitive) emissions per tonne of coke from the door and frame seals can be expected to be directly proportional to the reduction of the seal length compared to conventional coke ovens.

A reduction in emissions from pushing operations can be expected, given that fewer pushing operations are required per tonne of coke and that emissions are directly proportional to the number of pushes. Nevertheless, emission factors (e.g. emissions per lid, emissions per door) are not influenced by the application of larger coke oven chambers.

Cross-media effects
Visible fugitive door emissions may occur.
Operational data
Larger oven doors demand more intensive maintenance. Table 5.13 shows the characteristics of several coke ovens.

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Unit</th>
<th>Small</th>
<th>Medium</th>
<th>Tall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions (useful):</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• height</td>
<td>(m)</td>
<td>4.5</td>
<td>6.0</td>
<td>7.1</td>
</tr>
<tr>
<td>• length</td>
<td>(m)</td>
<td>11.7</td>
<td>14.2</td>
<td>15.9</td>
</tr>
<tr>
<td>• width</td>
<td>(m)</td>
<td>0.45</td>
<td>0.45</td>
<td>0.59</td>
</tr>
<tr>
<td>Useful volume</td>
<td>(m³)</td>
<td>22.1</td>
<td>36.4</td>
<td>62.3</td>
</tr>
<tr>
<td>Productivity</td>
<td>(t coke/oven)</td>
<td>12.7</td>
<td>21.3</td>
<td>39.8</td>
</tr>
<tr>
<td>Number of ovens</td>
<td>(#)</td>
<td>322</td>
<td>187</td>
<td>142</td>
</tr>
<tr>
<td>Total oven openings</td>
<td>(#)</td>
<td>2898</td>
<td>1496</td>
<td>1278</td>
</tr>
<tr>
<td>Length of sealing faces</td>
<td>(km)</td>
<td>10.5</td>
<td>6.9</td>
<td>6.2</td>
</tr>
<tr>
<td>Oven pushes</td>
<td>(#/d)</td>
<td>430</td>
<td>257</td>
<td>138</td>
</tr>
<tr>
<td>Total opening actions</td>
<td>(#/d)</td>
<td>3870</td>
<td>2056</td>
<td>1242</td>
</tr>
<tr>
<td>Length of sealing faces to be cleaned</td>
<td>(km/d)</td>
<td>14.0</td>
<td>9.5</td>
<td>6.0</td>
</tr>
</tbody>
</table>

Table 5.13: Characteristics of several coke oven types
[33] [204] [320] [335]

No specific problems are known with the plants with wide and high chambers. Greater demands are placed on wall strength.

Applicability
Only applicable to new plants. In some cases, a larger coke oven chamber can be chosen at a complete rebuild of the plant on the old foundations.

Economics
No data submitted.

Driving force for implementation
No data submitted.

Example plants
- coke oven battery, Hüttenwerke Krupp Mannesmann, Duisburg-Huckingen, Germany
- prosper No.3 coke oven battery, Bottrop, Germany
- coke plant Schwelgern, KBS, Duisburg-Schwelgern, Germany.

Reference literature
[33] [129] [204] [320] [335]

5.3.7 Improvement of oven door and frame seals

Description
Oven door gas-tightness is essential and can be achieved by applying the following techniques:

- use of spring-loaded, flexible sealing doors
- careful cleaning of the door and its frame at each coke push
- gas channels inside the doors.

Existing batteries can be equipped with new spring-loaded sealing doors if door frames and armour plates are not too deformed. In this respect, the strength of the buckstays plays an important role, because the armour plates (holding the brickwork in place) are preferably held in place by springs, which are mounted to the buckstays.
It must be noted that the situation differs for small and large ovens. For ovens less than 5 m high, knife-edge doors in combination with good maintenance may be sufficient to prevent door emissions.

The performance of the ascension pipe and charging hole sealings should be monitored. Different methods for estimating the fugitive emissions from coke ovens are in use. The achieved emission levels expressed as a frequency of leaking percentage of the total number of ascension pipes and charging holes showing visible leaks) or mass/time depend on the monitoring method. The EPA 303 method for example enables the results from the observation procedure to be expressed in percentages of leakage. However the DMT methodology, which is according to the EPA method, allows emissions per day based on basic measurements to be calculated, assigning four different degrees of strength to the emissions and taking the duration of the visible emissions during the observation into consideration.

**Achieved environmental benefits**
The specific emission values from flexible sealing doors are much lower than those from conventional doors. Provided they are kept clean, "new generation" doors make it possible to keep visible emissions below 5% of all the coke oven doors per battery, both on the pusher side and on the coke side over an average of 30 days. However, examples can be found of good results with traditional (knife-edge) doors on well maintained small ovens and bad results with flexible sealing doors on badly maintained large ovens but generally flexible sealings offer much better opportunities for tightness especially for large ovens.

Gas channels with large cross-sections behind the door body (by cutting back of the door plug or by a heat shield) or integrated in the sealing, reduce the pressure gradient between the inside and outside of the sealing edge.

A German coke oven equipped with spring-loaded door seals emitted 0.11 g polycyclic organic matter (POM) per tonne of coal charged. Improvements applied to the leveller door have achieved a 93% reduction in fugitive emissions from that door.

**Cross-media effects**
No cross-media effects occur.

**Operational data**
No data submitted.

**Applicability**
Applicable at new and, in some cases, existing plants.

**Economics**
The investments for replacing doors of a coke oven battery is around EUR 6 million in a coke oven plant with about a hundred ovens and which produces 1.2 - 1.5 Mt coke/yr.

The investment for replacing doors in a coke oven in ArcelorMittal, Gent, Belgium was of EUR 15 million for 240 ovens in 2006.

**Driving force for implementation force**
No data submitted.
Example plants
Many new and rebuilt plants apply spring-loaded flexible sealing doors.

- coke oven 1, Corus, IJmuiden, the Netherlands
- coke oven Hüttenwerke Krupp Mannesmann, Duisburg-Huckingen, Germany
- coke oven in BHP Steel in Australia
- ArcelorMittal, Fos, France
- ArcelorMittal, Dunkerque, France.

Reference literature
[161] [215] [223] [320] [331] [415]

5.3.8 Cleaning of oven doors and frame seals

Description
Many older European coke oven plants still have original non-spring-loaded knife-edge doors. In these plants, especially with ovens higher than 5 m, leaking doors can be a serious problem. However, with good maintenance any visible emissions from existing doors can be under 10%. The success of the maintenance plan depends, to a large extent, on a stable coking process, permanent staffing for maintenance, continuous monitoring and feedback regarding achievements. An indoor maintenance workshop for doors is highly recommended.

Advanced door cleaners using scrapers at every cycle also show good results. Another method of cleaning coke oven doors is to use a high pressure water-jet. High pressure water-jet coke oven door cleaning, however, cannot be performed every cycle.

Maintenance programmes applied to coke oven doors contain, for example, door cleaning equipment and a door service maintenance strategy.

Achieved environmental benefits
The high pressure water-jet cleaner system makes it possible to virtually eliminate visible emissions – a reduction of 95% of the time can be achieved (according to the EPA method). The use of a door cleaner system with scrapers also contributes to drastically reducing the visible emissions from the doors.

Cross-media effects
Cleaning with a high pressure water-jet generates a contaminated waste water flow, which can be treated along with the waste water from the coke oven batteries.

Operational data
No data submitted.

Applicability
Applicable both to existing and new plants.

Economics
No data submitted.

Driving force for implementation
No data submitted.

Reference plants:
coke oven 2, Corus, IJmuiden, the Netherlands
BHP Steel, Australia.
5.3.9 Maintaining free gas flow in the coke oven

Description
A free space is maintained at the top of the oven chamber to allow the gases and volatilised tar to flow towards the ascension pipe, which, depending on the design, is usually situated either on the pusher machine side of the oven or on both sides. The gas flow may be hampered by charged coal reaching the oven top and by the top of the oven becoming clogged with graphite. Whenever the gas flow in the oven is obstructed, door and charging hole leakage will occur because the over pressure behind the obstruction increases.

This situation can be prevented by adequate levelling of the charged coal. The build-up of graphite on the top of the chamber and on the oven roof can be minimised by adequate heat distribution over the oven walls and lowering the upper wall temperature to about 700 °C. Nevertheless, if the accumulation of graphite becomes too much, the leveller can get stuck in the coke oven chamber. To avoid this, the pusher is equipped with a special scratching device to clean the roof and the walls of the upper chamber area during pushing.

Achieved environmental benefits
A good pressure distribution in the coke oven chamber significantly reduces diffuse emissions and leakage. Furthermore, the risk of the coke charge jamming during pushing operations is reduced.

Cross-media effects
No cross-media effects occur.

Operational data
No data submitted.

Applicability
Applicable at new and existing coke ovens.

Economics
No data submitted.

Driving force for implementation
No data submitted.

Reference plants
All plants with a proper maintenance programme and which aim to minimise door leakage apply this technique.

Reference literature
[65] [320]
5.3.10 Variable pressure regulation of ovens during the coking process

Description
One of the most difficult environmental problems to avoid with conventional coke ovens are diffuse gaseous emissions, which mainly appear at coke oven closures such as coke oven doors, ascension pipe lids and at charging hole lids. The main cause and driving force of these emissions is the pressure in the oven chambers resulting from the raw gas generated during the carbonisation process. Driven by this pressure, the raw gas penetrates the seals of the diverse coke oven closures.

The oven chamber is usually kept under slightly positive pressure during coking. Negative pressure would allow air to penetrate the oven chamber and would partially burn the coke, leading to destruction of the oven. The oven bottom should be at atmospheric pressure. As a rule of thumb, the over pressure (in mm water column) in the collecting main is maintained at twice the height of the oven in metres. Hence, for a modern 7 m tall oven, the corresponding over pressure would be 14 mm water column. For older 4 m tall ovens, the overpressure in the collecting main would be 8 mm water column.

During the coking process the COG pressure reaches its maximum after a carbonisation period of 2 hours. Within the coking time, the specific raw gas ratio and the chamber pressure both decrease.

There are different possibilities for setting the pressure of the collecting main. The conventional way for pressure regulation and emission reduction are fixed high or low pressure adjustment.

High pressure adjustment always keeps the pressure in the oven chamber at a positive level (e.g. 12 mm water column for a 6 m tall oven). With high pressure adjustment, the air penetration into the oven is avoided. However, the emissions rate at the oven closures tend to increase. During charging and starting carbonisation, high amounts of raw gas must leave the oven. This raw gas should overcome the positive pressure of the collecting main. At this time, there is a high pressure of gas inside the oven to manage. The conventional way to manage this high pressure level is to adjust a common valve for a group of several ovens. The positive pressure of the collecting main keeps the pressure constant for all coupled ovens so that all ovens are secured to the end of their individual coking time. It is a well-known technique which is used by nearly all coke plants in the EU-25.

A low pressure adjustment (slight overpressure at the beginning and underpressure at the end of the coking times) reduces the pressure in the oven chambers and the emissions rate is lowered as well. However, at the end of carbonisation, the oven pressure at the bottom line is normally under negative pressure so that air could be sucked in, burning beyond the oven door, and could destroy the door sealing as well as the silica bricks.

The solution for optimised emissions reduction is a new way for pressure adjustment and emissions reduction. This system sets an optimum pressure at each chamber. During and after coal charging, the pressure in the standpipe is set very low in order to facilitate the discharge of the raw gas to the collecting main. With the increase in carbonisation time and the decrease in raw gas generation, the pressure in the standpipe increases step by step. This variable pressure regulation system is known under the brand name PROven.

While a negative pressure of approximately -3 to -3.5 hPa is maintained in the collecting main, the pressure inside the individual coke oven chambers (measured at the bottom of the door) is adjustable under these conditions to about 5 mm water column for the entire carbonisation time.

Achieved environmental benefits
The amount of dust and coke particulates in the coke oven gas are drastically reduced. Table 5.14 shows the results of measurements carried out before and after the installation of the variable pressure regulation technique.
### Cross-media effects

No significant cross-media effects are known.

### Operational data

The operational data of the conventional technique are well known. Experiences with the operational characteristics of the variable pressure technique have been gathered since 1999. No specific problems have been reported.

### Applicability

The variable pressure regulation technique is applicable to new coke plants and can be an option for existing plants. The possibility of installing this technique in existing plants has to be proved carefully and is subject to the individual situation of every plant.

### Economics

No data submitted.

### Driving force for implementation

Reduction of emissions.

### Example plants

In 1999, the variable pressure regulation system was tested in an old coking plant in Germany (52 coke ovens, 6 m height). It was working for three years before the coking plant was dismantelled. This system was then installed in a new coke plant in Germany (two batteries of 70 ovens each with a height of 8.4 m).

The variable pressure technique is applied at the Coke Plant Schwelgern in Duisburg, Germany (start-up March 2003) and in five coke ovens in China.

### Reference literature

[203] [204] [225] [320] [329]

### 5.3.11 Heat recovery coking

#### Description

This coking system is often also called 'non-recovery coking' because of unrecovered gas and coal chemicals. Nowadays, however, the term 'heat recovery' has succeeded, when the waste heat is used and the off-gas is desulphurised as is typical for new constructions.

In the heat recovery coking process, essentially all the tar and gases released from the coking process are combusted within the oven and the sole flue. The heat recovery coking process requires a different oven design from that traditional horizontal chamber system. A coke oven gas treatment plant and waste water treatment plant are not needed.
Traditional heat recovery plants without any waste gas use and/or cleaning are the so-called 'beehive ovens' which are still in operation in China. The basis for the heat recovery plants is the so-called 'Jewell - Thomson oven' (Figure 5.13), several ovens of which are grouped together to form one battery.

![Figure 5.13: Jewel-Thomson oven and heat recovery coke plant](image)

Shaped with a rectangular ground area and an arched top, the dimensions of the chambers of the plant run at Indian Harbor Coke Company in East Chicago (US) (see Figure 5.13) are 14 x 3.5 x 2.4 m (L x W x H). The oven brick lining is composed of refractory silica material. Coal charging (40 to 45 tonnes per charge) of ovens is accomplished through the open pusher side door with the aid of a water cooled coal conveyor. Typical charging heights are 1000 mm.

The carbonisation process is started by the heat which exists from the preceding carbonisation cycle. The released coke oven gas is partly burnt in the crown by the addition of ambient air through the oven doors, and passed through so-called 'downcomers' into the heating flues situated in the oven sole. By way of a further supply of ambient air, the complete combustion of raw gas is effected here at temperatures of between 1200 and 1400 °C.

Thus, coking of the input coal takes place by direct heating from the oven crown and by indirect heating from the refractory floor. The whole system operates at sub-atmospheric pressure. With the heat recovery of a modern plant, the hot waste gas is utilised to generate energy and subsequently subjected to desulphurisation before being emitted into the atmosphere.

The coking time in Jewell-Thomson ovens amounts to approx. 48 hours. After that time, the coke is pushed out and quenched in wet mode. The most essential features by which the heat-recovery technique differs from the conventional coke making technique are given in Figure 5.14 and can be summarised as follows:
• flat bed coke making
• operation of ovens under negative pressure
• supply of air directly into the oven chambers
• complete combustion of crude gas in each single oven
• no by-products or aqueous effluents.

![Diagram showing heat recovery and coke oven gas recovery](image)

**Figure 5.14:** Most essential features of the heat recovery technique in contrast to conventional coke making

Only about 6% of worldwide cokemaking capacities (approx. 556 m tonnes coke yearly), which were totally installed in 2005, are operated as heat recovery plants. The relevant plants are located in the US, South America, Asia and Australia. The heat recovery plant in Haverhill Ohio, US was commissioned in 2005.

**Achieved environmental benefits**

Table 5.15 gives figures for the emissions from a non-recovery coking plant. The values refer to emissions without the application of an emissions abatement system. At Vansant, Virginia, US, a portion of the flue-gas is scrubbed in a thermal dryer, but the remainder of the ovens operate without flue-gas purification devices.

Because the coke oven operates at sub-atmospheric pressure, emissions from the doors during the coking operation are negligible. Emissions from charging and pushing are given in Table 5.15. Note that the two existing batteries where this information comes from are not equipped with dedusting facilities during charging and pushing.
Chapter 5

### Component Value Charging Pushing Unit

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
<th>Charging</th>
<th>Pushing</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particulate matter</td>
<td>1960</td>
<td>7.35</td>
<td>276</td>
<td>g/t coke</td>
</tr>
<tr>
<td>SO₂</td>
<td>7000</td>
<td></td>
<td></td>
<td>g/t coke</td>
</tr>
<tr>
<td>NOₓ</td>
<td>380</td>
<td></td>
<td></td>
<td>g/t coke</td>
</tr>
<tr>
<td>CO</td>
<td>77</td>
<td></td>
<td></td>
<td>g/t coke</td>
</tr>
<tr>
<td>Benzene soluble organics</td>
<td>Not detected</td>
<td></td>
<td>0.65</td>
<td>g/t coke</td>
</tr>
<tr>
<td>Benzo(a)pyrene</td>
<td>1.3⋅10⁻⁵</td>
<td>Not detected</td>
<td></td>
<td>g/t coke</td>
</tr>
</tbody>
</table>

* Based on EPA-US emission factors calculated from g/t coal, based on assumption: 1 tonne coal yields 0.78 tonnes coke (see Section 5.1.2.3)

Table 5.15: Emissions from non-recovery coking without emissions abatement [74]

A precondition for an environmentally friendly operation of the heat recovery technique is the utilisation of waste gas heat and of an emissions abatement system (desulphurisation) for cleaning the off-gas.

NOₓ emissions can exceed typical emissions from stagewise combustion applied during conventional battery heating.

Because the coke oven operates under negative pressure, fugitive emissions from the doors caused by leakages during the coking operation are negligible. Thus, emissions with carcinogenic substances (e.g. benzo(a)pyrene) can almost be avoided. Emissions of both particulates and benzo(a)pyrene can occur during coal charging.

Improved emissions controls can be achieved by modified suction via the oven or by additional suction facilities at the pusher side including a dedusting system. Generally, particulate emissions from coke pushing are lower than those from horizontal chamber coking because of the lower height from which the coke is plunged from the flatbed down into the quench car. To capture remaining particulate emissions, a hood combined with relevant suction devices and a dedusting system are installed at the coke side.

**Cross-media effects**

A disadvantage of heat recovery coking is the large area occupied by the ovens, due to their flatbed design in comparison to conventional coke making systems.

Partial combustion of the coal during coking results in a smaller output of blast furnace coke.

The heat recovery technique can use lower quality coals, that means also cheaper coals, including weak coking coals and swelling coals for producing coke equivalent in quality to that produced in a conventional plant.

**Operational data**

The heat recovery plant at Indiana Harbor, US started operation in 1998. The reported data on operational experience are sufficient, and include consideration of environmental related aspects. Problems were reported on soot depositions in the waste gas boilers when the coke gas is not sufficiently combusted. Emissions during charging were also typical for the first time of operation, at least, due to the insufficient control of emissions during that period. Because of the negative pressure during carbonisation, visible emissions from the doors are negligible.

High quality coke can be produced by the heat recovery process using a wide variety of coals including those that producing a high swelling pressure. Coke qualities are comparable with those produced by the horizontal chamber coking technique. An additional improvement in coke quality can be achieved by compacting the charging coal.
Applicability
Only applicable as a whole new plant concept depending on the conditions at the operational site.

The decision for the construction of a heat recovery plant depends also on the site. It seems to be difficult to achieve an economically profitable energy link when integrating a heat recovery coking plant into an existing steelworks. A heat recovery plant generates no COG that can be used for heating so there must be consumers for the generated steam or electricity on-site.

Economics
Data are only available from the constructor/operator of the. Based on the information for the heat recovery plant in Indiana Harbor, US, the investment costs for a greenfield heat recovery plant producing 1.2 million tonnes coke per year was USD 365 million including the coke oven facilities, coal handling/blending and the power plant in 1998. For the energy facility, investment costs of only USD 140 million are reported for 1998.

Operational costs are generally lower compared to conventional coking. The main arguments are lower labour requirements and the chance to use lower quality input coals, that means cheaper coals.

Driving force for implementation
No data submitted.

Example plants
There are no heat recovery coking plants in operation or planned in Europe. Several plants are in operation in the US and China.

Reference literature
[200] [320] [463] [464] [465] [466]

5.3.12 Emissions reduction at coke oven firing
Firing a gaseous fuel in the heating chambers provides the heat for the coking process. Heat is transferred to the coke oven chamber by heat conduction through the refractory brick wall. A higher temperature in the oven chamber gives in a shorter coking time. The most important pollutants from coke oven firing are NOX, SO2 and particulate matter. Emissions reduction at the coke oven firing comprises a good maintenance of the brickwork as well as primary and secondary reduction measures for each pollutant.

5.3.12.1 Minimising leakage between coke oven chambers and heating chambers
Description
By performing systematic continuous maintenance of the coke oven, in accordance with the description given in Section 5.3.3, leakage through the brickwork can be avoided to a large extent. Leaks through cracks in the brickwork allow COG to reach the flue-gas from coke oven firing. This causes additional emissions of SO2, particulate matter and hydrocarbons. The presence of cracks is easily detectable by the visible black smoke emissions from the coke oven stack during firing. However, it is not easy to identify which coke oven chamber is leaking. The most common technique used to locate cracks is to observe the two heating walls after pushing and to look inside the heating flues immediately after charging. The position of the cracks is revealed by flames appearing in the flues.
Because of cracks in the walls, particulate emissions will often increase with the operation time and exceed 10 mg/Nm³. By monitoring the amount of soot in the gas vented through the stack, coke oven personnel are able to identify any pattern in black emissions from the stacks and relate the emissions to the particular ovens being charged. They are able to manage the cokemaking process to reduce leakage between the oven and the heating wall.

Once the problem is identified, cracks, holes and other damage to the surface of the refractory brickwork can be efficiently repaired by oxythermic welding, silicon welding, and by wet or dry spraying with refractory cement. In some extreme cases it may be necessary to renew the brickwork.

**Achieved environmental benefits**
Usually the particulate stack emissions are below 10 mg/Nm³. Emissions can be reduced to nearly zero when the spraying is properly applied and the occurrence of cracks is monitored. The quality and condition of the coke oven refractory walls are also very important in this respect.

**Cross-media effects**
No data submitted.

**Operational data**
No data submitted.

**Applicability**
This technique can only be used at existing plants.

**Economics**
No data submitted.

**Driving force for implementation**
No data submitted.

**Example plants**
Many plants in the EU.

**Reference literature**
[33] [65] [130] [215] [320] [338] [407]

### 5.3.12.2 Reduction of NOₓ by primary measures

**Description**
The case of NOₓ is somewhat more complicate. The NOₓ generated consists almost entirely of thermal NOₓ, which is formed by the reaction between N₂ and O₂ in the flame. Thermal NOₓ formation is strongly related to peak temperatures and O₂ concentrations in the flame. Indirectly, NOₓ emissions are also related to the fuel (enriched blast furnace gas or COG) and to the type of coal used, the specific charge weight of the coal, the coking time and the dimensions of the coke oven chamber.

The most effective way of reducing NOₓ formation is to reduce the flame temperature in the heating chamber. The aim is therefore to burn with a cool flame. Three methods have shown to be effective:
• waste gas recirculation: the waste gas from the coke oven is admixed with fuel and combustion air. The lower O$_2$ and higher CO$_2$ concentrations reduce the flame temperature. However, the preheat effect of waste gas recirculation may counteract the temperature reducing effect.

• staged air combustion: by adding the combustion air in several stages, combustion conditions become more moderate, and NO$_X$ formation is reduced.

• lower coking temperatures: these have an influence on economics and the energy efficiency of the coke ovens. A lower coking temperature requires a lower heating chamber temperature, which results in less NO$_X$ formation.

Furthermore, the heating chamber temperature (and thus NO$_X$ formation) can be reduced while a normal coking temperature is maintained by decreasing the temperature gradient over the refractory brick wall from the heating chamber side to the coke oven chamber side. This can be done by using thinner bricks and a refractory with a better thermal conductivity. Formerly, a heating chamber temperature of 1320 °C would lead to a coke oven chamber temperature of 1180 °C. Nowadays, a coke oven chamber temperature of 1200 °C is achieved at the same heating chamber temperature due to thinner bricks.

**Achieved environmental benefits**

Staged air heating in combination with internal waste gas recirculation generates a long and 'cool' flame which is a precondition for minimising NO$_X$ concentrations in the waste gas. Plants which have implemented process-integrated deNO$_X$ measures emit about 340 g NO$_X$/t coke (concentrations: 322 - 414 mg/Nm$^3$ at 5 % O$_2$).

Emissions shown by several German plants are in the following ranges:

• fired with mixed gas: NO$_X$ concentration is 322 - 358 mg/Nm$^3$
• fired with coke oven gas: NO$_X$ concentration is 332 - 414 mg/Nm$^3$.

**Cross-media effects**

When the cooling capacity of the crude gas coolers is increased to improve desulphurisation efficiency, the energy consumption increases and possible thermal emissions are increased. No cross-media effects have been identified as a result of lowering NO$_X$ emissions from coke oven firing.

**Operational data**

No data submitted.

**Applicability**

Process-integrated de-NO$_X$ measures are applicable in new plants. Lowering the temperature in an existing plant will result in longer coking time and operation below nominal capacity.

The use of thinner bricks and refractory with a better thermal conductivity can only be applied in new plants.

**Economics**

No data submitted.

**Driving force for implementation**

No data submitted.
Example plants
Newly built or renovated plants are equipped with low-NO\textsubscript{X} firing systems. For example:

- coke oven Hütt enwerke Krupp Mannesmann, Duisburg-Hucking en, Germany
- coke oven Prosper, Bottrop, Germany
- coke oven plant KBS, Schwelgern-Duisburg, Germany
- coke plant B3, ArcelorMittal, Fos sur Mer, France
- coke plant ArcelorMittal, Seremange, France
- coke plant 2, Battery ACo, Corus, Scunthorpe, United Kingdom
- coke plant, ArcelorMittal, Gent, Belgium.

Reference literature
[33] [130] [320] [333] [423] [253]

5.3.12.3 Reduction of NO\textsubscript{X} by secondary measures

Description
NO\textsubscript{X} emissions from coke oven firing are preferably minimised by process-integrated measures, but end-of-pipe techniques may also be applied.

In the SCR process, NO\textsubscript{X} in the flue-gas is catalytically reduced by ammonia (NH\textsubscript{3}) to N\textsubscript{2} and H\textsubscript{2}O. Vanadium pentoxide (V\textsubscript{2}O\textsubscript{5}) or tungsten oxide (WO\textsubscript{3}) on a titanium oxide (TiO\textsubscript{2}) carrier are often used as catalysts. Other possible catalysts are iron oxide and platinum. Optimal operating temperatures are in the 300 to 400 °C range. Such high temperatures decrease the energy recovery in the regenerators (180 - 250 °C is optimum) of the coke ovens or necessitate additional heating of the waste gas.

Special attention should be paid to the deactivation of the catalyst, the accumulation of the explosive ammonium nitrate (NH\textsubscript{4}NO\textsubscript{3}), the ammonia slip and the formation of corrosive SO\textsubscript{3}.

Achieved environmental benefits
A deNO\textsubscript{X} efficiency of 90 % can be achieved. There is not much experience in the sustainability regarding use in coke oven plants.

Cross-media effects
An increase in energy consumption and ammonia consumption occurs. Part of the catalyst has to be deposited when it is not effective any more.

Operational data
In 1976, an SCR was commissioned at Kawasaki Steel Chiba Works, Japan to treat the waste gas from coke oven firing. The SCR had a capacity of 500000 Nm\textsuperscript{3}/h. The operation temperature was 240 °C and the reduction medium is ammonia (NH\textsubscript{3}). DeNO\textsubscript{X} efficiency is 90 %. The formation of ammonium sulphate and accumulation of dust meant the catalyst had to be regenerated once a day by heating the waste gases to >260 °C.

In 1992, the SCR was taken out of operation with the closing down of batteries 2 to 4.

Applicability
SCR is only applicable to new plants.

Economics
- investments: EUR 47 million in 1976
- operational costs: Not available
The following costs have been reported for SCR in general: investment costs of EUR 50/\text{Nm}^3/\text{h} \pm 30\% in 1996. Thus, for a coke oven plant with a battery flue-gas flow of 300000 \text{Nm}^3/h and a production of 1 Mt coke per year this would lead to:

- investment: EUR 15 million \pm 5 million in 1996
- operational: EUR 0.17 - 0.51/t coke in 1996.

Example plants
DeNO\textsubscript{X} of waste gas from coke oven firing is only applied in one case worldwide: Coke oven battery 2, 3 and 6, Kawasaki Steelworks, Chiba, Japan.

Reference literature
[65] [339] [423]

5.3.12.4 Reduction of SO\textsubscript{2} by coke oven gas desulphurisation

Description
The level of SO\textsubscript{2} emissions is strongly related to the sulphur content of the fuel. Thus, emissions of SO\textsubscript{2} can be minimised by minimising the sulphur content of the fuel. Usually, (enriched) blast furnace gas or coke oven gas is used to fire the coke oven. The sulphur content of the coke oven gas depends on the desulphurisation performance of the coke oven gas treatment plant. The H\textsubscript{2}S content in the treated coke oven gas may vary from around 1 to 1000 mg/Nm\textsuperscript{3}, depending on the used type of desulphurisation process and the corresponding efficiency. If no desulphurisation is applied (which is still the case at some plants in the EU) the H\textsubscript{2}S content can be as high as 8000 mg H\textsubscript{2}S/Nm\textsuperscript{3}. Enriched blast furnace gas has a lower sulphur content.

Emissions of particulate matter may be significantly increased and SO\textsubscript{2} emissions may also increase when crude coke oven gas from the oven chambers leaks through cracks in the heating walls and is combusted together with the heating fuel. In parallel, particulate matter will be formed by the incomplete combustion of COG as well as of the used underfiring gas. If that occurs, particulate emissions (black smoke) can be visually detected at the battery stack. Particulate emissions will also occur when the underfiring gas contains particulate matter.

Unpurified COG is not suitable for use in many industrial applications due to its H\textsubscript{2}S content (up to 12 g/Nm\textsuperscript{3}). When the gas has been desulphurised, however, its use for a variety of applications becomes viable. Many plants sell coke oven gas after desulphurisation at a profit. Desulphurisation for commercial reasons coincides with the need to protect the environment from the effect of "acid rain", because desulphurised coke oven gas decreases SO\textsubscript{2} emissions at the site of coke oven gas combustion. In many cases, sulphur is removed in two stages: a low pressure stage and a high pressure stage. COG desulphurisation is becoming increasingly common in the EU-27.

Coke oven gas also contains a variety of organic sulphur compounds such as carbon disulphide (CS\textsubscript{2}), carbon oxysulphide (COS), mercaptans, etc. (approximately 0.5 g/Nm\textsuperscript{3} total). However, there is only limited knowledge so far about recovering organic sulphur compounds from coke oven gas.

As described in Section 5.1.4.4, there are two main types of coke oven gas desulphurisation processes: wet oxidative processes and absorptive processes. The absorptive processes combine H\textsubscript{2}S removal and processing with ammonia (NH\textsubscript{3}) removal and processing. Table 5.16 lists the different processes and their characteristics.
## Wet oxidative processes

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stretford</td>
<td>H₂S is scrubbed from the coke oven gas by a sodium carbonate solution (Na₂CO₃) and elemental sulphur (S⁰) is yielded using vanadate (VO₃⁻) as an intermediate. Regeneration of the scrubbing liquid takes place by aeration (O₂), using anthraquinone disulphonic acid (ADA) as an intermediate.</td>
<td>Carl Still, Diamex, Claus process or ASK*</td>
<td>H₂S is scrubbed from the coke oven gas by a NH₃ solution. The NH₃ solution is derived from the NH₃ scrubber. The H₂S and NH₃ are stripped from the washing liquor by steam stripping and the vapours are led to a Claus plant or a sulphuric acid plant.</td>
</tr>
<tr>
<td>Takahax</td>
<td>Similar to the Stretford process, except that 1,4-naphthoquinone-2-sulphonic acid is used as an intermediate for the regeneration.</td>
<td>Vacuum carbonate</td>
<td>H₂S (and also HCN and CO₂) is scrubbed from the COG with a sodium carbonate solution or a potassium carbonate solution (Na₂CO₃ or K₂CO₃). The potassium variant allows higher carbonate concentrations. The washing liquor is regenerated in a column, using high temperature and low pressure (0.12 - 0.14 bar). Acid gases are stripped from the liquor and can be treated in a Claus plant or a sulphuric acid plant.</td>
</tr>
<tr>
<td>Thylox</td>
<td>Sodium thioarsenate (Na₄As₂S₅O₂) binds the H₂S and regeneration is done by oxygen treatment. Elemental sulphur is yielded.</td>
<td>Sulfiban</td>
<td>Coke oven gas is scrubbed with monoethanolamine (MEA). NH₃ removal prior to H₂S removal is necessary to avoid pollution of the washing liquor. H₂S is stripped from the MEA solution using steam and can be treated in a Claus plant or a sulphuric acid plant. Insoluble organic S compounds are removed from the MEA solution as solid waste.</td>
</tr>
<tr>
<td>Perox</td>
<td>The gas is scrubbed with an ammonia solution. Parabenzquinone is used for sulphur oxidation and regeneration of the scrubbing liquor is done by oxygen.</td>
<td>DESULF</td>
<td>Virtually the same as the ASK process, but the NH₃ is removed from the NH₃/H₂S vapour in saturators, producing ammonium sulphate ((NH₄)₂SO₄).</td>
</tr>
<tr>
<td>Fumaks-Rhodacs</td>
<td>H₂S is oxidised by picric acid in the Fumaks-phase, yielding elemental sulphur. Cyanides are recovered in the Rhodacs phase.</td>
<td>Oxy-Claus process</td>
<td>This technique is the same as Claus process but air is replaced by oxygen. NH₃ is first removed by heat cracking (1450 °C) of the coke oven ammonia steams. H₂S is then removed by a pure oxygen treatment (Oxy-Claus) which yields liquid sulphur.</td>
</tr>
</tbody>
</table>

*ASK: Ammoniumsulphide Kreislaufwäscher

### Table 5.16: Coke oven gas desulphurisation processes and their characteristics

[21] [153] [242] [415] [416]

In Europe, the most commonly used process is the absorptive process using an ammonia liquor to scrub the H₂S from the coke oven gas (Carl Still, Diamex or Ammoniumsulphide Kreislaufwäscher (ASK) process). Figure 5.15 shows an example of the ASK process which was installed in 1997.
Figure 5.15: Flow diagram of a COG desulphurisation plant with ASK process installed in 1997 [200]
The most commonly applied wet oxidative process is the "Stretford" process. The Stretford process is applicable in a wide range of desulphurisation capacities. Reported coke oven gas desulphurisation design capacities range from 400 to 110000 Nm³/h.

More information on the sulphuric acid plants can be found in the BREF on Large Volume Inorganic Chemicals [484].

**Achieved environmental benefits**

Wet oxidative processes have a better desulphurisation efficiency than absorptive processes. Wet oxidative processes can have an efficiency of >99.9 %, achieving residual H₂S concentrations as low as 1 mg/Nm³ in the coke oven gas. Absorptive processes do not usually exceed 95 % desulphurisation efficiency and residual H₂S concentrations in the coke oven gas are usually between 500 - 1000 mg/Nm³.

None of the available techniques remove organic sulphur compounds with a high efficiency. In the low pressure stage of gas cleaning, organic sulphur compounds are only reduced from 0.5 g/Nm³ to 0.2 - 0.3 g/Nm³.

In total, the residual sulphur content of the treated coke oven gas should be below 0.8 g/Nm³.

In the optimised Oxy-Claus process, an NH₃ and H₂S reduction efficiency of 99.9 % can be achieved. This technique increases desulphurisation of up to 50 % more than traditional techniques.

Coke oven underfiring emissions shown by several German plants are in the following ranges:

- fired with mixed gas + coke gas desulphuration: SO₂ concentration 111 - 157 mg/Nm³
- fired with coke oven gas + coke gas desulphuration: SO₂ concentration 118 - 128 mg/Nm³.

**Cross-media effects**

Any wet oxidative process used for desulphurising coke oven gas will remove most of the hydrogen cyanide from the coke oven gas as well and form sodium thiocyanate by the following reaction:

$$2 \text{HCN} + \text{Na}_2\text{CO}_3 + 2 \text{S}_0 \rightarrow 2 \text{NaCNS} + \text{H}_2\text{O} + \text{CO}_2$$

The sodium thiocyanate and the small amounts of sodium sulphate and thiosulphate formed by side reactions are not regenerated by the process and build up in the circulating liquor.

It is therefore necessary to purge a liquid stream to prevent salting out of the chemicals. In the case of the Stretford process, this discharge flow contains vanadium compounds, quinone and hydroquinone compounds (from anthraquinone disulphonic acid), thiocyanate and thiosulphate. Discharge of these components is undesirable from an environmental and economic point of view (water pollution and loss of expensive chemicals). Normally this material is recycled via the coal blending.

To reduce chemical consumption, cyanic acid (HCN) can be removed prior to desulphurisation in a pre-washer using a sodium polysulphide or ammonium polysulphide solution. Preremoval of HCN does not reduce the total volume of effluent produced.

For the Oxy-Claus process, energy is needed for cracking but a catalyst is not needed for removing ammonia. NOₓ emissions are also reduced.

On rare occasions, e.g. when the production of COG exceeds the demand for it, the excess of COG should be flared off for safety reasons. The flaring of coke oven gas generates some emissions quantified as 2.4 kg CO/t, 390 kg CO₂/t, 0.05 kg H₂S/t, 0.85 kg heavy hydrocarbons/t and 6.5 kgSO₂/t. The combustion efficiency of the flare should be > 95 %.
Bypass operations can lead to significant emissions. At one of the two coke oven plants of Corus, Ijmuiden, the Netherlands, H₂S is removed from the coke oven gas by the Sulfiban absorptive process using MEA (monoethanol amine). The desulphurisation efficiency of this process is approximately 95%. The H₂S is stripped from the MEA and converted into sulphuric acid. The sulphuric acid plant is out of operation for 3 weeks per year due to maintenance of the MEA stripper (1.5 weeks) and of the sulphuric acid plant (1.5 weeks) itself. During this period raw coke oven gas is added to the fuel gas grid or is used for firing the coke ovens, leading to additional SO₂ emissions of approximately 400 tonnes.

**Operational data**
The Oxy-Claus process has been operational in the coke oven plant of Arcelor Fos, France since 2002. During this time SO₂ emissions have decreased from around 1900 to below 500 g/t coke.

**Applicability**
Coke oven gas desulphurisation of both the wet oxidative and the absorptive type can be applied at new and existing plants. The choice depends on the cleaned coke oven gas specifications, environmental considerations, integration within the gas cleaning plant, etc.

**Economics**
An overview of the economics of the two main types of coke oven gas desulphurisation techniques used in Europe (ASK and Stretford) is given in Table 5.17. It was reported that an increase in desulphurisation efficiency from 95 to 99.9% in the Stretford process only costs 10% extra. In the Stretford process, the most important operational cost items are the capital charges and the chemicals (see Table 5.16). Coke oven gas with high HCN concentrations (>2 g/Nm³) consumes relatively large amounts of chemicals. In this case it might be beneficial to install a HCN prewash before the Stretford unit.

Implementing the gas desulphurisation technique costs around EUR 30 million (capital cost) in a coke oven plant with about a hundred ovens (Arcelor).

<table>
<thead>
<tr>
<th>Costs and efficiency</th>
<th>Unit</th>
<th>Stretford process</th>
<th>ASK process</th>
<th>Vacuum carbonate</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂S removal efficiency</td>
<td>%</td>
<td>95 - 99.5</td>
<td>90 - 97</td>
<td>&gt;90</td>
</tr>
<tr>
<td>Capital costs</td>
<td>EUR million</td>
<td>4.43 - 5.99</td>
<td>n/a</td>
<td>19.3*</td>
</tr>
<tr>
<td>Operating costs:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- chemicals</td>
<td>EUR/1000 Nm³ COG</td>
<td>1.06 - 1.92</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>- electricity</td>
<td></td>
<td>0.46 - 0.60</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>- steam and water</td>
<td></td>
<td>0.12</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>- maintenance</td>
<td></td>
<td>0.3 - 0.4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>- labour</td>
<td></td>
<td>0.5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>- capital charges</td>
<td></td>
<td>2.9 - 4.0</td>
<td>n/a</td>
<td>1.90</td>
</tr>
<tr>
<td>- gross costs</td>
<td></td>
<td>5.8 - 7.3</td>
<td>n/a</td>
<td>2.38</td>
</tr>
<tr>
<td>Sulphur credit</td>
<td></td>
<td>0.4 - 0.7</td>
<td>n/a</td>
<td>0.48</td>
</tr>
<tr>
<td>Total net cost</td>
<td></td>
<td>5.1 - 6.9</td>
<td>n/a</td>
<td>1.90</td>
</tr>
</tbody>
</table>

* including sulphuric acid plants and calculated from a case with 30000 Nm³/h and 6 g H₂S/Nm³

Table 5.17: Typical operating and capital costs for the desulphurisation of 45000 Nm³/h coke oven gas containing 8 g/Nm³ H₂S

[65] [118] [320]

The cost of replacing an ammonia steam incineration plant by an Oxy-Claus desulphurisation plant was around EUR 12 million for a 1.5 Mt/yr coke oven plant.

**Driving force for implementation**
No data submitted.
## Example plants

Table 5.18 gives an overview of example plants (not exhaustive).

<table>
<thead>
<tr>
<th>Wet oxidative</th>
<th></th>
</tr>
</thead>
</table>
| **Stretford** | ArcelorMittal, Hamilton, Canada  
British Steel, Orgreave, United Kingdom  
British Steel, Redcar, United Kingdom  
Metarom, Romania  
Erdemir, Turkey  
ArcelorMittal, Lorraine, France  
Kobe Steel, Kakogawa Works, Japan  
Posco, Korea |
| **Takahax** | Nippon Steel, Yawata Works, Japan  
Nippon Steel, Nagoya Works, Japan  
Nippon Steel, Hirohata Works, Japan  
Nippon Steel, Oita Works, Japan  
Nippon Steel, Muroran Works, Japan  
Nippon Kokan, Fukuyama Works, Japan  
Nippon Kokan, Keihin Works, Japan |
| **Fumax** | Nippon Steel, Kimitsu Works, Japan  
Sumitomo Metal Industries, Wakayama Works, Japan  
Sumitomo Metal Industries, Kashima Works, Japan  
Kawasaki Steel, Chiba Works, Japan |
| **Thylox** | Not available |

<table>
<thead>
<tr>
<th>Absorptive processes</th>
<th></th>
</tr>
</thead>
</table>
| **Carl Still or Diamex or ASK** | Prosper, Bottrop, Germany  
Coke oven KBS, Duisburg-Schwelgern, Germany  
ZKS, Dillingen, Germany  
Kawasaki Steel, Mizushima Works, Japan  
Coke oven No.2, Corus, IJmuiden, the Netherlands  
Coke oven of Sidmar, Gent, Belgium  
Voestalpine, Linz, Austria  
Riva, Taranto, Italy |
| **Sulfiban** | Coke oven No.1, Corus, IJmuiden, the Netherlands  
Nippon Kokan, Keihin Works, Japan |
| **Oxy-Claus** | ArcelorMittal, Fos, France  
ArcelorMittal, Dunkerque, France |

**Table 5.18:** Table of reference plants for coke oven gas desulphurisation processes  
[65] [415]

**Reference literature**

[33] [65] [118] [223] [242] [297] [320] [412] [415] [416] [424]
5.3.13 **Emission reduction during coke pushing**

**Description**
Several techniques have been developed for minimising coke side particulate matter emissions from coke pushing:

- coke side sheds, including evacuation and dedusting. The particulate matter is evacuated by means of a coke side shed and dedusted in a bag filter
- container car. The coke is pressed directly from the coke oven chamber into a container car. The coke does not make contact with oxygen and only small amounts of particulate matter are generated. Usually applied in combination with coke dry quenching
- coke transfer machine with (integrated) hood, stationary duct and stationary gas cleaning, preferably by bag filtration (see Figure 5.16), so-called 'Minister Stein System'. During the whole pushing process, the quenching car is to be positioned in the catchment area of the dedusting collection system (use of a one-point or a mobile quenching car with (integrated) hoods on the coke transfer machine)
- maintaining a sufficient coking time, homogeneous heating and optimal charging heat are important in order to avoid 'green pushes'.

![Figure 5.16: Example for a dedusting system for dust from coke pushing](image)

[200]
Achieved environmental benefits
Particulate matter emissions without abatement are about 500 g/t coke. Of the four techniques mentioned above, the 'Minister Stein System' gives the best performance, achieving >99% collection efficiency, combined with good working conditions for operators (in contrast to coke side sheds). Emissions factors (at the stack) of below 5 g particulate matter/t coke can be achieved.

The air extraction capacity is often in the order of 200000 Nm$^3$/h in plants using the Minister Stein System but is dependent on chamber size. A bag filter is used to minimise particulate emissions.

At existing plants, a particulate matter collection rate of >99% is also achievable. A particulate matter concentration in the exhaust air of <30 mg/Nm$^3$ can be achieved. The system is also based on evacuation through a stationary duct.

In one case for a bag filter in coke pushing particulate matter emissions were reported to be 0.9 mg/Nm$^3$ as an annual average and 1.5 mg/Nm$^3$ for the 95 percentile (reference time period half hourly mean).

Cross-media effects
The operation of a dedusting device requires energy to drive the fans for air evacuation. The collected solids can be recycled back into the process.

Operational data
No data submitted.

Applicability
Coke side dedusting is applicable both at new and existing plants. At existing plants, a site-specific solution may have to be engineered. Sometimes lack of space at the plant is a constraint.

Economics
No data submitted.

Driving force for implementation
No data submitted.

Example plants
The 'Minister Stein System' is operational at the following plants:

- coke oven, United States Steel, Clairton Works, Pittsburgh, PA, US
- coke oven battery at ArcelorMittal, Gent, Belgium
- coke oven ArcelorMittal, Dunkerque, France
- coke oven ArcelorMittal, Fos sur Mer, France
- coke oven ArcelorMittal, Seremange, France
- coke oven Mannesmann Hüttenwerke Krupp, Duisburg-Huckingen, Germany
- coke oven Prosper, Bottrop, Germany
- coke oven 1, Corus, Ijmuiden, the Netherlands
- coke oven 2, Corus, Ijmuiden, the Netherlands
- Knsai Coke and Chemicals, Kakogawa, Japan
- coke oven plant voestalpine, Linz, Austria.

Reference literature
[33] [65] [223] [227] [253] [320] [407] [423]
5.3.14 Coke dry quenching (CDQ)

Description
Figure 5.17 shows a scheme of a CDQ plant design consisting of the shaft-like cooling unit, the waste heat boiler and the gas recycling system.

A coke dry quenching (CDQ) plant consists of two or more quenching chambers and their associated waste heat boilers and charging cranes as combined units. Coke is cooled in these chambers by means of circulation gas. The circulation gas is a mixture consisting mainly of nitrogen and other inert gases. This mixture is formed when the oxygen burns out during the start-up stage of the cycle. The temperature of the circulation gas after the chamber is about 780 °C and after the waste heat boiler about 150 °C. The temperature of the coke charged to the dry quenching chamber is about 1050 °C and after the chamber, about 180 °C. The coke flows through the chamber in about 5 hours. The nominal capacity of a typical CDQ plant is less than 100 t/h/chamber. A unit working at full capacity produces about 25 t/h high pressure steam (93 bar). Coke is transported with belt conveyors from the CDQ plant to the blast furnace coke screening station.

Achieved environmental benefits
The environmental advantages of CDQ are energy recovery and good environmental performance (reduction emissions of dust, carbon monoxide and hydrogen sulphide). There is also no significant difference in CO emissions because of the exclusion of excess gas from the gas circuit.

A modern CDQ is equipped with charging and discharging dust collecting systems and boilers with primary and secondary dust collectors. During final collecting by bag filters, emission factors of dust of less than 3 g/t coke are achievable, corresponding to less than 20 mg/Nm³. SO₂ emissions are at a level of 200 mg/Nm³. Emissions to surface water are close to zero. Collected coke dust is supplied as fuel to the sinter plant.

With CDQ, about 0.5 tonne steam/t coke can be recovered and used for electricity production. Dust emissions from dry coke handling and sieving can make it necessary to install an additional cooling step or to use water to obtain a moisture content of 1 %. Steam (93 bar) production is approximately 470000 t/yr and steam (8 bar) production is approximately 50000 t/yr. 93 bar steam is used mainly in Raahe Steel Plant’s power plant which means approximately 15 MW electricity output per year.
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Emissions into water are close to zero. PAH and COD values are marginal. No dusty quenching steam clouds are released to the atmosphere.

Cross-media effects
The H2O content of the coke is lower compared to wet quenching which could be a benefit in the blast furnace. The handling of dry quenched coke can cause more dust emissions than the handling of wet quenched coke. The electrical power consumption of fans, operation of various dedusting devices, etc. is not negligible. However, net energy output will be rather positive, due to the recovery of waste heat which is usually transferred into the electrical power.

Operational data
This system has a high availability of approx. 97%. Maintenance is usually carried out during the periodic maintenance of the coke ovens. Only a little additional maintenance time is required.

The moisture content of coke is approximately 0.05% compared to that of wet quenched coke which is approximately 2-5%. Therefore coke is more applicable and its quality is more uniform for blast furnace operation and the handling/preparation costs of dry coke are lower particularly during winter conditions. In addition, the strength of the coke is 1.5 to 2 times higher in terms of drum index 150/15 than water quenched coke due to the fact that shocked cracks do not occur because the coke is not rapidly cooled by wet quenching. This leads to an improved coke ratio, PCI ratio and higher productivity of the blast furnace.

Applicability
CDQ can be applied at new and existing plants. For the continuous operation of CDQ plants, there are two options. In one case, the CDQ unit comprises two up to four chambers. One unit is always on stand by. Hence no wet quenching is necessary but the CDQ unit needs an excess capacity against the coke oven plant with high costs. In the other case, an additional wet quenching system is necessary. For retrofitting wet quenching plants, the existing wet quenching system can be used. Such a CDQ has no excess processing capacity against the coke oven plant.

Economics
Investment costs of a CDQ with an annual processing capacity of 2 million tonnes coke is approx. EUR 100 million. The equipment costs are generally expected to be EUR 70 million, although it depends on the site conditions, scope, specifications and market conditions of materials etc. CDQ with an annual coke processing capacity of 2 million tonnes can generate approx. 320000 MW by 100% steam utilisation. This means that the payback period of investment is roughly 3 years depending on the electricity prices.

Driving force for implementation
Environmental reasons, stability of the coke quality (mainly related to moisture content) and energy efficiency,

Example plants
By March 2008 the number of CDQ plants (chambers) in operation was: 104 in East Asia, 12 in Central Asia, five in South America and 21 in Europe. From the latter, five are in Hungary, three in Finland, four in Poland, four in Rumania and five are in Turkey.

Reference literature
[207] [208] [227] [320] [334] [423] [424] [439]
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5.3.15 Coke wet quenching (CWQ)

Coke wet quenching can be performed by conventional wet quenching or by the more advanced coke stabilisation quenching.

5.3.15.1 Conventional wet quenching

Description
When coke is quenched with water in the quenching tower, particulate matter and water mist are generated by the evaporation of quenching water from the glowing coke and emitted with the plumes. The quantities of entrained particulate matter depends on the operating conditions, coke properties and the type of water addition. Attempts have been made to reduce particulate matter and water vapour emissions by means of constructional and other measures; for example, by spraying the plume with water.

Optimum solutions to reduce the emissions of particulate matter include the use of lamella stack baffles and favourable designs of the quenching tower (see Figure 5.18).

In addition, swamp top quenching can be applied as a modification to quench the coke with water. The water is partly injected through a piping system at the bottom of the quenching car (drowning the coke) and partly sprayed on the top of the coke (whereas, in most wet quenching systems, the water is only sprayed on the top of the coke). Nevertheless, the quenching tower itself is the same as for top quenching with the same dust arrestment device (see Figure 5.18). One disadvantage of swamp quenching are the emissions of pieces of coke from the quenching car due to the 'explosive' formation of steam under and inside the coke mass in the quenching car, especially when operating with high coke levels. Quench water is re-used.

The dust-catching equipment consists of individual frames in which the louvre-shaped plastic lamellae are installed. Quenching towers are made of wood and concrete.

Quenching towers are in use, e.g. every 15 minutes. In order to reduce emissions, a restricted number of hours per month (e.g. 4 hours) are scheduled for maintenance. Another way to decrease these emissions is to have a standby (second) quenching tower.
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Achieved environmental benefits
Emissions of particulate matter during wet quenching without reduction measures is about 200 - 400 g/t coke. With the system described, these can be reduced to at least 50 g/t coke (with an emissions factor before abatement of maximum 250 g/t coke and a solids content of quenching water below 50 mg/l).

In practice, emissions of less than 25 g/t coke are normally achieved. It must be noted that the emissions depend very much on the measurement method used. The emissions factors quoted were determined by the VDI 2303 method (Guideline for Sampling and Measurement of Dust Emissions from Wet Quenching which has never been implemented but measurements are still carried out in accordance with this guideline which corresponds to VDI 2066. The latter ensures that the sampling is carried out isokinetically which usually results in higher emission values).

Cross-media effects
Additional energy is consumed in water spraying, although this is not significant.

Operational data
There are many quenching towers round the world equipped with emissions reduction baffles. Good operational experience is reported.

Applicability
Wet quenching techniques are applicable at both new and existing plants. Existing quenching towers can be equipped with emissions reduction baffles. A minimum tower height of at least 30 m is necessary in order to ensure sufficient draught conditions.

Figure 5.18: Schematic diagram of a quenching tower with emissions reduction baffles [200]
Economics
The costs for the retrofitting of an existing quenching tower with emissions reduction baffles are in the order of EUR 200000. However retrofitting is only possible if the quenching tower is suitable. Otherwise a new tower must be installed and the costs are much higher.

Driving force for implementation
Normally legal requirements and enforcement by local authorities initiate the retrofitting of existing quenching towers.

Example plants
Examples of built or retrofitted quenching towers with emissions reduction baffles are located at:

- ArcelorMittal, Gent, Belgium
- Hüttenwerke Krupp Mannesmann, Duisburg-Huckingen, Germany
- Coke plant Arcelor Atlantique, Dunkerque, France
- Kokerei Salzgitter AG, Salzgitter, Germany
- UK.

All these plants achieve emissions factors of less than 25 g dust/t coke.

Reference literature
[100] [223] [227] [242] [320] [334]

5.3.15.2 Coke stabilisation quenching (CSQ)

Description
In the given example plant the quenching system is designed for six pushes per hour and a coke quantity of 54 tonnes per push. This system comprises the quenching tower, the quench water settling plant and the quenching car. These towers are bigger than conventional quenching towers (e.g. 16 x 16 x 70 m high). Two emissions control stages consist of baffle plates and water sprays for the quenching vapours which reduce the dust emissions. The special feature of this technique is the simultaneous application of spray and sump quenching.

Achieved environmental benefits
The dust emissions are 6 - 12 g/t of coke. The high quenching rate is an essential process element. It enables a rapid reduction of the coke temperature, a shorter reaction time, less formation of water gas and hydrogen sulphide as well as high mechanical impact and stabilisation of the quenched coke, uniform grain distribution and thus a better coke quality.

It must be noted that the emissions depend very much on the measurement method used. The emissions factors quoted were determined by the VDI 2303 method (Guideline for Sampling and Measurement of Dust Emissions from Wet Quenching which has never been implemented but measurements are still carried out in accordance with this guideline which corresponds to VDI 2066. The latter ensures that the sampling is carried out isokinetically which usually results in higher emission values).

Cross-media effects
No data submitted.

Operational data
The amount of coke breeze produced by this system is higher than in conventional quenching. The specific quenching water demand is 2 m³/t coke of which 1.5 m³ goes to the settling basin as circulated water.
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<table>
<thead>
<tr>
<th>Characteristics of the coke oven batteries</th>
<th>Values</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of coke ovens</td>
<td>140</td>
<td></td>
</tr>
<tr>
<td>Coke oven heating</td>
<td>1300</td>
<td>°C</td>
</tr>
<tr>
<td>Coking duration</td>
<td>25</td>
<td>h</td>
</tr>
<tr>
<td>Coke oven chamber volume</td>
<td>93</td>
<td>m³</td>
</tr>
<tr>
<td>Pushed coke mass (mean value)</td>
<td>56.6</td>
<td>t coke per oven</td>
</tr>
<tr>
<td>Nr of daily coke pushing processes in total</td>
<td>135</td>
<td></td>
</tr>
<tr>
<td>Daily coke production</td>
<td>7600</td>
<td>t</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Characteristics of the CSQ quenching tower</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Quenching method</td>
<td>CSQ (coke stabilising quenching)</td>
<td></td>
</tr>
<tr>
<td>Exhaust area</td>
<td>256 (16 m x 16 m)</td>
<td>m²</td>
</tr>
<tr>
<td>Tower height</td>
<td>70</td>
<td>m</td>
</tr>
<tr>
<td>Quenching water quality</td>
<td>Quenching tower recycling water</td>
<td></td>
</tr>
<tr>
<td>Water consumption per quenching</td>
<td>Total 98</td>
<td>m³</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Measurements over the total measure grid:</th>
<th>Measured dust concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurements from March - April 2004</td>
<td>6, 8, 9 and 12 g/t coke</td>
</tr>
<tr>
<td>Mean average value</td>
<td>9 g/t coke</td>
</tr>
<tr>
<td>Max. value</td>
<td>12 g/t coke</td>
</tr>
</tbody>
</table>

Table 5.19: Dust emissions from a CSQ wet quenching tower [418]

Applicability
As the system is bigger than that necessary for conventional quenching, more space is needed.

Economics
No data submitted.

Driving force for implementation
Lower dust emissions can be achieved.

Example plants
Coke plant KBS, Schwelgern-Duisburg, Germany.

Reference literature
[204] [207] [253] [418]

5.3.16 Emissions reduction in coke handling

Description
The grading process consists of crushing, grinding and sieving and generates particulate emissions which needs to be extracted and require further abatement. The dust emissions concentration as an annual mean after a bag filter has been observed in two plants to be 0.5 and 4.5 mg/Nm³. The handling of dry quenched coke causes more dust emissions than the handling of wet quenched coke. The grading plant building should be kept closed.

For the transport of the coke, enclosed or covered conveyors are used. For the storage of the coke, sprinklers can be used for surface moistening and to suppress dust formation. Windbreak fences or upwind mounds can be applied to lower the wind velocity. The free fall height of the materials should be less than 0.5 m.

Achieved environmental benefits
With bag filters, particulate emissions concentrations of between 0.5 - 4.5 mg/Nm³ can be achieved (annual averages).
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5.3.17 Closed belt conveyors

Description
A means for the transport of goods generating dust, such as fine granular coal or coke, is the pipe conveyor, which protects the environment against all material emissions. Pipe conveyors consist of a flexible conveying belt which is formed by special devices in a sealed pipe. At the beginning – in the material loading area – the belt is open and the coal or coke is supplied as in a normal belt conveyor. This area extends for about 12 m, when the belt is closed and forms a pipe over the entire conveying distance. At the end – about 12 m before the discharging point – the belt opens again. After the discharge, the belt is closed again as it can be seen in Figure 5.19.

![Figure 5.19: Example of the pipe conveyor system](image)

Achieved environmental benefits
The closed structure of the conveying belt prevents the diffuse and fugitive discharge of coal/coke during transport.

Cross-media effects
No data submitted.

Operational data
No data submitted.

Applicability
No data submitted.

Economics
No data submitted.

Driving force for implementation
No data submitted.

Example plants
No data submitted.

Reference literature
[227] [407]
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Cross-media effects
No data submitted.

Operational data
The technical data for a pipe conveyor at a coke oven plant in Germany are:

- diameter: 500 mm
- belt width: 1900 mm
- maximum capacity: 800 t/h
- velocity: 2.09 m/s
- length: 736 m.

Applicability
Pipe conveyors are generally applicable to old and new plants for the transport of goods generating dust such as coke, fine granular coal or sponge iron (DRI).

Economics
No data submitted.

Driving force for implementation
No data submitted.

Example plants
One coke oven plant in Germany.

Reference literature
[417] [419] [422] [435]

5.3.18 Gas-tight operation of the gas treatment plant

Description
In a gas treatment plant, the crude coke oven gas is cleaned in several stages for subsequent use as a fuel. The relatively volatile character of the crude coke oven gas components means emissions can occur at flanges, pressure valves, pumps, etc. Apart from the negative environmental effects, occupational safety considerations are also important as some COG compounds are known carcinogens (e.g. PAH and benzene). The BTX plant incorporated in the coke oven gas treatment plant is particularly important in this respect. In this plant BTX (which mainly consists of benzene, toluene and xylenes) is scrubbed from the coke oven gas by means of a scrubbing liquid. Subsequently, the loaded scrubbing liquid is regenerated and the BTX is recovered and can be sold.

The gas-tight operation of a gas treatment plant is mainly a health and safety issue.

All measures to enable virtually gas-tight operation of the gas treatment plant should be considered:

- minimising the number of flanges by welding piping wherever possible
- using of gas-tight pumps (e.g. magnetic pumps or double sealed pumps)
- avoiding emissions from pressure valves in storage tanks. This is most commonly achieved by connecting the valve outlet to the coke oven gas collecting main (collection of the gases and subsequent combustion or gas blanketing or vent scrubbers could also be possible)
- using special sealings for flanges and valves to prevent air pollution as well as closed processes without emissions such as the Claus process with tail gas recycling or the tar and liquid treatment with tar sludge recycling
• enclosing the tar sludge system. Solid particulates are separated from the raw tar coming from the tar decanter in a gas-tight centrifuge. The centrifuged tar is fed via a receiver vessel to the tar storage tanks. The separated tar sludge from the solid outlet of the centrifuge is collected in a vessel before it is pumped by a high pressure solid pump to the coal weighing hopper inside the coal tower. The charging is interlocked with the flow of the coal, so that a perfect mixture of tar sludge and coal is ensured. If necessary, disposal of the tar sludge into a mobile container is possible.

**Achieved environmental benefits**
No data submitted.

**Cross-media effects**
No cross-media effects occur.

**Operational data**
No data submitted.

**Applicability**
Applicable both at new and existing plants. In new plants, a gas-tight design will probably be easier to achieve than at existing plants.

**Economics**
Part of plant design.

**Driving force for implementation**
No data submitted.

**Example plants**
Voestalpine, Linz, Austria; Corus, IJmuiden, the Netherlands and ArcelorMittal, Gent, Belgium all operate virtually gas-tight treatment plant to treat the coke oven gas.

**Reference literature**
[65] [204] [216] [320]

### 5.3.19 Removing tar (and PAH) from still effluent

**Description**
The ammonia still effluent does not normally contain tar but when it does this tar has an adverse effect on the operation of the biological waste water treatment. In particular, the presence of polycyclic aromatic hydrocarbons (PAH) in the tar may cause problems as the PAH may have a toxic effect on the micro-organisms in the activated sludge and are relatively hard to degrade. Therefore, it is advisable to remove tar from the coal water prior to the biological treatment of the water.

The tar can be removed by adding coagulating chemicals and subsequent separation using a technique such as:

• gravitational sedimentation sometimes followed by filtration
• centrifuging the coal water
• flotation
• sand filtration.

This treatment removes most of the tar from the waste water in the form of a highly concentrated filter cake or sludge. This has to be treated further, e.g. by recycling to the coke ovens.
Chapter 5

Achieved environmental benefits
Effluent concentrations from the wood flour filter are 700 - 800 µg/l (EPA-PAH) at a removal efficiency of 99%. Emissions after the biological treatment are drastically reduced. This would correspond to EPA-PAH emissions of the biological treatment of 150 µg/l in the effluent. The PAH laden wood-flour is recycled to the coke oven.

Cross-media effects
All of these tar removal techniques generate a waste. However, this tar laden waste, including tar decanter sludge, can be recycled into the coke ovens.

Operational data
No data submitted.

Applicability
Removal of tar prior to waste water treatment is applicable both at new and existing plants.

Economics
No data submitted.

Driving force for implementation
No data submitted.

Example plants
- sedimentation and filtration: ACZ de Carbonisation, Sluiskil, the Netherlands
- wood-flour filter: Coke oven, Corus, IJmuiden, the Netherlands.

Reference literature
[65] [320] [340]

5.3.20 Stripping of ammonia from the waste water

Description
Keeping the concentration of ammonia in the stripper and still effluent low benefits the operation of a biological waste water treatment plant. The removal efficiency strongly depends on the alkaline and steam addition and on the design of the stripper (i.e. the number of stages). A larger dose of NaOH and an increase in the number of stages can significantly reduce the ammonia concentration in the effluent.

When plant effluent treatment involves nitrification and subsequent denitrification, ammonia stripping of the effluent is less critical. In this case, an economic and environmental optimum between ammonia stripping and ammonia removal in the biological waste water treatment plant should be found.

Achieved environmental benefits
Effluent ammonia concentrations may vary from 20 to 150 mg/l, depending on steam and alkali dosage and stripper design. Values of between 20 and 40 mg/l are achievable but may not be required because of adjustment of an appropriate balance of BOD₅/P/N ratio in the waste water prior to biological treatment.

Cross-media effects
Strippers consume energy in the form of steam (0.1 - 0.2 t steam/m³ waste water) and consume alkalis (NaOH; 6 - 22 l/m³). Formerly, lime was used instead of NaOH. Higher doses of steam and alkalis lead to lower NH₃ concentrations in the effluent. Furthermore, an ammonia (and H₂S) laden steam is generated, which must be treated, for example in a sulphuric acid plant, a Claus plant, or in ammonium sulphate crystallisation units.
Chapter 5

Operational data
No data submitted.

Applicability
Applicable both at new and existing plants.

Economics
Ammonia stripper, treating 150 m$^3$ effluent per hour:

- investments: EUR 0.75 - 0.9 million in 1993 for the columns
- operational costs: EUR 0.18 EUR/m$^3$ in 1993.

For an ammonia stripper, treating 120 m$^3$ effluent per hour the investment costs were EUR 0.8 million in 2005 as reported for a plant in Spain (Arcelor; Aviles Spain).

Driving force for implementation
No data submitted.

Example plants
Almost all coke oven plants around the world use an ammonia stripper.

Reference literature
[65] [320] [423]

5.3.21 Waste water treatment

The waste water from a coke oven plant contains a mixture of hydrocarbons, cyanide compounds and nitrogen compounds in relatively high concentrations. Several methods are available to treat this waste water. In all cases, the waste water goes through an ammonia stripper before further treatment.

The waste water can be treated biologically and chemically. When biological treatment is applied, tar is often removed by a physico/chemical process and the waste water is often diluted in order to avoid the influents having toxic effects on the micro-organisms, especially the inhibition of nitrifying bacteria.

The most commonly applied biological technique for the treatment of coke oven waste water is the aerobic biological system with activated sludge. In some cases, special attention has been paid to nitrification and (anoxic) denitrification. In some other cases, a biological system based on a fluidised bed is used to treat the waste water.

Description
Techniques included in this section are:

a. Aerobic system with activated sludge:

In an aerobic system with activated sludge, the biodegradable contaminants are mainly biologically degraded to CO$_2$, H$_2$O and minerals and the non-degradable, non-polar components (like most PAH and heavy metals) are removed from the water phase by partial adsorption to the activated sludge.

In practice, most of the potentially hazardous contaminants, such as phenols, cyanides and aromatic hydrocarbons, are biologically degraded and heavy metals are partially removed by adsorption to the activated sludge.
Activated sludge systems with a low food/micro-organism ratio (F/M) are preferred from an environmental point of view. A low F/M ratio enables also biodegradation of heavily biodegradable organic compounds. The F/M ratio is the ratio of organic matter to activated sludge (as mixed-liquor suspended solids (MLSS)) and it is expressed as 'kg COD/kg MLSS/d'; in which COD is the chemical oxygen demand.

Aeration may use oxygen instead of ambient air. This increases process control and reduces "stripping" of volatile components in the waste water. For example, oxygen aeration is used at ArcelorMittal, Gent, Belgium.

b. **Nitrification concept:**

Some waste water treatment plants are designed to remove ammonium (NH\(_4^+\)) efficiently by means of nitrification. The traditional design of an aerobic activated sludge system can be taken as a starting point for this kind of plant. The system should have a very low F/M ratio and a high recirculation rate in order to avoid the slow growing nitrification bacteria being washed out. The nitrification bacteria convert the ammonium into nitrate (NO\(_3^-\)). Under such conditions, heavily biodegradable organic compounds can also be mineralised with high removal efficiency.

c. **Nitrification-denitrification concept:**

In some cases, local authorities have demanded low discharges of all nitrogen compounds (including nitrates) from the effluent. This requires additional anoxic treatment of the waste water. Several plant layouts are possible, but good results have been obtained at waste water treatment plants with the so-called pre-denitrification-nitrification concept (pre-DN/N). Two examples are given below in Figure 5.20 and Figure 5.21.

![Figure 5.20: Typical example of biological waste water treatment with nitrification/denitrification steps](image-url)

In the pre-DN/N concept, the aerobic activated sludge system is also used as a starting point. However, before the waste water is aerated, nitrate-rich water from the nitrification step is added. Under anoxic conditions, bacteria use the nitrate as terminal electron acceptors instead of molecular oxygen (O\(_2\)). The nitrogen is emitted as molecular nitrogen (N\(_2\)). The overall reaction is:

\[
5 \text{C}_{\text{organic}} + 2 \text{H}_2\text{O} + 4 \text{NO}_3^- \rightarrow 2 \text{N}_2 + 4 \text{OH}^- + 5 \text{CO}_2
\]
The waste water treatment plant (WWTP) of Hüttenwerke Krupp Mannesmann in Duisburg, Germany is designed as a multistage biological system, made up of (according to the water flow):

- a heat exchanger to cool down the aqueous effluent from the H₂S/NH₃ stripping column
- an equalisation basin
- an aeration basin (activated sludge process for the degradation of the organic content) with a pre-installed denitrification part first (denitrification) step
- an intermediate clarifier
- a nitrification basin, designed as carrier biology
- a second denitrification, with methanol feed as the external carbon source
- a post-aeration basin, to resaturate the activated sludge
- a final clarifier.

To monitor the quality of the biologically purified waste water, the monitoring and control equipment includes online monitoring to alert the operators of irregular conditions early.

![Diagram of a biological treatment plant](image)

**Figure 5.21: Example of a biological treatment plant**

This plant shows very good results with the purification of coke oven waste water by very low emissions of nitrogen, sulphur and cyanide compounds. Influent and effluent concentrations are given in Table 5.21.

d. Other techniques sometimes also used to remove suspended solids are flotation and sandfilters.

**Achieved environmental benefits**

a. Aerobic system with activated sludge:

Table 5.20 gives the performance figures for aerobic activated sludge systems from European coke oven plants.
Table 5.20: Effluent concentrations and specific emissions from European coke oven plants using aerobic activated sludge waste water treatment

<table>
<thead>
<tr>
<th>Component</th>
<th>Concentration</th>
<th>Unit</th>
<th>Specific emissions value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD</td>
<td>140 - 700</td>
<td>mg/l</td>
<td>0.2 - 1</td>
<td>(kg/t coke)</td>
</tr>
<tr>
<td>TOC</td>
<td>37</td>
<td>mg/l</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N-Kjeldahl</td>
<td>20 - 120</td>
<td>mg/l</td>
<td>0.01 - 0.1</td>
<td>(kg/t coke)</td>
</tr>
<tr>
<td>NH₃</td>
<td>&lt;1 - 100</td>
<td>mg/l</td>
<td>0 - 0.1</td>
<td>(kg/t coke)</td>
</tr>
<tr>
<td>SCN</td>
<td>&lt;0.1 - 35</td>
<td>mg/l</td>
<td>0 - 0.05</td>
<td>(kg/t coke)</td>
</tr>
<tr>
<td>Cyanide</td>
<td>&lt;0.1</td>
<td>mg/l</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phenol</td>
<td>&lt;0.1 - 10</td>
<td>mg/l</td>
<td>0 - 0.005</td>
<td>(kg/t coke)</td>
</tr>
<tr>
<td>PAH</td>
<td>0.003 - 0.2</td>
<td>mg/l</td>
<td>0 - 0.001</td>
<td>(kg/t coke)</td>
</tr>
</tbody>
</table>

b. Nitrification:
Generally, systems with a low specific load give a better performance and allow the degradation of ammonia by means of nitrification. A low specific load also enhances the degradation of organic compounds with a low degradation rate. If nitrification is applied, the effluent nitrate (NO₃⁻) concentrations will be relatively high (in the order of 200 mg/l).

c. Nitrification-denitrification concept:
Nitrification-denitrification systems have a very low F/M ratio (0.05 - 0.2 kg COD/kg MLSS/d) and achieve very good results in cleaning coke oven waste water. Nitrogen emissions from these system are especially low compared to systems with high F/M ratios or with nitrification alone. Influent and effluent concentrations at four of these plants are given in Table 5.21.
Table 5.21: Influent and effluent concentrations and some aspects of waste water treatment systems with the pre-DN/N system

<table>
<thead>
<tr>
<th>Aspect/component</th>
<th>Unit</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effluent:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td>7.7</td>
<td>n/a</td>
<td>7.6</td>
<td>8.1±0.3</td>
</tr>
<tr>
<td>Suspended solids</td>
<td>mg/l</td>
<td>42</td>
<td>n/a</td>
<td>75</td>
<td>n/a</td>
</tr>
<tr>
<td>COD</td>
<td>mg/l</td>
<td>189±30</td>
<td>486±315</td>
<td>213±70</td>
<td>74±10</td>
</tr>
<tr>
<td>TOC</td>
<td>mg/l</td>
<td>n/a</td>
<td>n/a</td>
<td>45±16</td>
<td>n/a</td>
</tr>
<tr>
<td>BOD5</td>
<td>mg/l</td>
<td>8.1±2.3</td>
<td>19</td>
<td>15±5</td>
<td>4.8±1.7</td>
</tr>
<tr>
<td>Phenol</td>
<td>mg/l</td>
<td>0.06</td>
<td>&lt;2</td>
<td>&lt;0.1</td>
<td>0.02±0.01</td>
</tr>
<tr>
<td>SCN</td>
<td>mg/l</td>
<td>3</td>
<td>&lt;4</td>
<td>1.3</td>
<td>0.87±0.46</td>
</tr>
<tr>
<td>CN, volatile</td>
<td>mg/l</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>0.02±0.01</td>
</tr>
<tr>
<td>Sulphides, volatile</td>
<td>mg/l</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>0.03±0.02</td>
</tr>
<tr>
<td>N-Kjeldahl</td>
<td>mg/l</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>4.96±1.33</td>
</tr>
<tr>
<td>TNb</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ammonia</td>
<td>mg/l</td>
<td>0.7±0.8</td>
<td>32±53</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Nitrite</td>
<td>mg/l</td>
<td>3</td>
<td>0</td>
<td>1.3</td>
<td>0.01±0.07</td>
</tr>
<tr>
<td>Nitrate</td>
<td>mg/l</td>
<td>65</td>
<td>0</td>
<td>11</td>
<td>6.11±6.68</td>
</tr>
<tr>
<td>Oil and tar</td>
<td>mg/l</td>
<td>5</td>
<td>n/a</td>
<td>n/a</td>
<td>&lt;5$^1$</td>
</tr>
<tr>
<td>PAH (6 Borneff)</td>
<td>µg/l</td>
<td>&lt;50</td>
<td>n/a</td>
<td>n/a</td>
<td>1.06±1.12</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>mg/l</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>1.3±0.4</td>
</tr>
</tbody>
</table>

n/a not available; arithmetic average ± standard deviation
1) In the first of three stages.
2) Ranges reflect the daily averages for the effluent in 2005 except for SCN where the 2004 value has been used.
3) BTX

Cross-media effects
Activated sludge occurs from the waste water treatment plant. The surplus activated sludge can be added to the coal feed of the coke oven plant.

Operational data
a. Aerobic system with activated sludge:
Phosphate and caustic soda are added. Caustic soda is used for pH adjustment. Sedimentation is enhanced by addition of FeCl$_3$ and polymer.

Applicability
To obtain good results, an appropriate treatment will use the so-called pre-denitrification-nitrification concept (pre-DN/N) as described under c.

Economics
c. Nitrification-denitrification concept:
- investment: EUR 0.6 million in 1994 for an extension of a nitrification system to a pre-DN/N-system. Total investments were EUR 4.6 million
- operational costs: were EUR 345000 per year, including waste water levies calculated in 1996 (EUR 0.57/t coke).

Driving force for implementation
The demand for low discharges of nitrogen compounds requires a suitable waste water treatment system.
Chapter 5

Example plants
a. Aerobic system with activated sludge:
   SSAB Tunnplåt AB, Luleå Works, Sweden.

c. Nitrification-denitrification concept:
   Coke oven waste water treatment plants using the pre-DN/N concept have been installed at
   ArcelorMittal, Gent, Belgium; ArcelorMittal, Seremange, France; ZKS, Dillingen, Germany;
   Hüttenwerke Krupp Mannesmann, Duisburg-Huckingen, Germany (see Table 5.21).

Reference literature
[21] [65] [88] [89] [201] [208] [320] [341] [417] [420]
5.4 Best available techniques for coke oven plants

In understanding this section and its contents, the attention of the reader is drawn back to the Preface of this document and in particular the fifth section of the Preface: ‘How to understand and use this document’. The techniques and associated emission and/or consumption levels, or ranges of levels, presented in this section have been assessed through an iterative process involving the following steps:

- identification of the key environmental issues for coke oven plants in the iron and steel industry
- examination of the techniques most relevant to address those key issues
- identification of the best environmental performance levels, on the basis of the available data in the European Union and worldwide
- examination of the conditions under which these performance levels were achieved; such as costs, cross-media effects, main driving forces involved in implementation of these techniques
- selection of the best available techniques (BAT) and the associated emission and/or consumption levels for this sector in a general sense all according to Article 2(12) and Annex IV to the Directive.

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

On the basis of this assessment, best available techniques, and as far as possible emission and consumption levels associated with their use, are presented in this section that are considered appropriate to the coke oven plants and in many cases reflect current performance of some installations within the sector. Where emission or consumption levels ‘associated with best available techniques’ are presented, this is to be understood as meaning that those levels represent the environmental performance that could be anticipated as a result of the application, for coke oven plants, of the techniques described, bearing in mind the balance of costs and advantages inherent within the definition of BAT. However, they are neither emission nor consumption limit values and should not be understood as such. In some cases it may be technically possible to achieve better emission or consumption levels but due to the costs involved or cross-media considerations, they are not considered to be appropriate as BAT for the coke oven plants. However, such levels may be considered to be justified in more specific cases where there are special driving forces.

The emission and consumption levels associated with the use of BAT have to be seen together with any specified reference conditions (e.g. averaging periods).

The concept of ‘levels associated with BAT’ described above is to be distinguished from the term ‘achievable level’ used elsewhere in this document. Where a level is described as ‘achievable’ using a particular technique or combination of techniques, this should be understood to mean that the level may be expected to be achieved over a substantial period of time in a well maintained and operated installation or process using those techniques.

Where available, data concerning costs have been given together with the description of the techniques presented in the previous Section 5.3. These give a rough indication about the magnitude of costs involved. However, the actual cost of applying a technique will depend strongly on the specific situation regarding, for example, taxes, fees, subsidies and the technical characteristics of the installation concerned. It is not possible to evaluate such site-specific factors fully in this document. In the absence of data concerning costs, conclusions on economic viability of techniques are drawn from observations on existing installations.
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In this section, for coke oven plants specific techniques are considered as BAT (including the associated emission and consumption levels). ‘Best Available Techniques’ for a specific installation will usually be the use of one individual techniques or a combination of the techniques and measures listed in this section. Additionally, general BAT elements which can apply for the whole sector, mentioned in Section 2.8, have to be considered.

Where techniques identified individually as BAT can be used in combination, the effects of such combinations should be considered when drawing conclusions on BAT based permit conditions for individual cases.

If not otherwise mentioned, the BAT associated emission levels (BAT-AELs) given in this section are expressed on an annual average basis under standard conditions.

The BAT (including the associated emission and consumption levels) given in this chapter are ‘BAT in a general sense’ (i.e. considered to be appropriate to the sector as a whole). It is intended that they are a reference point against which to judge the current performance of an existing installation or to judge a proposal for a new installation. In this way, they will assist in the determination of appropriate ‘BAT-based’ conditions for the installation or in the establishment of general binding rules under Article 9(8) of the Directive. It is foreseen that new installations can be designed to perform at or even better than the BAT levels presented in this section. It is also considered that existing installations could move towards the BAT levels presented in this section or do better, subject to the technical and economic applicability of the techniques in each case.

While the BAT reference documents do not set legally binding standards, they are meant to give information for the guidance of industry, Member States and the public on achievable emission and consumption levels when using specified techniques. The appropriate permit conditions for any specific case will need to be determined taking into account the objectives of the IPPC Directive and the local considerations.

### Air

1. **BAT for the storage, handling and transport of coal, (see Sections 2.6.3 and 2.6.5)**

   *Grinding plant (raw material (coal) preparation (crushing, grinding, pulverising and screening)*

2. For these processes BAT is to prevent or reduce dust emissions by applying the following measure/techniques individually or in combination (see Section 5.3.1):
   I. building or device enclosure (crusher, pulveriser, sieves)
   II. efficient extraction and a subsequent dedusting systems.

   The **BAT-AEL** is <10 - 20 mg/Nm$^3$, as the average over the sampling period (spot measurement, for at least half an hour)

   *Storage and handling of pulverised coal*

3. BAT is to prevent or reduce diffuse dust emissions by applying the following techniques individually or in combination (see Section 5.3.1):
   I. storing pulverised materials in bunkers and warehouses
   II. using closed or enclosed conveyors
   III. limiting the drop heights to a maximum of 0.5 m
   IV. using efficient extraction and subsequent dedusting
   V. reducing emissions from charging of the coal tower and the charging car.
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Charging

4. **BAT is to charge with emission reduced charging systems (see Section 5.3.2)**
   From an integrated point of view, "smokeless" charging or sequential charging with double ascension pipes or jumper pipes are the preferred types, because all gases and particulate matter are treated as part of coke oven gas treatment. If, however, the gases are extracted and treated outside the coke oven, charging with land-based treatment of the extracted gases is the preferred method. Treatment should consist of efficient extraction of emissions with subsequent combustion to reduce organic compounds and bag filter to reduce particulates.

The **BAT-AEL** for dust emissions from coal charging is <5 g/t coke or <50 mg/Nm³, as the average over the sampling period (spot measurement, for at least half an hour).

Coking

5. **BAT is to extract the coke oven gas (COG) during coking as much as possible.**

6. **BAT is to reduce the emissions through achieving continuous undisrupted coke production by applying the following techniques individually or in combination (see Sections 5.3.1 - 5.3.8; 5.3.10 and 5.3.13):**
   I. extensive maintenance of oven chambers, oven doors and frame seals, ascension pipes, charging holes and other equipment (a systematic programme should be carried out by especially trained maintenance personnel) (see Sections 5.3.4 and 5.3.5)
   II. avoiding strong temperature fluctuations (see Section 5.3.4)
   III. comprehensive observation and monitoring of the coke oven (see Section 5.3.4)
   IV. cleaning of doors, frame seals, charging holes, lids and ascension pipes after handling (see Sections 5.3.7 and 5.3.8)
   V. maintaining a free gas flow in the coke ovens (see Section 5.3.9)
   VI. adequate pressure regulation during coking and application of spring-loaded flexible sealing doors or knife edged doors (in cases of ovens ≤5 m high and in good working order) to achieve:
      VIa. <5 % visible emissions from all doors in new plants and (see Section 5.3.7)
      VIb. <10 % visible emissions from all doors in existing plants
   VII. using water-sealed ascension pipes, to achieve <1 % visible emissions from the whole apparatus which provides a passage from the coke oven battery to the collecting main, gooseneck and stationary jumper pipes (see Section 5.3.3)
   VIII. luting charging hole lids with a clay suspension (or other suitable sealing material), to achieve <1 % visible emissions from all holes (see Section 5.3.3)
   IX. insuring complete coking (avoiding green coke pushes) by adequate techniques (see Section 5.3.4)
   X. installation of larger coke oven chambers (applicable only to new plants) (see Section 5.3.6)
   XI. applying variable pressure regulation of ovens chambers during coking (see Section 5.3.10)

The percentages in technique VI to VIII are related to frequency of any leaks compared to the total number of doors, ascension pipes or charging hole lids on a monthly average applying a monitoring method described in Sections 5.3.3 and 5.3.7.
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Gas treatment plant

7. BAT is to minimise diffuse gaseous emissions by applying the following techniques individually or in combination (see Section 5.3.18):
   I. minimising the number of flanges by welding piping connections wherever possible
   II. using gas-tight pumps (e.g. magnetic pumps)
   III. avoiding emissions from pressure valves in storage tanks:
      IIIa by connecting the valve outlet to the coke oven gas collecting main
      IIIb by collecting the gases and subsequent combustion.

8. BAT is to reduce the sulphur content of the coke oven gas by applying the following techniques individually or in combination (see Section 5.3.12.4):
   I. desulphurisation by absorption systems, with a corresponding BAT-AEL for the residual H₂S content of <500 mg/Nm³
   II. wet oxidative desulphurisation, with a corresponding BAT-AEL for the residual H₂S content of <10 mg/Nm³.

   These BAT-AELs are determined as the average over the sampling period (spot measurement, for at least half an hour).

Firing

9. BAT is to reduce the emissions from coke oven underfiring by applying the following techniques individually or in combination (see Section 5.3.12):
   I. preventing leakage between the oven chamber and the heating chamber by means of regular coke oven operation (see Section 5.3.12.1)
   II. repairing leakage between the oven chamber and the heating chamber (see Sections 5.3.4, 5.3.5, 5.3.12.1)
   III. incorporating low-NOₓ techniques in the construction of new batteries, such as staged combustion (see Sections 5.3.12.2 and 5.3.12.3)
   IV. using desulphurised COG process gases with a residual total sulphur content of <0.80 g/Nm³ (see Section 5.3.12.4)

   The BAT-AEL for SO₂ is <300 mg/Nm³.
   The BAT-AEL for dust is <10 mg/Nm³.
   The BAT-AEL for NOₓ is <500 mg/Nm³ for new plants.
   The BAT-AEL for NOₓ is <750 mg/Nm³ for existing plants.

   All of these BAT-AELs are determined as daily mean values and relate to an oxygen content of 5 %.

Pushing

10. BAT is to reduce the dust emissions from coke pushing by applying the following techniques individually or in combination (see Section 5.3.13):
    I. extraction by means of an integrated coke transfer machine equipped with a hood
    II. using land-based extraction gas treatment with a bag filter
    III. using a one point quenching car

   The BAT-AEL for dust emissions from coal pushing is <5 g/t coke or <10 mg/Nm³, the latter is determined as the average over the sampling period (spot measurement, for at least half an hour).

Quenching

11. BAT is to reduce the dust emissions by applying one of the following techniques:
    I. using coke dry quenching (CDQ) with the recovery of sensible heat and the removal of dust from charging, handling and screening operations by means of a bag filter (see Section 5.3.14)
    II. using emission minimised conventional wet quenching (see Section 5.3.15.1)
    III. using coke stabilisation wet quenching (CSQ) (see Section 5.3.15.2)
The **BAT-AEL** for dust is <3 g/t coke for coke dry quenching.
The **BAT-AEL** for dust is <25 g/t coke for conventional wet quenching.
The **BAT-AEL** for dust is <10 g/t coke for coke stabilisation wet quenching.

For the determination of dust emissions, the sampling should be carried out isokinetically. These **BAT-AELs** are determined as the average over the sampling period (spot measurement, for at least half an hour)

12. **BAT** is to minimise and re-use quenching water as much as possible (see Section 5.3.15).

13. **BAT** is to avoid the use of process water with a significant organic load (like raw coke oven waste water, waste water with a high content of hydrocarbons, etc.) as quenching water (see Section 5.3.15).

**Coke grading and handling**

14. **BAT** for these processes is to prevent or reduce dust emissions by applying the following measure/techniques individually or in combination (see Sections 5.3.16 and 5.3.17):
   I. building or device enclosure (screening, conveyors)
   II. efficient extraction and a subsequent dry dedusting.

The **BAT-AEL** is <10 mg/Nm³, determined as the average over the sampling period (spot measurement, for at least half an hour).

**Water**

**Waste water pretreatment**

15. For waste water from the coking process and coke oven gas cleaning, **BAT** is to pretreat prior to discharge to a waste water treatment plant by applying the following techniques individually or in combination:
   I. using efficient tar and PAH removal by using flocculation and subsequent flotation, sedimentation and filtration (see Section 5.3.19)
   II. using efficient ammonia stripping by using alkaline and steam (see Section 5.3.20)

The **BAT-AEL** for the stripper effluent for EPA-PAH is <0.7 mg/l

II. using efficient ammonia stripping by using alkaline and steam (see Section 5.3.20)

The **BAT-AEL** for the stripper effluent NH₃ concentration is <20 mg/l. However stripping efficiency should be related to subsequent waste water treatment. If the pretreated effluent is further processed in a waste water treatment plant with nitrification/denitrification the remaining NH₃ concentration is less critical.

The **BAT-AELs** are based on a qualified random sample or a 24-hour composite sample.
Waste water treatment

16. For pretreated waste water from the coking process and coke oven gas, BAT is to biologically treat waste water with integrated nitrification/denitrification (see Section 5.3.21).

The BAT-AELs are:

- Suspended solids <40 mg/l
- COD removal >95 %, corresponding to 150 mg/l
- $\text{BOD}_5$ <20 mg/l
- Sulphide <0.1 mg/l
- SCN$^-$ <4 mg/l
- CN$^-$ <0.1 mg/l
- PAH (6 Borneff) <0.02 mg/l
- Phenols <0.5 mg/l
- Sum of NH$_4^+$, NO$_3^-$ and NO$_2^-$ <20 mgN/l.

These concentrations are based on a specific waste water flow of 0.4 m$^3$/t coke.

Production residues like wastes and by-products

17. For tar from the coal water (see Section 5.3.19) and still effluent (see Section 5.3.20) and surplus activated sludge from the waste water treatment plant (see Section 5.3.21) BAT is to recycle production residues back to the coal feed of the coke oven plant.

Energy

18. BAT is to use the extracted COG as a fuel.

19. In cases where the COG has to be flared-off, BAT is a combustion efficiency of >95 % (see Section 5.3.12.4).

Noise

(see Section 2.6.9)
6 BLAST FURNACES

6.1 Applied processes

The first true coke-based blast furnace was introduced in 1735 [152]. The blast furnace remains by far the most important process for the production of hot metal (pig iron). The technique is likely to continue to dominate hot metal (HM) production in the medium term. Figure 6.1 shows a general view of two blast furnaces [344].

A blast furnace is a closed system into which iron-bearing materials (iron ore lump, sinter and/or pellets), additives (slag formers such as limestone) and reducing agents (i.e. coke) are continuously fed from the top of the furnace shaft through a charging system that prevents escape of blast furnace gas (BF gas). Figure 6.2 shows a simplified layout of a blast furnace consisting of the furnace itself, the cast house, the hot stoves and a two-stage treatment of BF gas.

A hot air blast, enriched with oxygen and auxiliary reducing agents are injected on the tuyère level providing a countercurrent of reducing gases. The air blast reacts with the reducing agents to produce mainly carbon monoxide (CO), which in turn reduces iron oxides to metal iron. The liquid iron is collected in the hearth along with the slag and both are cast on a regular basis. The liquid iron is transported i.e. in torpedo vessels to the steel plant and the slag is processed to produce aggregate, granulate or pellet for road construction and cement manufacture. The blast furnace gas is collected at the top of the furnace. It is treated and distributed around the works to be used as a fuel for heating or for electricity production.

Various reducing agents are available. Carbon/hydrocarbons in the form of granular or pulverised coal, heavy fuel oil, oil residues, used oils, fats and emulsions, animal fats, eco-oil, natural gas, coke oven gas, BOF gas, BF gas, waste plastics, coal tar, etc. are generally available in sufficient quantities at reasonable costs. However, the choice between several reducing agents is not determined by costs alone. Apart from being a reducing agent, coke also serves as a carrier of the bulk column in the blast furnace. Without this carrying capacity, blast furnace operation would not be possible.
Iron ore processed nowadays contains a large content of hematite (Fe₂O₃) and sometimes small amounts of magnetite (Fe₃O₄). In the blast furnace, these components become increasingly reduced, producing iron oxide (FeO) then a partially reduced and carburised form of solid iron. Finally, the iron charge melts; the reactions are completed and liquid hot metal and slag are collected in the bottom. The reducing carbons react to form CO and CO₂. Fluxes and additives are added to lower the melting point of the gangue, improve sulphur uptake by slag, provide the required liquid hot metal quality and allow for further processing of the slag.

As the blast furnace burden moves down, its temperature increases, thus facilitating oxide reduction reactions and slag formation. The burden undergoes a series of composition changes as this happens:

- the iron oxide in the burden becomes increasingly reduced (forming sponge iron and finally molten hot metal)
- the oxygen from the iron ore reacts with the coke or the carbon monoxide, thus forming carbon monoxide or carbon dioxide, which is collected at the top
- the gangue components combine with the fluxes to form slag. This slag is a complex mix of silicates of a lower density than the molten iron
- the coke primarily serves as a reducing agent, but also as a fuel. It leaves the furnace as carbon monoxide, carbon dioxide or carbon in the hot metal
- any hydrogen present also acts as a reducing agent by reacting with oxygen to form water.
The main operations are as follows:

- burden preparation
- charging and conveying of raw materials
- blast furnace process
- generation of hot blast
- direct injection of reducing agents
- casting
- slag processing.

### 6.1.1 Burden preparation

The production of hot metal huge requires amounts of bulk materials like lump ore, any blend of lump ore agglomerates and pellets and auxilleries are needed.

Excessively coarse lumps of ore have to be crushed, ground and screened to proceed defined sizes of particles required. Ores are usually undergo specific preparation steps.

Usually pretreated ores and other materials are delivered by ships, by trains and sometimes by lorries being unloaded by appropriate unloading devices. Depending on the prerequisites and their properties e.g. their drift sensitiveness and and their wettability they undergo outdoor, under roof, bunker, silo or packed short, intermediate or long-term storage. Irregularities within the ores from one or different provenances are balanced out by mixing. This homogenizing process is performed in bedding yards.

Concerning the allocation what burden preparation exactly comprises different views can be found. Commonly burden preparation comprises the ore preparation processes, the blending processes before the sinter plant in bedding yards, the conveying of the sinter, the coke and the possible direct conveying of lump ore and all batching processes till the BF top charging. Sometimes the unloading, conveying and storage of ores and coke is included and sometimes only ores are redarded.

The batching system includes screens (for iron ore and coke), vibro feeders (for fluxes) and weighing bins. From the weigh bins, the raw material is conveyed to the BF top via a belt conveyor. In case of use of sinter and/or pellets in addition to lump ore, suitable storage and batching systems are added to the stockhouse.

All raw material batching and BF top charging is handled automatically through a supervisory system from the control room. The burden preparation system is fully dedusted by a bag filter system.

### 6.1.2 Charging and conveying of raw materials

The mixture of iron-bearing materials (iron ore rubble, sinter and/or pellets) and additives (flux material) are known collectively as the "burden". The burden and the accompanying coke are charged into the top of the furnace either via skips or mechanical conveyor belts. It enters into the furnace via a sealed charging system which isolates the furnace gases from the atmosphere. This system is necessary because blast furnace pressure exceeds atmospheric pressure (0.25 - 2.5 bar gauge). Whilst many new large blast furnaces have high top pressures (up to 2.5 bar gauge), there are modern furnaces operating at pressures much lower than this. These pressures can be as low as 0.25 bar gauge, depending on the age of the furnace and other constraints such as available blast pressure and limitations due to the gas treatment plant construction.
Chapter 6

The sealed charging system can be a bell charging system or a bell-less charging system. Some particulate matter and BF gas emissions may arise during charging. The evacuation of gas at the top of the furnace and connection to the BF gas treatment system can be used to control emissions at this stage of the process.

6.1.3 Blast furnace operation

In a blast furnace, the raw materials enter at the top, while the products (molten iron and slag) are tapped from the bottom (the hearth). The solid burden moves downwards, meeting a rising stream of hot reducing gas. BF gas with residual calorific value is collected from the top of the furnace for treatment.

A blast furnace can be divided into six temperature zones:

- **The Top**: At the top, charging of the burden and evacuation of BF gas occurs
- **The Shaft**: In the Shaft, the hot BF gas gives its heat to the solid burden. The temperature of the burden rises from ambient temperature to approximately 950 °C and the iron oxide becomes partially reduced in this zone
- **The Belly**: The belly links the shaft to the bosh. In this section, the temperature rises further from 950 °C to approximately 1250 °C. Further reduction of the iron oxide takes place and coke reaction begins
- **The Bosh**: Coke reactions continue to take place in the zone of the bosh. The iron melts and slag is formed
- **The Tuyères**: In this zone the hot blast is introduced into the furnace by means of a series of tuyères (up to 42). The tuyères are located around the upper perimeter of the hearth and are fed by a large pipe (bustle pipe), circling the furnace at the height of the bosh. Temperatures here can exceed 2000 °C and the oxides are completely reduced
- **The Hearth**: The hearth collects the molten hot metal and slag. One to four tapholes are located around the hearth, with one or two in operation at any time.

The shaft, belly, bosh and tuyère belt are typically water-cooled with the hearth water, oil or air-cooled. The furnace is lined with refractory material (the hearth being up to 1.5 m thick at least at the hearth level).

Hot metal production ranges from approximately 0.5 Mt/yr for small blast furnaces to about 5.5 Mt/yr for large blast furnaces.

Blast furnace technology uses high-grade ore. Any elements accompanying the iron are distributed between the hot metal phase and slag. Those passing into the hot metal include phosphorus, sulphur, manganese and silicon. Titanium, aluminium, calcium, magnesium and the bulk of silicon and sulphur pass into the slag as oxides or metalloids. It is also possible for a variety of elements to volatilise and deposit on different parts of the blast furnace. This is especially the case for zinc (Zn) and lead (Pb) which reach the blast furnace via iron ores and recycled by-products via the sinter plant.

The total zinc in the charge generally varies from 100 - 250 g/t of hot metal produced. As a rule of thumb, most modern plants restrict zinc to 100 - 150 g/t hot metal. Dusts and sludges with high zinc or lead content are usually not accepted as returns to the sinter plant, or are only used in limited amounts [344].

Removal of Zn and Pb from the furnace is done by operating the blast furnace in such a way that the temperature in the centre of the furnace is kept above 400 °C. The zinc is then more likely to be removed with the top gas as fine ZnO particles, which are almost completely retained in the BF gas treatment [105].
Blast furnace top gas
BF gas contains about 20 - 28 % CO, 1 - 5 % H₂, inert compounds (50 - 55 % N₂, 17 - 25 % CO₂), some sulphur and cyanide compounds and large amounts of dust from the burden. BF's with NG and COG injection have higher hydrogen contents of up to 10 % in the top gas. The amount of cyanide may be especially high during blow down operations of the blast furnace; but this only occurs occasionally and then additions are made to the system to minimise cyanide formation. The heating value of BF gas is approximately 2.7 - 4.0 MJ/Nm³. The production of BF gas is approximately 1200 - 2000 Nm³/t hot metal.

After cleaning, the BF gas is often used as a fuel after enriching with coke oven gas, BOF gas or natural gas, which have higher heating values. BF gas can also be used without upgrading (e.g. in the hot stoves) if modern burners and/or combustion air preheating are applied and if appropriate safety precautions are taken [145].

6.1.3.1 Reducing agents application

The reducing agents used for processing the iron ores in the blast furnace are coke, coal, oil and gas. These are mainly used to produce the reducing gas and thus to promote the reduction of the iron oxides to metallic iron, and then for carburising the iron. The most important reducing agent is coke provided by the coking process (see Chapter 5).

A portion of the coke in the blast furnace might be replaced by coal, oil or gas injected at the tuyère level, which is also called direct injection.

![Figure 6.3: Average consumption of reducing agents of the blast furnace in Germany][479]

Figure 6.3 shows the development in reducing agent demand and types. What can be seen is that the total demand has been reduced drastically over the years by the mentioned measures. The application of oils started in the late 60s, whereas coal injection appeared in 1985 and has increased since.
Coal or oil injection into blast furnaces is a technique now widely applied in Europe and worldwide. Figure 6.4 gives the reducing agents consumption levels for different countries or regions in the year 2006. It can be seen that worldwide, coke and coal are the main reducing agents used. The use of coke replacement through coal injection depends upon factors such as productivity, coke properties, desired hot metal quality, type (e.g. anthracite) and condition (humidity) of coal, etc. [11] [65].

It should be stressed, however, that a certain amount of coke is still necessary in the blast furnace to allow proper blast furnace operation. The theoretical maximum for coal injection at the tuyère level is thought to be 270 kg/t hot metal. This limit is set by the carrying capacity of the coke and the thermochemical conditions in the furnace. The coke provides the required carrying capacity to sustain the blast furnace charge and ensures sufficient gas penetration.

![Figure 6.4: Reducing agent consumption in blast furnaces in the world in 2006](479)

Direct injection of reducing agents means replacing part of the coke by another hydrocarbon source, which is injected in the furnace at the tuyère level (see also Section 6.2.2.4). As mentioned above, coal and oil are the most commonly used of the tuyère injectants. Other hydrocarbons may be used such as heavy fuel oil, oil residues, recovered waste oil, granular material or more common pulverised coal, natural gas or coke oven gas and plastics. By reducing the need for coke, overall pollution and energy demand decrease.

Pulverised coal injection (PCI) or oil injection can provide important economic and operational benefits. These include:

- lower consumption of expensive coking coals and a wider range of coals to be used
- extended coke oven life
- higher BF productivity
- greater flexibility in BF operation (adjusting the tuyère input is much easier than the burden adjusting charge)
- improved consistency in hot metal quality and silicon content
- reduced overall emissions from steel plants due to lower emissions from coke making.
The disadvantages of PCI are:

- additional costs for air enrichment, providing constant huge oxygen amounts requires an air separation plant
- additional demand on the pulverisers in existing plants additional requirements for injection unit maintenance.

The injection of relevant amounts of coal and oil tend to decrease raceway temperatures which would influence the efficiency of the blast furnace. This means that in blast furnaces with conventional heating, the allowed coal injection is limited to 150 kg/t hot metal. To maintain suitable raceway conditions and at the same time achieve higher input rates of coal and/or oil (up to 260 kg/t hot metal), different options exist. The blast temperature can be increased using electrically-powered plasma blast superheating. This is only economically reasonable where cheap electricity is available. The other option is to use oxygen to enrich the blast or to inject the coal or oil together with the oxygen at the tuyère level. The latter ones are called oxy-coal or oxy-oil injection (see Section 6.3.12).

Nowadays new BFs or upgraded existing injection systems are designed for PCI rates of 200 kg/t hot metal or more.

**Reference literature**
[208] [424] [448] [479] [480]

### 6.1.4 Hot stoves operation

The hot blast for the blast furnace operation is provided by the hot stoves (sometimes called "blast furnace cowpers"). Stoves are auxiliary installations used to heat the blast. Increased blast temperature results in a reduction of carbon requirements. A hot blast is needed to transfer heat to the solid burden in order to raise the temperature for reaction. The blast also helps to provide the oxygen necessary for coke gasification, and to transport the gas that, on contact with the burden, reduces iron oxides.

The stoves operate on a cyclical basis. They are heated up by burning gases (usually enriched BF gas) until the dome is at the correct temperature (approximately 1100 - 1500 °C). Combustion gas is then cut off and cold ambient air is forced through the stoves in the reverse direction. The cold air is heated by the hot bricks and thus forms the hot blast (900 - 1350 °C), which is fed to the blast furnace. The process continues until the stove can no longer generate the proper blast gas temperature, after which the initial heating cycle is started again. The duration of each cycle depends on individual site conditions such as energy source, system characteristics and conservation measures.

In principle, hot stoves can be classified as being of either the internal or external combustion chamber type (see Figure 6.5). This distinction is important for CO emissions.
Three or four hot stoves are necessary for each blast furnace. Emissions to air occur during the heating phase of the stove.

6.1.5 Casting

The blast furnace is periodically cast to remove the hot metal and slag from the hearth. For this purpose, one of the tap holes is opened in the side wall of the hearth by means of a tap hole drill or soaking bar. In some cases, an oxygen lance is used to open the tap hole. Usually, a blast furnace has one to four tap holes. The number of tap holes is determined by the capacity (size) of the blast furnace.

In modern blast furnaces, hot metal and slag are tapped together (typically slag starting to run after the hot metal). The slag and hot metal are subsequently separated at the skimmer in the cast house, after which each continues in a separate runner.

Hot metal tapped from the blast furnace flows along refractory or low cement covered runners, lined with a heat-resistant alumina-carbon or silica-carbide mixtures, and is poured into ladles (directly or via tilted runners). These ladles can be open or closed top types, or torpedo cars. In this molten state, the metal has a temperature of approximately 1440 - 1500 °C.

Slag tapped from the furnace flows in runners to a granulation plant to slag ladles or to an open pit.

At the end of the casting cycle, the tap hole is closed mechanically by injecting a specific heat-resistant tap hole clay mixture, using a "mud gun" or "tap hole gun".
6.1.6 Slag processing
[347]

The amount of slag produced depends upon the gangue content of the blast furnace, the ferrous burden, the coke ash and ash from the injection material, e.g. coal, and the amount of flux required to achieve the necessary hot metal quality. In order for blast furnace slag to be acceptable for use outside the I&S works, it is necessary to take additional measures to ensure that the slag chemistry and/or physical properties are requisite. Slag can be put to a variety of uses including material for road building, concrete aggregate, thermal insulation (mineral wool), and as a clinker substitute in cement production. Total utilisation of blast furnace slag is a target that has already been met in many cases [347].

Currently, three principal processes are used to treat liquid blast furnace slag:

- a slag granulation process with water
- a slag pit process (also called cooling in air)
- a slag pelletising process.

All of these slag cooling processes may generate hydrogen sulphide, which can result in odour.

The granulation by air presently is used for processing blast furnace slags in some industrial scale plants. In all air granulation processes, the slag is dispersed and the particles are cooled off during their way through the surrounding air. Often an additional water spray is applied to the dispersed slag in order to achieve a faster cooling. Due to some disadvantages (e.g. high space requirements, noise, uncontrollable gaseous sulphur compound emissions, PM emissions), the air granulation is only operated in very few industrial plants.

Other processes such as blowing to produce slag wool and foaming to produce foamed blast furnace slag are used less frequently.

The possible flow lines for the liquid slag tapped from the blast furnace and the measures to influence the quality are shown in Figure 6.6.
### Chapter 6

<table>
<thead>
<tr>
<th>Process</th>
<th>Measures to influence the quality</th>
<th>Influenced properties</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Raw material preparation</strong></td>
<td>Selection, arrangement and pre-treatment of raw materials relating to the chemical composition of the blast furnace slag</td>
<td>Chemical composition, e.g.: CaO, SiO₂, Al₂O₃, MgO, Alkalies</td>
</tr>
<tr>
<td><strong>Melting process</strong></td>
<td>Selection of suitable process conditions (blast temperature, reduction rate, carbon rate, gas flow)</td>
<td>Temperature, composition of the products</td>
</tr>
<tr>
<td><strong>Heat treatment</strong></td>
<td>Different cooling rates: a) Quick: - blowing - granulation - pelletising</td>
<td>Glass content, structure, porosity</td>
</tr>
<tr>
<td></td>
<td>b) Moderate - Foaming</td>
<td>Bulk density, strength, porosity</td>
</tr>
<tr>
<td></td>
<td>c) Slow - Air cooling</td>
<td>Strength, porosity, resistance to polishing, grain size</td>
</tr>
</tbody>
</table>

#### Selection of suitable process conditions:
- **Quick:**
  - Blowing
  - Granulation
  - Pelletising
- **Moderate:**
  - Foaming
- **Slow:**
  - Air cooling

#### Foaming:
- Moderate cooling with less water to produce a crystalline/glassy and porous material

#### Slow cooling in air in slag pits to produce crystalline material

#### Blowing:
- Quick cooling by air and steam to produce glass fibre

#### Granulation:
- Quick cooling with water to produce vitrified granulates (<5mm)

#### Pelletising:
- Quick cooling in air to produce glassy/crystalline pellets (<20mm)

#### Foaming:
- Moderate cooling with less water to produce a crystalline/glassy and porous material

#### Cooling in air:
- Slow cooling in air to produce crystalline material

---

**Figure 6.6:** Summary of control methods and flow sheet for liquid BF slags

[344] [347]
Granulation is the most common process currently used in the EU to treat blast furnace slag. The process involves pouring the molten slag through a high-pressure water spray in a granulation head (sometimes in granulation chambers), located in close proximity to the blast furnace.

After granulation, the slag/water slurry is typically transported to a drainage system, consisting of a horizontal filtering basin (e.g. the OCP - open circuit process), a vertical filtering hopper or a rotating dewatering drum (e.g. the INBA and the RASA process). In several cases, the slag/water slurry is transported to a separation tank prior to water drainage. In some cases, water vapour is collected and condensed or emitted via a stack.

After dewatering, the residual moisture of the slag sand is generally around 10 %. The filter bed is periodically backwashed with water and air to remove the fine particles. Figure 6.7 and Figure 6.8 show two examples of granulation techniques: the OCP process and the INBA process.

Figure 6.7: Granulation of slag from the blast furnace in the OCP process

[111]
6.1.6.2 Slag pelletising process

The pelletising process is only in use in a few plants in the EU and in some plants in Canada. The molten slag is spread in a layer on a plate, which acts as a deflector. The sheet of slag is sheared by controlled water jets which initiate the swelling and cooling of the slag. The slag is then projected centrifugally into the air on a rotating drum to complete the blowing up and cooling. The slag particles follow different trajectories according to their size, which range from granulated sand to expanded pellets [347].

When properly applied, process water is totally consumed by evaporation and as moisture in the product. Specific water consumption is less than that required for wet granulation.

The pelletised slag is used as a clinker substitute in cement production.

6.1.6.3 Slag pit process

[392]

The slag pit process (also called cooling in air) involves pouring thin layers of molten slag directly into slag pits adjacent to the furnaces. Alternatively, after the collection of slag in ladles, the molten slag is slowly cooled and crystallised in the open air. The pits are alternately filled and excavated, and lump slag is broken up and crushed for use as coarse aggregate. In practice, cooling time can be reduced by spraying the hot slag with a controlled amount of water, although this increases the potential for odour emissions. When properly applied, the cooling water is totally consumed by evaporation.
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The slag pit process produces lump crystalline slag that is a desirable aggregate in construction (i.e. raw material for road construction). The cooling time has a strong influence on the quality of lump slag produced. Water cooling also improves the microstructure, achieving better mechanical properties.

Some disadvantages identified of this process are that the product quality can hardly be influenced which leads to limited product applications, and that the handling of liquid slag and the crushing of solid slag requires a great deal of work.
6.2 Current emission and consumption levels

6.2.1 Mass stream overview and input/output data

Figure 7.6 provides an overview for the input and output mass streams of a blast furnace. This overview may be used for the collection of data from single blast furnaces.

![Mass stream overview of a blast furnace](image)

Figure 6.9: Mass stream overview of a blast furnace

[200]

Figure 6.10 shows an example of the general process layout of a blast furnace along with the input and output mass streams.
Subsequently, both specific input factors and specific emission factors have been determined. Following tables give figures for these factors taken from many blast furnaces, thus giving a representative picture of modern plants.
### Inputs

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Units</th>
<th>Maximum</th>
<th>Minimum</th>
<th>Weighted average value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Raw materials</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sinter</td>
<td>kg/tHM</td>
<td>1621</td>
<td>116</td>
<td>1088</td>
</tr>
<tr>
<td>Iron ore</td>
<td>kg/tHM</td>
<td>684</td>
<td>0</td>
<td>180</td>
</tr>
<tr>
<td>Pellets</td>
<td>kg/tHM</td>
<td>972</td>
<td>0</td>
<td>358</td>
</tr>
<tr>
<td>Coke</td>
<td>kg/tHM</td>
<td>515</td>
<td>282</td>
<td>359</td>
</tr>
<tr>
<td>Returned material</td>
<td>kg/tHM</td>
<td>106</td>
<td>0</td>
<td>20.1</td>
</tr>
<tr>
<td>Limestone/Lime</td>
<td>kg/tHM</td>
<td>80</td>
<td>0</td>
<td>25.7</td>
</tr>
<tr>
<td><strong>Tuyère injection</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oil</td>
<td>kg/tHM</td>
<td>116</td>
<td>0</td>
<td>30.1</td>
</tr>
<tr>
<td>Coal</td>
<td>kg/tHM</td>
<td>232</td>
<td>0</td>
<td>162</td>
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<tr>
<td>COG</td>
<td>kg/tHM</td>
<td>46.9</td>
<td>0</td>
<td>1.1</td>
</tr>
<tr>
<td>Natural gas</td>
<td>kg/tHM</td>
<td>5.6</td>
<td>0</td>
<td>2.2</td>
</tr>
<tr>
<td>Oxygen</td>
<td>kg/tHM</td>
<td>85.1</td>
<td>0</td>
<td>54.4</td>
</tr>
<tr>
<td>Others 1)</td>
<td>kg/tHM</td>
<td>73.5</td>
<td>0</td>
<td>3.6</td>
</tr>
<tr>
<td><strong>To stoves</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BF gas</td>
<td>MJ/tHM</td>
<td>2287</td>
<td>1.2</td>
<td>1536</td>
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<tr>
<td>COG</td>
<td>MJ/tHM</td>
<td>817</td>
<td>0.024</td>
<td>284</td>
</tr>
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<td>Natural gas</td>
<td>MJ/tHM</td>
<td>819</td>
<td>0</td>
<td>168</td>
</tr>
<tr>
<td>BOF gas</td>
<td>MJ/tHM</td>
<td>259</td>
<td>0.124</td>
<td>213</td>
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<tr>
<td><strong>Energy</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Electricity</td>
<td>MJ/tHM</td>
<td>850</td>
<td>107</td>
<td>268</td>
</tr>
<tr>
<td><strong>Others</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxygen</td>
<td>m³/tHM</td>
<td>67</td>
<td>4.6</td>
<td>43</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>m³/tHM</td>
<td>59</td>
<td>33</td>
<td>46</td>
</tr>
<tr>
<td>Steam</td>
<td>MJ/tHM</td>
<td>435</td>
<td>14.8</td>
<td>48</td>
</tr>
<tr>
<td>Compressed air</td>
<td>m³/tHM</td>
<td>35</td>
<td>0.008</td>
<td>9.1</td>
</tr>
<tr>
<td>Cooling water 2)</td>
<td>m³/tHM</td>
<td>22.9</td>
<td>0.37</td>
<td>4)</td>
</tr>
<tr>
<td>Process water 3)</td>
<td>m³/tHM</td>
<td>13</td>
<td>0.28</td>
<td>3.4</td>
</tr>
</tbody>
</table>

Note: Blast furnace input data for 2004, based upon production of 73.4 Mt HM. HM: hot metal
1) Others could include plastic, recovered oils, fats, emulsions, etc.
2) Water that does not have direct contact in the process.
3) Process water is an integral part of the process and is not contained in a defined cooling system, e.g. slag pit water.
4) Differences reflect once-through systems and closed systems. Weighted averages are not calculated since once-through systems should not be compared to closed systems.

Table 6.1: Input data from blast furnaces in different EU member states
[346] [403] [471]
Outputs

<table>
<thead>
<tr>
<th>Units</th>
<th>Maximum</th>
<th>Minimum</th>
<th>No.</th>
<th>Tonnage HM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy BF gas</td>
<td>6061</td>
<td>3377</td>
<td>16</td>
<td>62956753</td>
</tr>
<tr>
<td>Electricity</td>
<td>91</td>
<td>40</td>
<td>6</td>
<td>31160302</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Production residues (waste/by-products)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slag kg/t HM</td>
</tr>
<tr>
<td>Top gas dust kg/t HM</td>
</tr>
<tr>
<td>Top gas sludge kg/t HM</td>
</tr>
<tr>
<td>Dust from cast house dedusting kg/t HM</td>
</tr>
</tbody>
</table>

Production residues (waste/by-products)

| Used refractory, etc. kg/t HM | 5.9 | 0.3 | 8 | 48063570 |
| Waste water m³/t HM           | 13.736 | 0.096 | 2) | 54428253 |

Notes: Data based based upon:
Tonnes of hot metal = 73459787 1)
Tonnes of BF slag = 19562299
HM: hot metal; No: Number of EU installations that have reported; Tonnage of hot metal: Amount of hot metal produced by the installations that have reported data for each item.
1) No single output has been reported for all installations. This is the reason why this figure is higher than any other in the column. Tonnare hot metal
2) Differences reflect once-through systems and closed systems.

Table 6.2: Blast furnace output data for 2004

The following tables complement the information with more details on emission factors to air (after abatement) for the main individual operations associated with a blast furnace.

<table>
<thead>
<tr>
<th>Operation/emission source</th>
<th>Dust (g/t HM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>coal preparation for inject. n/r</td>
<td>15/2 - 54</td>
</tr>
<tr>
<td>x±s</td>
<td>12±16</td>
</tr>
</tbody>
</table>

Legend: HM = hot metal (crude liquid steel); x±s = mean value and standard deviation (only calculated if enough data are available); n = number of data; r = range of data; (min-max); l.s. = low significance; n/a = not available

Table 6.3 Emission factors for coal preparation for injection

<table>
<thead>
<tr>
<th>Species</th>
<th>Units</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust</td>
<td>g/t HM</td>
<td>2.7 - 81.4</td>
</tr>
<tr>
<td>PM₁₀</td>
<td>g/t HM</td>
<td>0.2 - 11.0</td>
</tr>
</tbody>
</table>

Table 6.4: Emission factors for the charging zone

High values for dust emissions from the charging zone have been reported depending on the type of mouth and the presence or not of an offtake system directing the gas from the airlock to the BF gas treatment system (see Section 6.3.5). In the absence of the latter device the emission factors for the charging zone are reported to be as high as 400 and 850 g dust/t hot metal in two Belgium plants[530].
### Table 6.5: Emission factors for emissions to air from BF cast house (end-of-pipe)

<table>
<thead>
<tr>
<th>Species</th>
<th>Units</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust</td>
<td>g/t HM</td>
<td>41.95</td>
<td>0.42</td>
</tr>
<tr>
<td>PM$_{10}$</td>
<td>g/t HM</td>
<td>25.92</td>
<td>0.26</td>
</tr>
<tr>
<td>SO$_2$</td>
<td>g/t HM</td>
<td>193.80</td>
<td>7.34</td>
</tr>
<tr>
<td>NO$_x$</td>
<td>g/t HM</td>
<td>2.08</td>
<td>2.08</td>
</tr>
<tr>
<td>CO</td>
<td>g/t HM</td>
<td>35.63</td>
<td>21.52</td>
</tr>
<tr>
<td>Cr</td>
<td>mg/t HM</td>
<td>10.41</td>
<td>2.76</td>
</tr>
<tr>
<td>Mn</td>
<td>mg/t HM</td>
<td>53.02</td>
<td>45.12</td>
</tr>
<tr>
<td>Ni</td>
<td>mg/t HM</td>
<td>10.61</td>
<td>1.99</td>
</tr>
<tr>
<td>Pb</td>
<td>mg/t HM</td>
<td>24.33</td>
<td>2.19</td>
</tr>
<tr>
<td>Zn</td>
<td>mg/t HM</td>
<td>12.9</td>
<td>3.81</td>
</tr>
<tr>
<td>Hg</td>
<td>µg/t HM</td>
<td>200.3</td>
<td>55.50</td>
</tr>
<tr>
<td>As</td>
<td>µg/t HM</td>
<td>299.8</td>
<td>205.69</td>
</tr>
<tr>
<td>Cd</td>
<td>µg/t HM</td>
<td>223.3</td>
<td>65.3</td>
</tr>
</tbody>
</table>

HM: hot metal

Particulates from Table 6.3 are generated in the air during casting as a consequence of the oxidation. Two areas are of concern; the area at the tap hole and the area at the spout to the torpedo. To reduce the pollution to the atmosphere from this minor oxidation of the hot metal, the runners are covered and a suction is applied at both the tap hole and the torpedo filling station. The air from this is treated in ESPs or bag filters before discharge to the atmosphere. The data provided in Table 6.3 refer to discharge from the abatement equipment.

### Table 6.6: Emission factors for emissions to air for specific processes in blast furnaces

<table>
<thead>
<tr>
<th>Operation/emission source</th>
<th>Dust (g/t HM)</th>
<th>H$_2$S (g/t HM)</th>
<th>SO$_2$ (g/t HM)</th>
<th>NO$_x$ (g/t HM)</th>
<th>CO (g/t HM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>slag granulation</td>
<td>n/r</td>
<td>14/1 – 300</td>
<td>13/1 – 142</td>
<td>l.s.</td>
<td>l.s.</td>
</tr>
<tr>
<td></td>
<td>±s</td>
<td>±95</td>
<td>±42</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Legend: HM = hot metal (crude liquid steel); ±s = mean value and standard deviation (only calculated if enough data are available); n = number of data; r = range of data (min-max); l.s. = low significance; n/a = not available

* Low values (around 1 g/t HM) are for slag granulation plants with fume condensation.

### 6.2.2 Environmental issues for the blast furnace process

The blast furnace is primarily a source of particulate matter and gaseous emissions to air. When abatement techniques are applied to reduce emissions, cross-media can effects occur.

Generally, Sections 6.2.2.1 to 6.2.2.5 below describe the most relevant environmental issues in the blast furnace process:

- **Emissions to Air**
  - Burden preparation
  - Charging and conveying
  - Blast furnace gas (as an indirect emission at the site of combustion)
  - Hot stoves
  - Cast house
  - Slag processing
- **Waste water**
  - Overflow water from BF gas scrubbing
  - Waste water from slag granulation
  - Blow down from cooling water circuits
6.2.2.1 Emissions to Air

Burden preparation
Emissions from the drying-crushing of coal can be relevant. Available data from one Belgium plant show that the emissions for dust are between 54 - 139 mg/Nm$^3$, for CO 292 - 383 mg/Nm$^3$ and for CH4 1250 mg/Nm$^3$. All values are related to an oxygen content of 3% [531].

Charging and conveying
Since the furnace pressure is higher than atmospheric pressure, a sealed charging system based on "bell-shaped" or "bell-less type" charging is used.

All components present in the BF gas may be emitted here, but the main components are carbon monoxide (CO) and particulate matter. When using systems with gas recovery, much lower charging and conveying emissions are possible.

Blast furnace gas
Raw BF gas contains particulate matter (including heavy metals and carbon), carbon monoxide, carbon dioxide, sulphur compounds, ammonia, cyanide compounds, hydrocarbons and PAH. BF gas is contained and used as an energy source. The gas is purified in order to meet quality specifications and is re-used for various firing processes such as blast generation in the hot stoves (see Section 6.1.4) or for coke oven firing (see Section 5.1.2.2). Thus (indirect) emissions of combusted BF gas occur.

BF gas treatment usually consists of pretreatment for the removal of coarse particulate matter and subsequently wet scrubbing for the removal of fine particulate matter (and thus heavy metals), SO$_2$ and cyanide compounds. In some plants an electrostatic precipitation is applied.

The particulate matter content of raw BF gas is very different from one plant to another and is also highly dependent on process conditions, varying from 5.5 - 40 kg/t hot metal produced. After cleaning, the BF gas contains normally less than 10 mg/Nm$^3$ particulate matter. This is emitted at the site of combustion.

In Table 6.7 specific factors of several components in raw untreated BF gas are given.
Chapter 6

<table>
<thead>
<tr>
<th>Raw BF gas component</th>
<th>Value</th>
<th>Unit</th>
<th>Specific factor</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>BF gas production</td>
<td>1.0 - 7.0</td>
<td>10^8 Nm^3/h</td>
<td>1200 - 2000</td>
<td>Nm^3/t HM</td>
</tr>
<tr>
<td>Particulate matter</td>
<td>3500 - 30000</td>
<td>mg/Nm^3</td>
<td>7000 - 40000</td>
<td>g/t HM</td>
</tr>
<tr>
<td>Hydrocarbons (C,H)</td>
<td>67 - 250</td>
<td>mg/Nm^3</td>
<td>130 - 330</td>
<td>g/t HM</td>
</tr>
<tr>
<td>Cyanide compounds</td>
<td>0.26 - 1.0</td>
<td>mg/Nm^3</td>
<td>0.5 - 1.3</td>
<td>g/t HM</td>
</tr>
<tr>
<td>Ammonia (NH3)</td>
<td>0.08 - 0.28</td>
<td>mg/Nm^3</td>
<td>0.15 - 0.36</td>
<td>g/t HM</td>
</tr>
<tr>
<td>PAH</td>
<td>n/a</td>
<td>mg/Nm^3</td>
<td>0.15 - 0.36</td>
<td>g/t HM</td>
</tr>
<tr>
<td>Carbon dioxide (CO2)</td>
<td>20 - 28</td>
<td>vol. %</td>
<td>300 - 700</td>
<td>kg/t HM</td>
</tr>
<tr>
<td>Carbon monoxide (CO)</td>
<td>17 - 25</td>
<td>vol. %</td>
<td>400 - 900</td>
<td>kg/t HM</td>
</tr>
<tr>
<td>Hydrogen (H2)</td>
<td>1 - 5</td>
<td>vol. %</td>
<td>1 - 7.5</td>
<td>kg/t HM</td>
</tr>
</tbody>
</table>

1) emissions during blow down may be significantly higher.
2) many other polycyclic aromatic hydrocarbons (PAH) are also present.

Table 6.7: Raw blast furnace gas composition (before treatment) [65] [344]

During the two-stage treatment of BF gas, dust is removed with a high degree of efficiency as are compounds associated with particulate matter such as most heavy metals and PAH. Table 6.8 shows the BF gas composition after treatment. The gas still contains some heavy metals but compared with sinter plants (see Section 4.2.1), the load is much lower.

<table>
<thead>
<tr>
<th>Treated BF gas component</th>
<th>Concentration</th>
<th>Unit</th>
<th>Specific factor</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>BF gas production</td>
<td>1.0 - 7.0</td>
<td>10^8 Nm^3/h</td>
<td>1200 - 2000</td>
<td>Nm^3/t HM</td>
</tr>
<tr>
<td>Particulate matter</td>
<td>1 - 10</td>
<td>mg/Nm^3</td>
<td>1 - 20</td>
<td>g/t HM</td>
</tr>
<tr>
<td>Hydrocarbons (C,H)</td>
<td>n/a</td>
<td>mg/Nm^3</td>
<td>n/a</td>
<td>g/t HM</td>
</tr>
<tr>
<td>H2S</td>
<td>14</td>
<td>mg/Nm^3</td>
<td>17 - 26</td>
<td>g/t HM</td>
</tr>
<tr>
<td>Cyanide compounds</td>
<td>n/a</td>
<td>mg/Nm^3</td>
<td>n/a</td>
<td>g/t HM</td>
</tr>
<tr>
<td>Ammonia (NH3)</td>
<td>n/a</td>
<td>mg/Nm^3</td>
<td>n/a</td>
<td>g/t HM</td>
</tr>
<tr>
<td>Heavy metals</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mn</td>
<td>0.10 - 0.29</td>
<td>mg/Nm^3</td>
<td>0.22 - 0.37</td>
<td>g/t HM</td>
</tr>
<tr>
<td>Pb</td>
<td>0.01 - 0.05</td>
<td>mg/Nm^3</td>
<td>0.02 - 0.07</td>
<td>g/t HM</td>
</tr>
<tr>
<td>Zn</td>
<td>0.03 - 0.17</td>
<td>mg/Nm^3</td>
<td>0.07 - 0.22</td>
<td>g/t HM</td>
</tr>
<tr>
<td>Carbon monoxide (CO)</td>
<td>20 - 28</td>
<td>vol. %</td>
<td>300 - 700</td>
<td>kg/t HM</td>
</tr>
<tr>
<td>Carbon dioxide (CO2)</td>
<td>17 - 25</td>
<td>vol. %</td>
<td>400 - 900</td>
<td>kg/t HM</td>
</tr>
<tr>
<td>Hydrogen (H2)</td>
<td>1 - 5</td>
<td>vol. %</td>
<td>1 - 7.5</td>
<td>kg/t HM</td>
</tr>
</tbody>
</table>

n/a = data not available

Table 6.8: Blast furnace gas composition (after two-stage treatment) [65] [344]

In the EU, wet scrubbing is the technique most commonly applied as a second step in BF gas treatment. Scrubbing generates a contaminated waste water flow, containing suspended solids (e.g. carbon and heavy metals), cyanide compounds, nitrogen compounds, etc. The separated solids generate a waste problem because of heavy metals, especially zinc. Whereas coarse dust is normally recycled to the sinter plant, sludge from scrubbing is usually dewatered and either recycled to the sinter plant (normally via a hydrocyclone that separates fractions with low and high concentration of heavy metals) or put to secure landfill [409] [410].
Chapter 6

Hot stoves

Hot stoves are fired with gas. Depending on the installation, the combinations are:

- BF gas + COG gas
- BF gas + natural gas
- BF gas + BOF gas
- any other combination of the four gases used (BF gas, COG gas, Natural gas, BOF gas) or pure gas.

Coke oven gas contains sulphur compounds, which are emitted as SO\(_2\) at the hot stove when the gas is used for firing. [145] reports that several hot stoves with modern burners and combustion air preheating are operated using BF gas without enrichment [344].

Flue-gas flow from the hot stoves is approximately 100000 to 500000 Nm\(^3\)/h per blast furnace. The specific off-gas flow is 400 - 1000 Nm\(^3\)/t hot metal. Emissions concentrations for SO\(_2\) are in the range of 4 - 154 mg/Nm\(^3\) depending on the used gas (on an annual average basis, see Table 6.2) which corresponds to 1.6 - 154 g/t hot metal. In case of a mixture of BF gas and non-desulphurised COG, the emission factor can be up to 400 g SO\(_2\)/t hot metal which corresponds to up to 400 mg/Nm\(^3\).

The hot stoves are the main source of emissions of NO\(_X\) in the blast furnace process. NO\(_X\) is formed as a result of high temperatures in the stove. Emission concentrations are in the range of 20 - 120 mg/Nm\(^3\) (on an annual average basis, see Table 6.2) which corresponds to 8 - 120 g/t hot metal produced [344].

Particulate matter emissions from the hot stoves are usually between 1 and 12 mg/Nm\(^3\) which corresponds to 0.4 - 12 g/t hot metal [344].

CO emissions are considerable in the case of internal combustion chambers (see Figure 6.5). Cracks in the brick work, which are very difficult to avoid, mean BF gas can move without combustion to the waste gas and can be emitted in concentrations of up to 2891 mg CO/Nm\(^3\) equivalent to as much as 2891 g CO/t hot metal. In the case of an external combustion chamber with controlled combustion, the concentration is about <50 mg CO/Nm\(^3\) [344] [531].

| PM | 0.1 - 12 |
| CO | 4.11 - 2891 |
| NO\(_X\) | 19 - 115 |
| SO\(_X\) | 4 - 154 |
| Hg | 0.003 |
| Cd,Tl | 0.0057 |
| Sb,Pb,Cr,Co,Cu,Mn,Ni,V | 0.24 |
| HF | <0.08 |
| HCl | 3 |
| PCDD/F | 0.002 - 0.004 (ng/Nm\(^3\)) |

Note: The values are derived from seven EU installations and correspond to annual averages and for three German plants additionally to half-hourly averages.

Table 6.9: Emission concentrations from hot stoves

[200] [346] [407] [531]
Chapter 6

Cast house
The casting of hot metal generates particulate matter emissions. On average, unabated emissions are in the range of 400 - 1500 g/t hot metal produced. These emissions mainly arise from contact between the hot metal and slag and ambient oxygen. In order to catch the dust formed during casting, in many blast furnaces in the EU cast house dedusting systems are used (dust extraction at tap hole, skimmer and hot metal charging to the torpedo ladle) with flows of between 200000 and 700000 Nm³/h. Dust emissions depend on applied abatement technique (in some cases there are still none) and dust collection efficiency. In many cases, bag filters are applied, achieving less than 10 mg dust/Nm³. Dust emission factors vary between 0.5 and 45 g/t hot metal with an average of 32 g dust/t hot metal. Furthermore, a certain amount of SO₂ is emitted from the liquid slag and iron during casting (7 - 195 g/t hot metal) [344].

<table>
<thead>
<tr>
<th>Species</th>
<th>Range (mg/Nm³)</th>
<th>Annual average</th>
<th>Range (mg/Nm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust</td>
<td>0.3 - 10.4</td>
<td></td>
<td>5 half-hourly average</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.38 - 0.49 daily average</td>
</tr>
<tr>
<td>SOₓ</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hg</td>
<td>&lt;0.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cd,Tl</td>
<td>0.00004</td>
<td></td>
<td></td>
</tr>
<tr>
<td>As,Co,Ni,Se,Te</td>
<td>&lt;0.003</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pb,Co,Ni,Se,Te</td>
<td>&lt;0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pb,Cr,Cu,Mn,V</td>
<td>0.004 - 0.014</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sb,Cr,CN,F,Cu,Mn,V,Sn</td>
<td>&lt;1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HCl</td>
<td>0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H₂S</td>
<td>1.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Values are the ranges derived from four EU installations and correspond to annual averages and for dust to the half-hourly and daily average for one German plant.

Table 6.10: Emission concentrations from the BF cast house and burden dedusting [200] [346] [407]

Slag processing
The reaction of water with molten slag, particularly with sulphur compounds (essentially CaS and MnS) generates both steam and diffuse H₂S and SO₂ emissions. These emissions cause potential odour and corrosion problems. Their importance varies according to the slag processing technique used. Blast furnace slag taken from the slag runner has a sulphur content of around 1 - 2 wt- %. The major sulphur compound in the slag is CaS [392].

Emissions can vary greatly from one plant to another, from one slag treatment cycle to another and within the slag treatment cycle itself. The range of available emission factors is wide. Available figures vary from 1 - 320 g H₂S/t hot metal and 1 - 150 g SO₂/t hot metal for slag granulation. For an industrial INBA plant with an average slag flow rate of 3.5 t/min and a supposed exhaust air/steam flow rate of 10000 Nm³/h at the chimney, the resulting concentrations of H₂S and SO₂ are in the range of 50 - 28000 mg/Nm³ for H₂S and 135 - 15600 mg/Nm³ for SO₂. If slag is not exposed to water but air-cooled, long-lasting small emissions of mainly SO₂ will occur. From the perspective of nuisance abatement, this can be considered an advantage [344] [392].

Emissions of H₂S and SO₂ cause potential odour and corrosion problems. The gaseous sulphur compounds emissions depend strongly on the kind of granulation system, slag flow rate, slag/water ratio and on the granulation water temperature. Since the solubility of H₂S and SO₂ decreases with rising water temperatures, at cold water granulation systems, lower gaseous sulphur compounds emissions are observed than at hot water systems [392] [242].

In order to reduce emissions, some plants are operated with fume condensation. The condensate and the slag dewatering water are circulated after cooling. With this technique, H₂S emissions within the range of 1 - 10 g per tonne of hot metal are achievable.
The water used in the granulation and the pelletising process can largely be collected and re-used. These systems can be operated so as to generate very small amounts of waste water. The steam generated during this process contains particulate matter, SO$_2$ and H$_2$S, which is usually emitted to the atmosphere. Tests have been carried out to re-use the sensible heat of the slag, but no system is commercially available at the moment. The potential for energy recovery is approximately 0.35 GJ/t hot metal.

The production of lump slag from pits usually leads to larger emissions of SO$_2$ and H$_2$S, which can be more difficult to control. Conditioning with water can influence the emissions of H$_2$S.

6.2.2.2 Waste water

Waste water from BF gas treatment

Water from BF gas scrubbing is normally treated, cooled and recycled to the scrubber (see Figure 6.11). Treatment usually takes place in circular settling tanks.

The overflow of the circuit is normally 0.1 - 3.5 m$^3$/t hot metal depending on raw material quality/specification and water availability which influences the measures taken to optimise water recycling. Especially high salt content raw materials can require significant higher volumes of wash-water.

Table 6.11 shows some data about the composition of the waste water from BF gas scrubbing before treatment.
Table 6.11: Composition of waste water from BF gas scrubbing before treatment [232][233]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Average</th>
<th>Median</th>
<th>Range (min-max)</th>
<th>SD</th>
<th>Emission factor</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water demand</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.57</td>
</tr>
<tr>
<td>Pb</td>
<td>µg/l</td>
<td>2.52</td>
<td>2.00</td>
<td>&lt;2.00 - 6.40</td>
<td>1.10</td>
<td>7.13</td>
<td>mg/t HM</td>
</tr>
<tr>
<td>Cr</td>
<td>µg/l</td>
<td>2.41</td>
<td>2.00</td>
<td>&lt;2.00 - 6.90</td>
<td>1.08</td>
<td>7.13</td>
<td>mg/t HM</td>
</tr>
<tr>
<td>Cu</td>
<td>µg/l</td>
<td>4.06</td>
<td>3.80</td>
<td>&lt;2.00 - 9.50</td>
<td>2.05</td>
<td>13.55</td>
<td>mg/t HM</td>
</tr>
<tr>
<td>Zn</td>
<td>µg/l</td>
<td>20.92</td>
<td>20.00</td>
<td>&lt;20.00 - 38.00</td>
<td>3.62</td>
<td>71.31</td>
<td>mg/t HM</td>
</tr>
<tr>
<td>Cd</td>
<td>µg/l</td>
<td>0.20</td>
<td>0.20</td>
<td>&lt;0.20 - 0.23</td>
<td>0.01</td>
<td>0.71</td>
<td>mg/t HM</td>
</tr>
<tr>
<td>Ni</td>
<td>µg/l</td>
<td>3.74</td>
<td>3.15</td>
<td>&lt;2.00 - 10.00</td>
<td>1.98</td>
<td>11.23</td>
<td>mg/t HM</td>
</tr>
<tr>
<td>Fe</td>
<td>mg/l</td>
<td>0.44</td>
<td>0.18</td>
<td>0.03 - 2.60</td>
<td>0.61</td>
<td>0.64</td>
<td>g/t HM</td>
</tr>
<tr>
<td>Cl</td>
<td>mg/l</td>
<td>262.96</td>
<td>264.00</td>
<td>140 - 402</td>
<td>57.60</td>
<td>941.26</td>
<td>g/t HM</td>
</tr>
<tr>
<td>AOX</td>
<td>µg/l</td>
<td>21.63</td>
<td>16.50</td>
<td>&lt;10.0 - 66.0</td>
<td>13.18</td>
<td>58.83</td>
<td>g/t HM</td>
</tr>
<tr>
<td>Suspended solids</td>
<td>mg/l</td>
<td>27.11</td>
<td>5.90</td>
<td>0.6 - 145.0</td>
<td>42.68</td>
<td>21.04</td>
<td>g/t HM</td>
</tr>
<tr>
<td>DOC</td>
<td>mg/l</td>
<td>4.70</td>
<td>4.00</td>
<td>3.10 - 8.70</td>
<td>1.46</td>
<td>14.26</td>
<td>g/t HM</td>
</tr>
</tbody>
</table>

Cyanide content is shown to increase during a burden descent in the blast furnace and transition periods (stopping, restarting) that are more frequent at the end of a production campaign. Under these conditions, higher values of cyanide in the scrubbing water can be found. It seems that the formation of cyanides in the blast furnace are related to the presence of alkali metals [232][233].

**Waste water from slag granulation**

Overflow of water from slag granulation primarily depends on water availability and is in the range of 0.125 - 10 m³/t hot metal produced. Information on chemical composition is available in Table 6.12. The emission factors are based on a water consumption of 7921113 m³ and a hot metal production of 2221686 t which results in a specific water demand of 3.57 m³/t hot metal.
**Parameter** | **Unit** | **Average** | **Median** | **Range (min-max)** | **SD** | **Emission factor** | **Unit**
--- | --- | --- | --- | --- | --- | --- | ---
TOC | mg/l | 5.51 | 5.00 | 3.10 - 11.3 | 2.06 | 17.83 | g/t HM
COD | mg/l | 22.17 | 22.50 | 14.00 - 27.00 | 4.22 | 80.22 | g/t HM
HC | mg/l | 0.15 | 0.10 | <0.10 - 0.25 | 0.05 | 0.36 | g/t HM

*based on the median of 24 measurements (for COD on six measurements)

SS: suspended solids; HC: mineral oil hydrocarbons; SD: standard deviation.

Data from Stahlwerke, Bremen Germany, random sample measurements for the composition of waste water from slag granulation from March 2000 to November 2006. Figures in italic indicate that measurement values below the detection limit have been computed as the detection limit.

Table 6.12: Pollutant concentrations and emission factors for waste water from blast furnace slag granulation

[357]

**Blow down from cooling water circuits**

Blow downs of the cooling water circuit take place (see Figure 6.11). Information on representative quantities and chemical composition is not available.

### 6.2.2.3 Process residues such as wastes/by-products

**Dust from casting**

Between 0.6 and 5.1 kg of dust can be extracted from the cast house per tonne of hot metal (see Table 6.2). It is common practice to separate this dust in a bag filter so that it can easily be recycled to the sinter strand [344].

**Dust and sludge from BF gas treatment**

BF gas is usually treated in two stages: coarse dusts separation, i.e. by cyclones, followed by fine dust separation in a wet scrubber. This produces 3.5 - 18 kg of dry dust per tonne of hot metal and 2 - 22 kg of sludge/t hot metal (see Table 6.2).

Table 6.13 shows the typical composition of dry coarse dust. This dust mainly contains carbon and iron from coke and sinter abrasion respectively. This coarse dust is normally returned to the sinter strand. This is much more difficult for the sludge because its zinc content is 10 - 20 times higher and lead content is 20 - 30 times higher.

<table>
<thead>
<tr>
<th>C</th>
<th>Fe</th>
<th>Pb</th>
<th>Zn</th>
<th>Mn</th>
<th>Al₂O₃</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 - 40</td>
<td>15 - 40</td>
<td>0.02 - 0.07</td>
<td>0.1 - 0.5</td>
<td>0.1 - 0.5</td>
<td>0.2 - 3.7</td>
<td>0.02 - 0.2</td>
</tr>
<tr>
<td>S</td>
<td>SiO₂</td>
<td>P₂O₅</td>
<td>CaO</td>
<td>MgO</td>
<td>Na₂O</td>
<td>K₂O</td>
</tr>
<tr>
<td>0.2 - 1.3</td>
<td>4 - 8</td>
<td>0.04 - 0.26</td>
<td>2 - 8</td>
<td>0.3 - 2</td>
<td>0.03 - 0.64</td>
<td>0.24 - 0.96</td>
</tr>
</tbody>
</table>

Table 6.13: Typical composition in (wt-%) of dry coarse dust from BF gas treatment

[64] [95]

The zinc and lead compounds are mainly removed from BF gas in the scrubber. Most of the particles associated with zinc and lead compounds or these heavy metals themselves have grain sizes of less than 25 μm and concentrate in this fraction of the sludge. This makes them amenable to separation from the ferrous and carbon-rich fraction, i.e. in a hydrocyclone [344].

<table>
<thead>
<tr>
<th>C</th>
<th>Fe</th>
<th>Pb</th>
<th>Zn</th>
<th>Mn</th>
<th>Al₂O₃</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 - 47</td>
<td>7 - 35</td>
<td>0.8 - 2.0</td>
<td>1 - 10</td>
<td>0.12 - 0.14</td>
<td>0.8 - 4.6</td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>SiO₂</td>
<td>P₂O₅</td>
<td>CaO</td>
<td>MgO</td>
<td>Na₂O</td>
<td>K₂O</td>
</tr>
<tr>
<td>2.4 - 2.5</td>
<td>3 - 9</td>
<td>0.1 - 0.44</td>
<td>3.5 - 18</td>
<td>3.5 - 17</td>
<td>0.15 - 0.24</td>
<td>0.08 - 0.36</td>
</tr>
</tbody>
</table>

Table 6.14: Typical composition in (wt-%) of sludge from BF gas treatment

[64] [95]
Figure 6.12 shows the fate of dust and sludge from BF gas treatment without distinguishing them.

![Figure 6.12: Fate of dust and sludge from BF gas treatment in the EU](30)

**Slag from blast furnaces**

The specific quantity of slag mainly depends on the raw materials used, but generally lies in the range of 175 - 350 kg/t hot metal produced. The composition of different blast furnace slags is given in Table 6.15 [344].

<table>
<thead>
<tr>
<th>Classification</th>
<th>CaO/SiO2</th>
<th>&gt;1.0 middle</th>
<th>&lt;1.0 high</th>
<th>BF1</th>
<th>BF2</th>
<th>BF3</th>
</tr>
</thead>
<tbody>
<tr>
<td>FeO</td>
<td>0.2 - 0.6</td>
<td>0.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MnO</td>
<td>0.2 - 0.7</td>
<td>0.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TiO2</td>
<td>0.5 - 2.7</td>
<td>0.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al2O3</td>
<td>9.0 - 14.0</td>
<td>9.2</td>
<td></td>
<td>13.09</td>
<td>12.63</td>
<td>10.90</td>
</tr>
<tr>
<td>SiO2</td>
<td>33.2 - 37.0</td>
<td>38.4</td>
<td></td>
<td>32.88</td>
<td>36.78</td>
<td>36.90</td>
</tr>
<tr>
<td>CaO</td>
<td>38.1 - 41.7</td>
<td>35.6</td>
<td></td>
<td>33.76</td>
<td>36.64</td>
<td>35.80</td>
</tr>
<tr>
<td>MgO</td>
<td>7.0 - 11.0</td>
<td>18.0</td>
<td></td>
<td>15.96</td>
<td>11.19</td>
<td>10.70</td>
</tr>
<tr>
<td>Na2O</td>
<td>0.3 - 0.6</td>
<td>0.5</td>
<td></td>
<td>0.35</td>
<td>0.35</td>
<td></td>
</tr>
<tr>
<td>K2O</td>
<td>0.6 - 0.8</td>
<td>0.8</td>
<td></td>
<td>0.54</td>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td>CaO/SiO2</td>
<td>1.1 - 1.2</td>
<td>0.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(CaO+MgO)/SiO2</td>
<td>1.3 - 1.5</td>
<td>1.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TiO2</td>
<td>2.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6.15: Chemical composition in (wt- %) of blast furnace slag for basicity below and above 1.0 and other examples [47] [270] [385] [392] [394]

The slag is normally used for various purposes (see Table 6.16).

![Figure 6.13: Final use of blast furnace slag in the EU](30)
6.2.2.4 Energy and reductant demand

A major parameter for the consumption of energy is the use of reducing agents (e.g. coke, coal, oil), which also determines CO₂ emissions of the blast furnace process to a major extent. Input of reducing agents is influenced by several operating parameters, such as hot blast temperature, rates and quality of sinter and pellets, quality of coke (ash content, sulphur content, CSR value), input of alkaline, slag amount, ilmenite, Pb/Zn and Si. Thus, the average reducing agent demand for different counties within the European Community in 2002 show a wide range from 453 - 514 kg per tonne of hot metal, with an average reducing demand in the EU-15 of 486 kg per tonne of hot metal.

The blast furnace process is the most energy-consuming process and thus CO₂ emitting unit (inform of reducing agents) in iron and steel production (see Figure 2.1, Figure 2.3 and Figure 2.2). Table 6.16 gives figures for the energy input/output of a blast furnace using coal injection and top gas pressure recovery for electricity generation without considering the energy content of the hot metal.

<table>
<thead>
<tr>
<th>Energy carrier</th>
<th>Specific energy value (GJ/t HM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input:</td>
<td></td>
</tr>
<tr>
<td>• coke</td>
<td>12.4</td>
</tr>
<tr>
<td>• powdered coal</td>
<td>1.63</td>
</tr>
<tr>
<td>• hot blast (from stoves)</td>
<td>4.52</td>
</tr>
<tr>
<td>• electricity</td>
<td>0.12</td>
</tr>
<tr>
<td>• Total (gross)</td>
<td>18.67</td>
</tr>
<tr>
<td>Output</td>
<td></td>
</tr>
<tr>
<td>• electricity</td>
<td>0.35</td>
</tr>
<tr>
<td>• BF gas</td>
<td>5.15</td>
</tr>
</tbody>
</table>

Table 6.16: Example of energy input/output of a blast furnace with high top pressure using coal injection and top gas pressure recovery in 1986

[65]

Many plants with adequate top gas pressure (>1.5 bar gauge) and sufficient pressure drop are suitable for installation of expansion turbines for the recovery of top gas pressure energy.

Process improvements have meant that the specific coal consumption in European steelworks has decreased considerably.

A trend towards direct reducing agent injection will probably further decrease specific coke consumption. Direct reducing agent injection in the blast furnace replaces the use of coke, thus saving energy in coke production. Most blast furnace installations inject reducing agents into the furnace at the tuyère level. This partially replaces coke in the top charge. This practice enables the operator to optimise on the use of reducing agents. Other advantages are a lowered production of coke, thereby decreasing the specific coke oven emissions per tonne of steel produced. Many plants inject pulverised or granular coal or oil. Some blast furnace operators now inject coke oven gas or natural gas. Two companies have been injecting plastic waste to their furnaces to utilise the high hydrocarbon content for reduction processes for several years [145] and at least one new facility has been installed in the EU since 2001. Where appropriate, other injectants classified as eco-oils, reclaimed or waste oils, fats, tar, animal fats and emulsions have also received attention [344].
6.2.2.5 Noise emissions

[242]

Noise emissions may be generated from blast furnace tuyères, particularly when they are not aligned.
6.3 Techniques to consider in the determination of BAT

This section sets out techniques considered generally to have potential for achieving a high level of environmental protection in the industries within the scope of the document. Management systems, process-integrated techniques and end-of-pipe measures are included, but a certain amount of overlap exists between these three when seeking the optimum results.

Prevention, control, minimisation and recycling procedures are considered as well as the re-use of materials and energy.

Techniques may be presented singly or as combinations to achieve the objectives of the IPPC Directive. Annex IV to this Directive lists a number of general considerations to be taken into account when determining BAT and techniques within this section will address one or more of these considerations. As far as possible, a standard structure is used to outline each technique, to enable comparison of techniques and an objective assessment against the definition of BAT given in the IPPC Directive.

The content of this section is not an exhaustive list of techniques and others may exist or be developed which may be equally valid within the framework of the IPPC and BAT.

The standard structure used to outline each technique is shown in Table 6.17.

<table>
<thead>
<tr>
<th>Type of information considered</th>
<th>Type of information included</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Technical description of the technique (including drawings, schematics if necessary)</td>
</tr>
<tr>
<td>Achieved environmental benefits</td>
<td>Main environmental benefits (including energy, water, raw material savings, as well as production yield increases, energy efficiency, etc.) addressed by the technique</td>
</tr>
<tr>
<td>Cross-media effects</td>
<td>Main environmental side effects and disadvantages to other media caused by using the technique. Details of the environmental effects of the technique in comparison with others</td>
</tr>
<tr>
<td>Operational data</td>
<td>Data on consumption and emission levels from operational plants using the technique (including any reference conditions and monitoring methods used). Any other relevant information on how to operate, maintain and control the technique</td>
</tr>
<tr>
<td>Applicability</td>
<td>Indication of the type of plants in which the technique may be applied, considering, e.g. plant age (new or existing), plant size (large or small), techniques already installed and type or quality of product</td>
</tr>
<tr>
<td>Economics</td>
<td>Information on costs (both investment and operational) and any possible savings (e.g. reduced raw material or energy consumption, waste charges) or revenues including details on how these costs/savings or revenues have been calculated/estimated</td>
</tr>
<tr>
<td>Driving force for implementation</td>
<td>Local conditions or requirements which lead to, or may stimulate, implementation. Information on reasons other than environmental ones for implementation (e.g. increase in productivity, safety)</td>
</tr>
<tr>
<td>Example plants</td>
<td>Reference to (a) plant(s) in which the technique is applied and from which information has been collected and used in writing the section</td>
</tr>
<tr>
<td>Reference literature</td>
<td>Literature or other reference material (e.g. books, reports, studies, websites) that was used in writing the section and that contains more details on the technique</td>
</tr>
</tbody>
</table>

Table 6.17: Information breakdown for each technique described in this section
6.3.1 Cast house dedusting (tap holes, runners, skimmers, torpedo ladle charging points)

Description
Hot metal and slag are cast from the blast furnace and run through the runners to the ladle and the slag treatment unit respectively. During tapping/casting, the liquid metal comes into contact with atmospheric oxygen (O₂) when flowing along the runners. As a result of the high temperature of the iron (1300 - 1500 °C) it reacts with the oxygen to form iron oxides (e.g. Fe₂O₃), "brown fume." Slag does not react with atmospheric oxygen because most of its components are already oxidised. However, alkaline oxides (e.g. Na₂O and K₂O) can vaporise out of the slag forming particulate emissions.

First measurements of flue-gas of the cast house dedusting indicate emissions in the range of 100 - 400 mg/Nm³ (single measurements).

Generally, two types of measures can be applied to reduce dust emissions from casting:

- covering the runners with movable lids
- dissipating oxygen from the tapped hot metal by means of covering the hot metal with nitrogen (N₂). In this way, the formation of iron oxides is avoided (see Section 6.3.2).

Achieved environmental benefits
During tapping, approximately 400 - 1500 g particulate matter is generated per tonne of hot metal when no abatement measures are applied. Evacuation of air from above the runners essentially leads to greater particulate matter generation, due to the increased availability of oxygen.

In cases where the runners are covered by lids and particulate matter is evacuated and treated, the most important parameter is evacuation efficiency. Special attention should be paid to the covering of the runners. The runner covers should be tightly connected, aiming for a leak-free system. At the tap hole, efficient evacuation of the generated particulate matter is difficult, due to the space required for operation of the tap hole drill and the mud gun and due to the presence of the bustle pipe, which serves the tuyères and circles the blast furnace at the height of the bosh. Usually, a very large flow is needed to efficiently evacuate the particulate matter generated in the vicinity of the tap hole.

The main evacuation points in a cast house are:

- the tap hole
- the skimmer
- the tilted runner (charging the torpedo ladle).

The specific flow of evacuated gas (waste gas) is 1200 - 3300 Nm³/t hot metal. With an effective dust collection and abatement system (e.g. bag filter), specific emission factors of less than 10 g/t hot metal can be achieved [65]. The dust collection efficiency can exceed 99 % and the dust removal efficiency of bag filters can also exceed 99 % [65].

At Voestalpine blast furnace A (hot metal production of about 3.5 Million t/yr), a cast house dedusting with a bag filter system treating 700000 m³/h has been installed. Dust emissions are measured continuously. Annual average emissions have been at 11.0 mg/Nm³ (2004), and 2.2 mg/Nm³ (2005) after relining the blast furnace and adapting the cast house dedusting emissions, which took place at the end of 2004. Recent daily average emission values are in the range of 3 - 10 mg/Nm³ (see Section 2.5.5).
At Voestalpine, a cast house dedusting system with a bag filter treating 355000 m³/h was installed for blast furnaces 5 and 6 at the end of 2005. Dust emissions are measured continuously. Recent emission values based on daily average values are about 1 mg/Nm³ (see Section 2.5.5).

German installations achieve dust emissions applying bag filters of 0.3 - 1 mg/Nm³ (annual average).

<table>
<thead>
<tr>
<th></th>
<th>ESP</th>
<th>bag filter</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM</td>
<td>10.4</td>
<td>0.3 - 1</td>
</tr>
<tr>
<td>Hg</td>
<td></td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Hg,Tl</td>
<td></td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>Cd,Tl</td>
<td>0.00004</td>
<td>&lt;0.0018</td>
</tr>
<tr>
<td>As,Co,Ni,Se,Te</td>
<td>0.003</td>
<td></td>
</tr>
<tr>
<td>As, Co,Ni</td>
<td></td>
<td>&lt;0.003</td>
</tr>
<tr>
<td>Pb,Co,Ni,Se,Te</td>
<td>0.014</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>Pb, Cr, Cu, Mn, V</td>
<td>0.00434</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Sb,Cr,CN,F,Cu,Mn,V,Sn</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Data from abatement of gases from casting bay and burden dedusting. Annual averages in mg/Nm³.

Table 6.18: Emission concentrations from the BF cast house and burden dedusting

[407]

Figure 6.14 shows achieved daily average emissions over three month in the cast-house emissions from three blast furnaces.
Chapter 6

Figure 6.14: Daily average emission values of cast house dedusting systems at tapholes and runners of blast furnaces. Voestalpine - Austria

[424]

Cross-media effects
The application of evacuation and treatment of gases consumes additional energy as it requires powerful fans. From [65], an energy consumption of approximately 0.007 GJ/t hot metal can be calculated, based on an annual hot metal production of 3 million t by BF-7 at 8640 operational hours.

The collected dust has a high iron content and can be recycled to the sinter plant.

Operational data
The described technique is operated, in practice, without significant problems.

Applicability
Covering of runners and subsequent evacuation and cleaning can be applied at new and existing plants.

Economics
At Corus, Ijmuiden, the Netherlands investments for a bag filter system treating 690000 Nm³/h is reported to be in the range of EUR 1 million - 2.3 million. This only includes the bag filter equipment. Runner covering and evacuation layout are not included in this figure.
Operational costs can be calculated as EUR 0.5 million - 2.8 million/t hot metal, based on an annual production of 3 million t hot metal/yr by BF-7 and 8640 operational hours [65].

Installation costs for the cast house dedusting system at blast furnace A of Voestalpine, Linz, Austria (about 3 million t/yr BF) was approximately EUR 14.5 million. Operational costs (without energy) are about EUR 0.42 million per year.

For all examples the currencies were converted into Ecu in 1996 and for the review into EUR.

Installation cost for Corus, Scunthorpe, United Kingdom (EUR 1 million/t BF) for one cast house dedusting system was approximately EUR 4.0 million in 1997.

**Driving force for implementation**
No data submitted.

**Example plants**
*Evacuation and treatment of gases:* Blast furnaces 7, Corus, IJmuiden, the Netherlands; blast furnaces 5 and 6 A, Voestalpine, Linz, Austria; blast furnace Schwelgern, Thyssen Krupp Stahl AG, Duisburg, Germany; ArcelorMittal, Dąbrowa Górnicza, Poland.

**Reference literature**
[65] [353] [404] [407] [424]

### 6.3.2 Fume suppression during hot metal charging

**Description**
Section 6.3.1 describes conventional dedusting systems of cast house emissions. These systems are rather complex and costly. New approaches prevent the molten iron from reacting with atmospheric oxygen to form "brown fume" (fume suppression). In order to prevent the reaction, the whole transport route for the hot metal, from the tap-hole via various distribution and transfer points to the torpedo ladle is enclosed by means of carefully designed screening structures. The space between the molten metal and the covers is kept as small as possible, and it is, if necessary, flooded with nitrogen (inert gas). In integrated steelworks, the nitrogen yielded in air separation for oxygen generation may be available for this purpose.

This new method eliminates the installation and operation of complex and expensive exhaust and filter systems which was necessary previously, and thus leads to considerable cost savings. The cost of recycling filter dust is also reduced. This method works particularly well when the volumes to be enclosed at both the tap hole and the torpedo charging point are relatively compact. Under these conditions, closed housings can be constructed of limited volume facilitating the application of this technique. However, it has been found necessary to use an exhaust system at the tap-hole and when the charging point to the torpedo has a large volume e.g., when using a tipping spout (as opposed to a swinging spout), then the efficiency of the nitrogen suppression system is not sufficient and it is necessary to switch to the classical exhaust suction system. A common filter for the exhaust systems for both the tap-hole and torpedo charge point can be used.

Figure 6.15 shows the quantity of dust generated during charging of hot metal with and without dust suppression. These figures are about 100 times lower when nitrogen inertisation is used.
Figure 6.15: Dust generation with and without nitrogen inertisation during hot metal charging (to the torpedo level) depending on the flow of hot metal

[52]

Achieved environmental benefits

During conventional casting 0.4 - 1.5 kg dust/t hot metal is generated (see Table 6.10). This quantity is reduced by dust suppression to about 0.012 kg dust/t hot metal [52]. Figure 6.16 shows the effect of dust suppression during charging of hot metal to the torpedo ladle.

Figure 6.16: Charging of hot metal into torpedo ladle with dust suppression with inert gas

[52]
Cross-media effects
There are no significant cross-media effects if the system is compared to conventional dedusting systems. When using such large amounts of nitrogen, it should be ensured that the nitrogen does not accumulate within the casthouse due to the danger of suffocation.

Operational data
Experience with fume suppression at ArcelorMittal, Bremen, Germany shows constant operational conditions without significant problems.

Applicability
Applicable both at new and existing plants, albeit that the efficiency of the system is restricted if the volumes to be suppressed are large.

Economics
A comparison of costs is shown in Figure 6.17 shows the comparison of costs. The new fume suppression technique is considerably cheaper. The installation at ArcelorMittal, Bremen, Germany with a production of 3 million t hot metal/yr required an investment of EUR 6.8 million including dust suppression and tap hole dedusting with a subsequent bag filter. For the example the currencies were converted into Ecu in 1996 and for the review into EUR.

![Figure 6.17: Comparison of investment, Energy and maintenance costs for the installation at Arcelor Mittal, Bremen Germany](image)

Energy costs are about EUR 190000/yr and maintenance costs about EUR 170000/yr. This is also much lower than conventional systems. Nitrogen costs can, however, vary depending on local circumstances.

Driving force for implementation
No data submitted.

Example plants
At Arcelor Mittal, Bremen, Germany, this fume suppression technique has been in operation since 1991.
6.3.3 Use of tar-free runner linings

Description
The runner system in the cast house of a blast furnace is made of a refractory outer layer (e.g. concrete). The runners are lined with a heat-resistant material, which is based on alumina embedded in a carbon matrix. Coal tar pitch can serve as a binder.

The linings protect the outer layer against the heat of the liquid iron and (especially) the liquid slag. The linings are subject to wear and are renewed every few weeks. The quality of the carbon matrix is an important factor in the durability of runner linings. A weak matrix does not hold the alumina and causes the linings to wear more rapidly.

The required strength of the mixture is only achieved after heating for several hours with burners. Tar decomposition during heating gives rise to emissions of hydrocarbons (and PAH). A minor part of the emissions occur during the casting of slag and hot metal.

A new type of runner lining which does not contain tar has been developed and is being applied successfully. With the new runner lining, emissions of volatile organic compounds (VOC) and polycyclic aromatic hydrocarbons (PAH) are much lower. The new material has the same slag resistance and the durability can be even better than that of traditional runner linings.

Achieved environmental benefits
Table 6.19 shows figures for the emission reduction resulting from the use of tar-free runner linings. The figures shown are estimates based on a theoretical model.

<table>
<thead>
<tr>
<th>Component</th>
<th>Traditional runner lining (g/t HM)</th>
<th>Tar-free runner lining (g/t HM)</th>
<th>Emission reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volatile organic compound (VOC)</td>
<td>100</td>
<td>1</td>
<td>99 %</td>
</tr>
<tr>
<td>Polycyclic aromatic hydrocarbons (PAH)</td>
<td>3.5</td>
<td>0.03</td>
<td>99 %</td>
</tr>
</tbody>
</table>

Table 6.19: Emissions from runner linings

Cross-media effects
Application of this measure has a positive effect on the health of employees because they are less exposed to harmful components. No other cross-media effects are known.

Operational data
At Corus Ijmuiden, the Netherlands the tar-free runner linings are currently applied without problems and have even led to improved runner lining durability.

Applicability
In principle, tar-free runner linings are applicable at both new and existing blast furnaces.

Economics
No data submitted.

Example plants
Many blast furnace operators in the EU use tar-free runners linings.
6.3.4 Blast furnace gas treatment

Description
Blast furnace gas must be cleaned in order to meet grid gas requirements. When leaving the blast furnace, the BF gas (or "top gas") contains particulate matter, cyanides (HCN), ammonia (NH₃) and sulphur compounds (see Table 6.7 and Table 6.8).

BF gas is usually treated in two stages. In the first stage, coarse particulate matter is removed by means of dry cyclonage, a deflector, etc. The coarse particulates collected in this way have a high iron content and can be recycled to the sinter plant (see Table 6.13). In the second stage, particulate matter – including zinc oxide (ZnO) and carbon (C) – cyanide and ammonia are removed by wet scrubbing. The scrubbers are specially designed hurdle type, venturi or annular gap scrubbers. In some cases, wet electrostatic precipitation is applied.

In modern plants, special attention is paid to the pressure drop of the gas cleaning system, because a high-pressure drop has a negative effect on the energy efficiency of the top gas pressure recovery turbine (see 6.3.13). The aim is therefore to construct gas cleaning systems with a low-pressure drop and a high gas cleaning efficiency.

Achieved environmental benefits
BF gas cleaning systems are usually highly efficient, achieving a residual particulate matter concentration of 1 - 10 mg/Nm³. Particulate matter not caught by the gas cleaning system is emitted or combusted at the site of combustion of the BF gas.

The pressure drop of the gas cleaning system depends on the type of equipment used. Reported pressure drops of two modern systems were between 0.07 and 0.14 bar. Pressure drops in older systems range from 0.15 - 0.5 bar.

Cross-media effects
It should be noted that the scrubbers generate a contaminated waste water flow. Gross water consumption of the blast furnace systems is 0.1 - 3.5 m³/t hot metal. Raw materials with a higher salt content can make greater flows necessary in order to clean the BF gas. The water flow generated contains suspended solids, e.g. carbon and heavy metals (Zn, Pb), cyanide compounds and ammonia. Usually, the waste water is treated by means of heavy metal precipitation and a solid waste (sludge) is generated.

This blast furnace sludge contains relatively high concentrations of zinc (Zn) and lead (Pb) (see Table 6.14). This hampers the recycling of the sludge into the production process. Zinc in particular is a ‘poison’ to the blast furnace. Therefore, some plants apply hydrocyclonage to separate the sludge flow into two flows; one with a low zinc content, which can be returned to the sinter plant, and a second with a high zinc content, which can be stored or disposed of (see Section 6.3.7).

Operational data
No data submitted.

Applicability
Blast furnaces around the world apply BF gas cleaning systems. At new plants, a modern system with a low-pressure drop and low water and energy consumption can be applied. Many old blast furnaces are equipped with "old-fashioned" scrubbers. These scrubbers are able to achieve the grid gas requirements, but consume considerable amounts of water and energy and have a relatively large pressure drop. It is sometimes possible to replace the scrubber with a more modern one, but this should be considered in conjunction with the application of a top gas pressure turbine (see 6.3.13), which depends on the operating pressure of the furnace, amongst other factors.
Economics
No data submitted.

Driving force for implementation
No data submitted.

Example plants
BF gas treatment is widely applied at blast furnaces around the world.

Reference literature
[65] [105] [352] [404] [407]

6.3.5 Gas recovery system for top hopper release

Description
The blast furnace burden (coke and ferrous materials) enters the blast furnace at the top (see Section 6.1.2) via a sealed charging system that isolates the furnace gases from the atmosphere. It is necessary to use such a system because the pressure inside the blast furnace is in excess of atmospheric pressure (0.25 - 2.5 bar gauge). The charging system may be a double bell arrangement or, more common in modern blast furnace operation, a bell less system (such as those supplied by Paul Wurth, see Figure 6.18).

Filling of the top hopper is done at atmospheric pressure. For charging the blast furnace, the pressure of the gas in the top hopper has to be matched to the gas inside the blast furnace. There are various means to achieve this pressurisation; the most common is to use semi-clean blast furnace gas drawn from the blast furnace gas system after the removal of the coarse particulate matter and led it into the bunker via the primary equalizing valve. Minor pressure losses are equalised by means of a secondary valve with nitrogen.

In some installations, the top hoppers are purged and pressurised using nitrogen gas only.
Once the hopper has discharged its contents into the blast furnace, it is isolated from the furnace and the pressure is normally equilibrated with atmospheric pressure by discharging the gas via a silencer to the air. Depending on the size of the blast furnace there is therefore a potential to release 40 to 80 m³ of dirty blast furnace gas per charge.

The discharge of blast furnace gas to the atmosphere during pressure equilibration of the top hopper(s) can be prevented by a gas recovery system in which the gases are redirected via the gas recovery valve into the clean gas main after the scrubber. An example is shown in the Figure 6.19.

An alternative system for blast furnaces operating at normal pressure is to pressurise the furnace top bunkers with a gas, e.g. nitrogen or steam, which currently being installed at the blast furnaces 5 and 6 of Voestalpine Stahl GmbH, Linz, Austria. The achieved environmental benefits are nearly the same as with the gas recovery system for top hopper release.

Figure 6.19 Diagram of a bell less top with equalising, relief and gas recovery system [488]

Achieved environmental benefits
The reduction in the emission of top gas (CO and H₂) and particulate matter during charging is dependent upon factors such as the top hopper volume, number of dumps per day and top gas pressure. The conditions for voestalpine Stahl GmbH, Blast Furnace A, Linz, Austria are given in Table 6.20.
Chapter 6

<table>
<thead>
<tr>
<th>Units</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>t/day</td>
</tr>
<tr>
<td>Equivalent HM</td>
<td>t/charge</td>
</tr>
<tr>
<td>Charges</td>
<td>Number/day</td>
</tr>
<tr>
<td>Discharges</td>
<td>Number/day</td>
</tr>
<tr>
<td>Top hopper volume</td>
<td>m³</td>
</tr>
<tr>
<td>Top pressure (abs.)</td>
<td>kPa</td>
</tr>
<tr>
<td>Top gas temperature</td>
<td>°K</td>
</tr>
<tr>
<td>Reference temperature</td>
<td>°K</td>
</tr>
<tr>
<td>Reference pressure</td>
<td>kPa</td>
</tr>
<tr>
<td>Furnace availability</td>
<td>days per year</td>
</tr>
<tr>
<td>Top gas emission</td>
<td>Nm³/dump</td>
</tr>
<tr>
<td>CO in top gas</td>
<td>%</td>
</tr>
<tr>
<td>Emission of CO</td>
<td>Nm³/yr</td>
</tr>
</tbody>
</table>

Table 6.20: Conditions for Blast Furnace A at voestalpine, Linz, Austria

There will be times when the blast furnace operations are suspended, e.g. for plant maintenance, when it is not possible to prevent some diffuse emissions from the blast furnace top. However, an application of this system at Blast furnace A at voestalpine Stahl GmbH, Linz, Austria, has resulted in a reduction in the diffuse top gas emission of between 70 and 95%.

Cross-media effects
There are no known cross-media effects.

Operational data

<table>
<thead>
<tr>
<th>Components</th>
<th>Total reduction of emission</th>
<th>Specific reduction of emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>BF dust total</td>
<td>6.19 t/yr</td>
<td>1.73 g/t HM</td>
</tr>
<tr>
<td>PM₁₀ (50 %)</td>
<td>3.09 t/yr</td>
<td>0.86 g/t HM</td>
</tr>
<tr>
<td>CO</td>
<td>3262 t/yr</td>
<td>911 g/t HM</td>
</tr>
<tr>
<td>Pb</td>
<td>16.0 kg/yr</td>
<td>4.5 mg/t HM</td>
</tr>
<tr>
<td>Cr</td>
<td>1.09 kg/yr</td>
<td>0.30 mg/t HM</td>
</tr>
<tr>
<td>Hg</td>
<td>0.0105 kg/yr</td>
<td>0.0029 mg/t HM</td>
</tr>
<tr>
<td>Ni</td>
<td>0.22 kg/yr</td>
<td>0.06 mg/t HM</td>
</tr>
<tr>
<td>Cd</td>
<td>0.314 kg/yr</td>
<td>0.088 mg/t HM</td>
</tr>
<tr>
<td>V</td>
<td>1.36 kg/yr</td>
<td>0.38 mg/t HM</td>
</tr>
<tr>
<td>Zn</td>
<td>1.34 kg/yr</td>
<td>0.40 mg/t HM</td>
</tr>
<tr>
<td>HF</td>
<td>1.39 kg/yr</td>
<td>0.39 mg/t HM</td>
</tr>
<tr>
<td>HCl</td>
<td>0.026 t/yr</td>
<td>0.007 g/t HM</td>
</tr>
</tbody>
</table>

Table 6.21: Reduction in fugitive emissions with gas recovery system for top hopper release at voestalpine Stahl GmbH, Blast Furnace A, Linz, Austria

The data shown in Table 6.21 show the effect of the application of this system at Blast Furnace A at voestalpine Stahl GmbH, Linz, Austria. The operating costs for this system are about EUR 0.01/t hot metal, including the costs of maintenance. Therefore, for this furnace, the costs are approximately EUR 26600 per year.
Applicability
Applicable for both new plants and existing plants provided the furnace has a bell less charging system. It is not suited to plants where the gases other than blast furnace gas (e.g. nitrogen) are used to pressurise the furnace top bunkers. However, the capital investment will be minimised when a complete rebuild of the furnace top is made or when first installing a bell less top.

Economics
The investment costs were EUR 1.2 million in 2004 for the voestalpine Stahl GmbH, Linz, Austria blast furnace, with a production of 2.75 million t hot metal/yr. Operating costs including the costs of maintenance are about EUR 0.01/t hot metal. In terms of dust releases over a ten year period, this investment prevents the release of 62 tonnes of dust. On the other hand, it may be possible to realise a return on the investment from the saving in the CO and H₂ release. These are thought to amount to no more than EUR 151000/yr.

Driving force for implementation
A reduction in the fugitive dust emissions is the principal environmental driving force but there may be an energy savings associated with the utilisation of the recovered CO and H₂ in the blast furnace stoves, for example.

Example plants
The only known example of the application of this technology is at Blast Furnace A of voestalpine Stahl GmbH, Linz, Austria.

Reference literature
[424] [487]

6.3.6 Treatment and re-use of scrubbing water

Description
BF gas is usually cleaned in specially designed hurdle type, venturi or annular gap scrubbers (see also Section 6.3.4). This generates a contaminated water flow containing suspended solids (1 - 10 kg/t hot metal; including heavy metals), cyanides and phenols. Measures can be taken to minimise discharges to water and to minimise water consumption.

To scrub the pollutants from the BF gas, approximately 0.3 - 4.0 l/Nm³ are needed. This figure corresponds to a gross water consumption of 0.4 - 8 m³/t hot metal. A large part of this water can be treated and recycled.

The treatment is usually performed in circular settling tanks. The sedimentation properties of the sludge is very often improved by dosage of flocculation agents (anionic polyelectrolytes, mixed polymers or activated silicic acids) or by sludge contact plants. Attention must be paid to pH value and water hardness. Operational data from seven German sludge contact plants can be seen in Table 6.22.
### Table 6.22: Operational data from seven German sludge contact plants for the treatment of scrubbing water

[136]

Depending on the operational conditions of the blast furnace, cyanide treatment may be necessary, particularly during blow down operations. Meanwhile, this is mainly performed by formaldehyde addition to the water circuit (see Figure 6.20). Available experience indicates that:

- optimum pH is between 8 - 9
- there is no reaction below pH 7
- glyconitrile is decomposed at above pH 10 into cyanide and formaldehyde.
The sludge from the fine particle precipitation has a relatively high zinc content (see Table 6.14) and can be treated by means of hydrocyclonage (see also Section 6.3.12).

A new concept of waste water treatment is used at Corus, Ijmuiden, the Netherlands. It is called BIO 2000 and consists of the combined treatment of waste water from the coke oven plant, the blast furnaces and from the sinter plant in an activated sludge system with pre-denitrification and nitrification in order to minimise COD and nitrogen compounds emissions.

Combined treatment of four waste water flows in a biological treatment plant according to the ‘pre-DN/N’ concept where pre-DN/N stands for pre-denitrification-nitrification, has been successfully in operation since the year 2000.

Nitrification and COD removal takes place simultaneously in the aerobic part of the installation. The end-products from this conversion are CO₂, water and nitrate, NO₃⁻.

Denitrification is the biological process where nitrate is converted by bacteria into nitrogen gas. This process happens under anaerobic or anoxic conditions. So, there should be a special part of the installation where dissolved oxygen concentrations are more or less equal to zero. However, in denitrifying bacteria, some COD as feed is also needed. By putting in (part of) the influent in the anoxic part of the installation and recycling nitrified waste water, COD and nitrate come together in this part. Because the denitrification takes place in the first part of the installation, this is called pre-denitrification.
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<table>
<thead>
<tr>
<th>Units</th>
<th>Blast Furnace</th>
<th>Sinter Plant</th>
<th>Coke Plant</th>
<th>Ground Water</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow m3/h</td>
<td>140 - 150</td>
<td>50 - 55</td>
<td>80 - 90</td>
<td>35 - 40</td>
<td>320</td>
</tr>
<tr>
<td>Temperature °C</td>
<td>40 - 44</td>
<td>35 - 40</td>
<td>30 - 35</td>
<td>10 - 12</td>
<td>33</td>
</tr>
<tr>
<td>Suspended solids mg/l</td>
<td>25 - 35</td>
<td>10 - 25</td>
<td>20 - 50</td>
<td>&lt;10</td>
<td>25</td>
</tr>
<tr>
<td>COD mg/l</td>
<td>65 - 120</td>
<td>250 - 450</td>
<td>3000 - 3500</td>
<td>150 - 350</td>
<td>1100</td>
</tr>
<tr>
<td>Temperature °C</td>
<td>40 - 44</td>
<td>35 - 40</td>
<td>30 - 35</td>
<td>10 - 12</td>
<td>33</td>
</tr>
<tr>
<td>Total Kjeldahl-N mg/l</td>
<td>130 - 150</td>
<td>200 - 300</td>
<td>200 - 300</td>
<td>100 - 200</td>
<td>180</td>
</tr>
<tr>
<td>CN total mg/l</td>
<td>5 - 20</td>
<td>-</td>
<td>20 - 60</td>
<td>20 - 50</td>
<td>15</td>
</tr>
<tr>
<td>Zinc mg/l</td>
<td>2 - 4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Metals mg/l</td>
<td>1 - 3</td>
<td>1 - 3</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Phenols mg/l</td>
<td>-</td>
<td>-</td>
<td>500 - 700</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CNS mg/l</td>
<td>-</td>
<td>-</td>
<td>200 - 250</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

1) Polluted groundwater from the coke plant

Table 6.23: Composition of the different waste water flows at Corus, Ijmuiden, the Netherlands (2007)

The heart of the new water treatment configuration at Corus in Ijmuiden is the biological treatment plant, a carrousel type of installation that was built from 1999 - 2000 (see Figure 6.21 and Figure 6.22). Carrousels are quite famous in Western Europe where they are applied quite often for the treatment of domestic waste water.

The large basins with surface aerators and the relatively high velocities make the installation more of a complete mix reactor than a plug flow. The aerators are controlled by measuring dissolved oxygen continuously and comparing it with a set point of 1.5 - 2 mg/l. Also, pH is controlled by adding caustic soda when the pH is lower than 6.8 or by adding sulphuric acid when the pH in the basin is higher than 7.4.

Behind the BET plant continuous backwashing sand filters were installed. Despite the fact that the combination of waste waters can easily be treated, sometimes very fine biological flocks are present in the overflow of the final settling basin.

Excess sludge is pumped to a thickener first. Thereafter the sludge is dewatered and mixed with the coal that is used as input for the ovens.

The carrousel with the surface aerators installed in the blue boxes is visible in Figure 6.20 below. These boxes are isolated to prevent problems with noise in the direct neighbourhood of the installation. The light blue columns in front are the six sand filters. Blast furnaces nr 6 and 7 are visible in the back.

Some dimensions: the aeration volume is 15000 m³; this means a hydraulic retention time of 33 hours. The settling volume is 1500 m³. The diameter of the settling basin is 29 m. The surface load is 5 m³/m²/h.

The sludge thickener is a basin with a diameter of 9.5 m and a volume of 250 m³. Average sludge waste is 45 m³/day with 3 % dry solids. The sludge recirculation flow is max 640 m³/h (twice the amount of influent). Dosage of phosphoric acid is based on 2 mg/l phosphate in effluent. That means app. 5 l/h 75 % phosphoric acid has to be added [452].
Achieved environmental benefits
High recycling efficiency of the scrubbing water can be achieved with an overflow of only 0.1 m$^3$/t hot metal. This water is removed from the system with the blast furnace sludge and may undergo further treatment.
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### Table 6.24: Discharge concentrations for the biological waste water treatment plant at Corus, Ijmuiden, the Netherlands (2007) after combined treatment of waste water from the coke oven plant, the blast furnaces and from the sinter plant

<table>
<thead>
<tr>
<th>Unit</th>
<th>Average</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow m³/h</td>
<td>282</td>
<td>179 - 354</td>
</tr>
<tr>
<td>Suspended solids mg/l</td>
<td>30</td>
<td>3 - 110</td>
</tr>
<tr>
<td>COD mg/l</td>
<td>102</td>
<td>81 - 164</td>
</tr>
<tr>
<td>Total Kjeldahl-N mg/l</td>
<td>5.5</td>
<td>2 - 14.6</td>
</tr>
<tr>
<td>Total Phosphate mg/l</td>
<td>2.4</td>
<td>0.8 - 6.9</td>
</tr>
<tr>
<td>CN total mg/l</td>
<td>4.8</td>
<td>1.6 - 9.0</td>
</tr>
<tr>
<td>CN free mg/l</td>
<td>0.09</td>
<td>0.02 - 0.38</td>
</tr>
<tr>
<td>Thiocyanate mg/l</td>
<td>1.7</td>
<td>0.4 - 4.9</td>
</tr>
<tr>
<td>Cr mg/l</td>
<td>0.013</td>
<td>0.011 - 0.013</td>
</tr>
<tr>
<td>Cu mg/l</td>
<td>0.018</td>
<td>0.015 - 0.028</td>
</tr>
<tr>
<td>Pb mg/l</td>
<td>0.166</td>
<td>0.041 - 0.380</td>
</tr>
<tr>
<td>Ni mg/l</td>
<td>0.020</td>
<td>0.010 - 0.061</td>
</tr>
<tr>
<td>Zn mg/l</td>
<td>0.125</td>
<td>0.051 - 0.262</td>
</tr>
<tr>
<td>Cd µg/l</td>
<td>14</td>
<td>6 - 32</td>
</tr>
<tr>
<td>Hg µg/l</td>
<td>0.5</td>
<td>0.2 - 1.0</td>
</tr>
<tr>
<td>As µg/l</td>
<td>13</td>
<td>6 - 19</td>
</tr>
<tr>
<td>Phenols mg/l</td>
<td>&lt;0.15</td>
<td>-</td>
</tr>
<tr>
<td>EPA PAH mg/l</td>
<td>0.0013</td>
<td>0.0003 - 0.0045</td>
</tr>
</tbody>
</table>

Note: Data are from 24 hour samples taken at 120 days in 2007.

### Table 6.25: Pollutant load of waste water discharged from BF gas scrubbing water circuit after treatment

<table>
<thead>
<tr>
<th>Units</th>
<th>No. measurements</th>
<th>Mean value</th>
<th>Median</th>
<th>Max</th>
<th>Min</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cd µg/l</td>
<td>39</td>
<td>0.36</td>
<td>0.20</td>
<td>3.00</td>
<td>0.20</td>
<td>0.58</td>
</tr>
<tr>
<td>Cr µg/l</td>
<td>39</td>
<td>2.20</td>
<td>2.00</td>
<td>3.90</td>
<td>2.00</td>
<td>0.47</td>
</tr>
<tr>
<td>Cu µg/l</td>
<td>39</td>
<td>9.52</td>
<td>6.10</td>
<td>13.00</td>
<td>2.00</td>
<td>13.75</td>
</tr>
<tr>
<td>Fe µg/l</td>
<td>39</td>
<td>460.77</td>
<td>90.00</td>
<td>3700.00</td>
<td>13.00</td>
<td>861.79</td>
</tr>
<tr>
<td>Ni µg/l</td>
<td>39</td>
<td>12.93</td>
<td>8.90</td>
<td>39.00</td>
<td>2.00</td>
<td>10.10</td>
</tr>
<tr>
<td>Pb µg/l</td>
<td>39</td>
<td>24.93</td>
<td>8.00</td>
<td>390.00</td>
<td>&lt;2.00</td>
<td>62.08</td>
</tr>
<tr>
<td>Zn µg/l</td>
<td>39</td>
<td>354.00</td>
<td>130.00</td>
<td>2600.00</td>
<td>20.00</td>
<td>582.73</td>
</tr>
<tr>
<td>CN mg/l</td>
<td>39</td>
<td>0.84</td>
<td>0.22</td>
<td>9.80</td>
<td>0.01</td>
<td>2.05</td>
</tr>
<tr>
<td>CN easily released mg/l</td>
<td>39</td>
<td>0.25</td>
<td>0.04</td>
<td>5.50</td>
<td>0.01</td>
<td>0.89</td>
</tr>
<tr>
<td>Cl mg/l</td>
<td>39</td>
<td>1000.21</td>
<td>854.00</td>
<td>1360.00</td>
<td>452.00</td>
<td>414.52</td>
</tr>
<tr>
<td>AOX µg/l</td>
<td>39</td>
<td>37.33</td>
<td>19.00</td>
<td>450.00</td>
<td>10.00</td>
<td>70.13</td>
</tr>
<tr>
<td>Suspended solids mg/l</td>
<td>39</td>
<td>21.91</td>
<td>9.60</td>
<td>166.00</td>
<td>0.60</td>
<td>31.79</td>
</tr>
<tr>
<td>DOC mg/l</td>
<td>39</td>
<td>55.25</td>
<td>54.25</td>
<td>170.00</td>
<td>1.70</td>
<td>40.77</td>
</tr>
<tr>
<td>TOC mg/l</td>
<td>39</td>
<td>55.66</td>
<td>45.00</td>
<td>174.00</td>
<td>2.20</td>
<td>42.06</td>
</tr>
<tr>
<td>COD mg/l</td>
<td>28</td>
<td>144.12</td>
<td>145.50</td>
<td>280.00</td>
<td>&lt;15</td>
<td>69.84</td>
</tr>
<tr>
<td>mineral oil hydrocarbons mg/l</td>
<td>39</td>
<td>0.16</td>
<td>0.18</td>
<td>0.56</td>
<td>0.10</td>
<td>0.08</td>
</tr>
<tr>
<td>Fish egg toxicity</td>
<td>12</td>
<td>6.58</td>
<td>4.00</td>
<td>32.00</td>
<td>1.00</td>
<td>8.16</td>
</tr>
</tbody>
</table>

Note: ArcelorMittal, Bremen, Germany, random sample measurement data from April 2000 to November 2006. Figures in italics indicate that measurement values below the detection limit have been computed as the detection limit.
The total water demand in 2006 was 719,713 m³. With a hot metal production of 3,152,134 t, this equates to a specific waste water amount of 0.23 m³/t hot metal.

**Cross-media effects**
When large amounts of water are recirculated, an efficient water treatment system must be used. Otherwise, operational problems will occur affecting the scrubbers (clogging, etc.) and scrubbing efficiency will drop. Water treatment and recycling generates a (zinc-rich) sludge. A small overflow from the circuit is necessary to avoid accumulation of minerals/salts.

Scrubbing water recycling requires a significant amount of energy is required (see Table 6.22). In addition, the dosage of flocculation agents has to be considered.

**Applicability**
Both new and existing plants can apply treatment and recycling of scrubbing water. Modern plants have a significant advantage because the plant can be designed with an efficient water circuit. The salt content of the wash-water influences the recycling rate. However, it is also possible to install an efficient water circuit in older plants.

**Economics**
Total investment for the blast furnace waste water treatment at Corus, Ijmuiden, the Netherlands was reported to be approximately EUR 18 million. The waste water treatment includes suspended solid separation (two stages) and pH correction. Operational costs are not stated.

For the example the currency was converted into Ecu in 1996 and for the review into EUR.

**Driving force for implementation**
No data submitted.

**Example plants**
ArcelorMittal, Bremen, Germany; Corus, Ijmuiden, the Netherlands.

**Reference literature**
[65] [138] [136] [358] [417] [452]

### 6.3.7 Hydrocyclonage of blast furnace sludge

**Description**
Blast furnace top gas contains large amounts of particulate matter (7 - 40 kg/t hot metal – see Table 6.7). A large part of this particulate matter is removed in the dry first step of the BF gas treatment system. This part mainly consists of relatively coarse material with a high iron and carbon content and is recycled to the sinter plant.

The remainder (1 - 10 kg/t hot metal) is scrubbed from the BF gas by means of wet scrubbing. After precipitation 3 - 5 kg of sludge per tonne of hot metal is generated. This sludge has a relatively high zinc (Zn)-content. The high zinc content is presents an obstacle to reusing the sludge in the sinter plant.

By means of hydrocyclonage of the sludge, a zinc-rich and a zinc-poor sludge can be generated out of the total sludge. The zinc is mainly present in the form of zinc oxide (ZnO), which appears as very small particles. Hydrocyclonage concentrates these small particles in the overflow, whereas the zinc-poor fraction leaves the cyclones through the underflow. It should be noted that the efficiency of hydrocyclonage depends on the sludge characteristics.
Chapter 6

The sludge from the underflow is re-used in the sinter plant. Note that this re-use should be seen in relation to the total zinc input in the blast furnace. The zinc-rich sludge from the overflow is stored or landfilled. Some of the material have been successfully recovered for its zinc content e.g., by DK Recycling (see Section 2.5.4.4.2). Additional problems may arise from radioactive components which preferably remain in the fine fraction.

**Achieved environmental benefits**

In Table 6.26 the zinc contents of the sludges are given.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Specific sludge generation (kg/t hot metal)</th>
<th>Zn content (%)</th>
<th>Weight on dry basis (%)</th>
<th>Specific sludge generation (kg/t hot metal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated sludge</td>
<td>1.0 - 9.7</td>
<td>0.1 - 2.5</td>
<td>100</td>
<td>Hydrocyclonage</td>
</tr>
<tr>
<td>Hydrocyclonage overflow</td>
<td>0.2 - 2.7</td>
<td>1 - 10</td>
<td>20 - 40</td>
<td>Stored on stock pile/landfill</td>
</tr>
<tr>
<td>Hydrocyclonage underflow</td>
<td>0.8 - 7.8</td>
<td>0.2 - 0.6</td>
<td>60 - 80</td>
<td>Recycled to sinter plant</td>
</tr>
</tbody>
</table>

Table 6.26: Example for the zinc content of hydrocyclonaged blast furnace sludge

[65] [105]

**Cross-media effects**

A small but unquantified amount of energy is consumed to operate the cyclones.

**Operational data**

The system operates without problems.

**Applicability**

Hydrocyclonage can be applied at new and existing plants as an end-of-pipe technology whenever wet dedusting is applied and where grain size distribution allows for reasonable separation.

**Economics**

[116] reports that investment cost for a three-stage plant with a capacity of 20000 t/yr is EUR 2 million and operational costs are EUR 25/t.

For the example the currency was converted into Ecu in 1994 and for the review into EUR.

**Driving force for implementation**

No data submitted.

**Example plants**

Corus, IJmuiden, the Netherlands; Thyssen Krupp Stahl AG, Duisburg, Germany.

**Reference literature**

[105] [116]
6.3.8 Condensation of fume from slag processing

Description
As mentioned in Section 6.2.2.1 there are H₂S and SO₂ emissions from slag processing. This may lead to odour problems. In order to solve this problem, some granulation plants are operated with fume condensation (see Figure 6.23). The condensate and the slag dewatering water are also circulated after cooling.

Figure 6.23: Granulation of blast furnace slag with fume condensation
[111]

Figure 6.24: Granulation of ironmaking and steelmaking slags
[208]
Chapter 6

Achieved environmental benefits
With fume condensation, H$_2$S emissions are within the range of 1 - 10 g H$_2$S per tonne of hot metal produced.

Cross-media effects
Cooling the circulated water needs considerable amounts of energy. Energy generation itself is very often linked with sulphur emissions. During fume condensation, the absolute quantity of reduced sulphur is relatively small and may be related to the quantity emitted during energy generation. In the design of these units, safety issues should be considered, especially concerning problems with hydrogen.

Operational data
No data submitted.

Applicability
Applicable both at new and existing plants.

Economics
No data submitted.

Driving force for implementation
No data submitted.

Example plants
Several slag granulation plants in Germany are equipped with a fume condensation system, e.g. at Thyssen AG, D-Duisburg, but also Corus plants at Port Talbot and Scunthorpe. Other plants are available in Finland.

Reference literature
[208] [242] [354]

6.3.9 Use of high-quality ores

Description
The idea of this technique is to use preferably sinter or pellets as raw material with high iron content and low gangue content. Sinter with an iron content of 61 - 63.5 % and pellets with an iron content in the range of 66.6 - 66.8 % are used. Other important factors are moderate ash content of coke and low ash content of coal for injection.

Achieved environmental benefits
The use of high quality ores increases the productivity and the energy efficiency of the ironmaking process. The consumption of a reductant agent is lowered which leads to reduced CO$_2$ emissions. A yield of 3.4 tonnes/m$^3$/day and reduction of CO$_2$ emissions by 15 - 80 kg/t of hot metal can be achieved. Additionally, the slag volume is reduced to about 150 - 200 kg/t hot metal which also lowers the emissions from slag processing.

Cross-media effects
No data submitted.

Operational data
Using high iron rich sinter and pellets as raw materials is, in principle, applicable to other plants, but it needs development and a fundamental understanding of the effects of different iron ores to the blast furnace, i.e. one effect associated with low slag practice can be the reduced life of blast furnace refractory.
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Applicability
The applicability is strongly limited to the availability of ores with a high iron content.

Economics
The economic benefits are connected with increased productivity, reduced energy consumption and a decrease in demand of reducing agents. The availability of iron-rich ores is limited. The introduction of this practice in European blast furnaces will lead to the building of monopolies for mines whose iron ore content is very high, against the principles of a free market and workable and fair competition. The generated stringency would cause worldwide higher prices for such qualities of iron ores.

Driving force for implementation
To improve productivity and energy efficiency.

Example plants
Sinter – Ruuki in Finland
Pellets – SSAB Oxelosund, Sweden
Pellets – SSAB-Lulea, Sweden

Reference literature
[208]

6.3.10 Increase of energy efficiency in blast furnaces

Description
Use of models for controlling of wear in the blast furnace hearth. There are two separate methods in use:

a) A model, which is estimates the location of the 1150 °C isotherm based on thermal conductivities and thermocouple measurements in the hearth refractory lining by using the Finite Element Method (FEM).

b) A model, which approximates the height of the “dead man” in the hearth according to the thermal conductivity.

Close loop operations of cooling water helps to provide good furnace management.

c) Smooth continuous operations at steady state.

Achieved environmental benefits
Increase the energy efficiency and reduction of CO₂ emissions and reduction in maintenance (e.g. refractories). The consumption of reducing agents are reduced approximately with 5 kg/t hot metal on a long-term basis. This means a reduction of CO₂ emissions by approximately 15 - 20 kg/t hot metal. The BF campaign life can be prolonged by several years.

c) they minimise releases and reduce the likelihood of burden slips.

Cross-media effects
No data submitted.

Operational data
High availability (e.g. > 99 %)
The blast furnace is very well controlled.
Chapter 6

The models are of significant importance for the control of the blast furnace process and for the wear in the BF hearth. Also the quality of the BF iron can be held on good and constant level (exp. C- and Si- and S-contents), when the phenomena in the hearth can be controlled.

**Applicability**

Systems to increase the energy efficiency are usually applied in blast furnaces all over Europe.

**Economics**

No data submitted.

**Driving force for implementation**

Other benefits are the improvement of process control and an improvement in iron quality.

**Example plants**

Ruukki, Finland.

SSAB, Lulea, Sweden

Ovako, Koverhar, Finland.

UK plants

**Reference literature**

[208] [242] [442]

### 6.3.11 Recovery and use of blast furnace gas

**Description**

A typical blast furnace produces approximately 1200 - 2000 Nm$^3$ of BF gas per tonne of hot metal. The BF gas consists of 20 - 28 % of carbon monoxide (CO) and 1 - 5 % hydrogen (see Table 6.7 and Table 6.8). The carbon monoxide is formed during oxidation of carbon in the blast furnace. Much of the CO is further oxidised to CO$_2$ in the blast furnace. Carbon monoxide and hydrogen represent a potential energy source and measures are taken at all blast furnaces around the world to recover this energy.

Blast furnace top gas is therefore cleaned and stored in gasholders for subsequent use as a fuel. Given the low energy content of BF gas per Nm$^3$, it is often enriched with coke oven gas, BOF gas or natural gas prior to use as a fuel.

**Achieved environmental benefits**

The energy content of BF gas typically varies from 2.7 - 4.0 MJ/Nm$^3$, depending on its carbon monoxide concentration. This is only 10 % of the energy content of natural gas. Nevertheless, the large amounts of BF gas generated mean the energy recovering potential is very high. Total export from the blast furnace is approximately 5 GJ/t hot metal, which equals 30 % of the gross energy consumption of the blast furnace.

**Cross-media effects**

BF gas cleaning is unavoidable and results in waste water and solid residues.

**Operational data**

No specific operational data is required.

**Applicability**

Applicable at all new and existing plants.

**Economics**

Significant economies are achieved through energy savings.
Driving force for implementation
Benefits from the efficient use of energy and economics.

Example plants
Applied at many new and existing blast furnaces in the world.

Reference literature
[200]

6.3.12 Direct injection of reducing agents

General
Direct injection of reducing agents means replacing part of the coke by another hydrocarbon source, which is injected in the furnace at the tuyère level (see more information in Section 6.1.3.1). These hydrocarbons may be in the form of heavy fuel oil, oil residues, recovered waste oil, granular or pulverised coal, natural gas or coke oven gas and waste plastics. Coal and oil are the most commonly used of the tuyère injectants. By reducing the need for coke, overall pollution and energy demand decrease.

It should be stressed, however, that a certain amount of coke is still necessary in the blast furnace to allow proper blast furnace operation. The coke provides the required carrying capacity to sustain the blast furnace charge and ensures sufficient gas penetration. Tuyère injection of hydrocarbons requires an additional injection of oxygen (at increasing levels as tuyère injection rates increase), in order to achieve the required temperatures within the furnace raceway. Little experience has been gained at very high tuyère injection rates (and thus elevated oxygen levels), and here, safety also becomes a more important issue, among other things.

<table>
<thead>
<tr>
<th>Type</th>
<th>Injection rate (kg/t HM)</th>
<th>Residual coke rate (kg/t HM)</th>
<th>Total coal consumption$^{11}$ (kg/t HM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>0</td>
<td>500</td>
<td>625</td>
</tr>
<tr>
<td>Typical</td>
<td>150 - 180</td>
<td>310</td>
<td>568</td>
</tr>
<tr>
<td>Higher achieved</td>
<td>~240</td>
<td>270 - 300</td>
<td>547 - 585</td>
</tr>
</tbody>
</table>

$^{11}$ kg of coke is assumed to be produced from 1.25 kg of coal. Figures are related to dry coke and dry coal.

Table 6.27: Comparison of residual coke consumption and total coal consumption at different levels of direct injection of pulverised coal

[348] [410] [423]

Figure 6.25, Table 6.27 and Table 6.28 show typical injection rates for reducing agents in existing blast furnaces.
The net energy savings of coal injection have been calculated at 3.76 GJ/t coal injected. At an injection rate of 180 kg/t hot metal, energy savings amount to 0.68 GJ/t hot metal or 3.6% of the gross energy consumption of the blast furnace (see Table 6.16). These energy savings are achieved indirectly as a consequence of reduced coke consumption. Higher input rates will enable higher energy savings.

Direct injection of reducing agents is applicable both at new and existing blast furnaces. It should be noted that this highly process-integrated measure is closely related to the operation of the blast furnace itself, the resulting stability, and the hot metal and slag quality.
6.3.12.1 Coal injection

Description
The injection of relevant amounts of coal tends to decrease raceway temperatures which would influence the efficiency of the blast furnace. This means that in blast furnaces with conventional heating, the allowed coal injection is limited to 150 kg/t hot metal. To maintain suitable raceway conditions and at the same time achieve higher input rates of coal of up to 260 kg/t hot metal, oxygen enrichment of the hot blast and oxy-coal injection at the tuyère level (see Section 6.1.3.1) are applied in EU blast furnace plants.

At Corus, Ijmuiden, the Netherlands pulverised coal is injected on a commercial scale. A standard rate of 250 kg coal per tonne of liquid metal is applied. Depending on the carbon content of the pulverised coal between 210 and 260 kg of coal per tonne of liquid metal is injected nowadays (2006) (the data differs from Table 6.1 since the considered reference data there are for 2004).

The blast temperature can also be increased using electrically powered plasma blast superheating. Information about this technique being applied was not submitted.

Achieved environmental benefits
Direct injection of reducing agents decreases the need for coke production. Thus, emissions at the coke oven plant are avoided. For every kg of coal injected, approximately 0.85 - 0.95 kg of coke production is avoided.

The application of the oxy-coal injection has increased the injection rate by approximately 20 % and correspondingly decreased the coke rate. The performance of the ESP used for the BF gas cleaning has improved. Together with the improved positive effect on the permeability in the blast furnace and the improved coal distribution, the whole blast furnace performance has improved.

Cross-media effects
Reduced coke consumption and improved cleaning of blast furnace gas.
Measurements have indicated that less than 1 % of the injected coal escapes through the blast furnace top.

Operational data
In the case of oxy-coal injection, the two BFs have restrictions concerning hot blast temperature and oxygen enrichment of the hot blast. Therefore, oxy-coal injection is applied by a swirl type, coaxial, oxy-coal lance to improve the combustion of the coal. The oxy-coal lances have eliminated earlier experienced problems with lance clogging and thereby have improved the distribution of the coal between the tuyères of the blast furnaces.

At high coal injection rates, the furnace tends toward low wall working and an increase in blast furnace resistance. This indicates that careful control of the burden distribution with low coke rates and a delicate balance between wall and central gas flow are necessary.

In general, a fully prepared burden is necessary to be able to consistently achieve the highest levels of coal injection.

At constant blast furnace output levels, the introduction of high coal injection rates will result in an increase in the residence time of coke and burden in the blast furnace compared to an “all coke” operation. As such, the coke and the ferrous burden materials will be subject to a longer time under the influence of halogenated alkali metal species in the blast furnace gas. However, the introduction of coal injection provides an opportunity to increase blast furnace productivity through co-injection of oxygen. Dependent upon the absolute levels of coal and oxygen injection and the gain in furnace productivity, the rate at which the coke transits the stack may be lower than under conditions of all coke operation.
The presence of ungasified coal char particles modifies the characteristics of the melted ferrous materials, thus affecting the position and the shape of the melting zone in the blast furnace.

**Applicability**

The method is applicable at all blast furnaces equipped with pulverised coal injection and oxygen enrichment. Direct injection of reducing agents is applicable both at new and existing blast furnaces.

**Economics**

There are economic incentives for using high rates of coal injection to achieve greater cost savings, particularly at plants which might otherwise face capital expenditure on rebuilding coke ovens or may have to purchase coke. Furthermore, coal injection can allow the use of coals of a lower quality compared to coking coals. This may also reduce costs.

Costs at EUR 10/GJ in 1988 are reported [65]. However, [11] indicate that costs are saved, due to the lower coke consumption. The capital cost of installing coal injection at Corus, UK - Port Talbot No. 4 Blast Furnace in 1997 was approximately EUR 24 million (including some redundant parts from another site). For the examples the currency was converted into Ecu in 1996 or 1997 and for the review into EUR.

Additional costs will arise for air enrichment providing constant huge oxygen amounts, the additional demand on the pulverisers in existing plants and additional requirements for the injection unit maintenance.

**Driving force for implementation**

Cost savings, increased productivity and reduced CO₂ emissions and environmental benefits as a result of improved BF operation.

**Example plants**

Coal or oil injection into blast furnaces is a technique now widely applied in Europe and worldwide (e.g. coal injection into blast furnaces in ArcelorMittal, Corus, TKS, etc.).

Corus, Ijmuiden, the Netherlands.

Oxy-coal injection has been used in SSAB Oxelösund AB in Sweden since 1993.

**Reference literature**

[208] [348] [471]

The theoretical maximum for coal injection at the tuyère level is thought to be 270 kg/t hot metal. This limit is set by the carrying capacity of the coke and the thermochemical conditions in the furnace.

Coke replacement through coal injection depends upon factors such as productivity, coke properties, desired hot metal quality, type (e.g. anthracite) and condition (humidity) of coal etc. [11] [65].
6.3.12.2 Oil injection

Injection of used oils, fats and emulsions as reducing agents and of solid iron residues

**Description**

As for coal injection the injection of relevant amount of oil tends to decrease raceway temperatures which would influence the efficiency of the blast furnace. This means that in blast furnaces with conventional heating, the possible amount of oil injected is limited to approximately 65 kg/t hot metal. To maintain suitable raceway conditions and at the same time achieve higher input rates of oil, up to 130 kg/t hot metal oxy-oil injection is applied. In this case, oxy-oil burners are installed at all tuyères designed for the use of heavy oil only. Oil and oxygen is fed separately and the oil must be preheated up to 220 °C. The amount of oxygen enrichment is 7 - 9 %.

Information about other options like increasing the blast temperature using electrically-powered plasma blast superheating or using oxygen enrichment of the hot blast has not been submitted.

**Achieved environmental benefits**

With oxy-oil technology the amount of oil injected doubles. Coke consumption can be decreased and the CO₂ emissions can be decreased as well. The oil consists of carbon and hydrogen and compensates coke with a ratio of 1:1.2 (1 kg oil also compensates 1.2 kg coke). With the help of the oxy-oil equipment the oil amount is doubled to a level of 130 kg/t hot metal. The saving of coke is thus about 15 kg/t hot metal and the reduction in CO₂ emissions is roughly 50 kg/t hot metal. The environmental benefits and energy efficiency are thus significant.

**Cross-media effects**

No data submitted.

**Operational data**

In practice, oxy-oil injection is working very reliably. The applicability of the equipment for the feeding of oil and oxygen is good.

**Applicability**

The practice of applying oxy-oil injection is regarded to be well established. Direct injection of reducing agents is applicable both at new and existing blast furnaces.

**Economics**

Cost savings, increased productivity

Additional costs will arise for air enrichment to provide constant huge oxygen amounts and additional requirements for the injection unit maintenance.

**Driving force for implementation**

Cost savings, increased productivity and reduced CO₂ emissions are the driving forces for implementation which are both economic and environmental as a result of an improved BF operation.

**Example plants**

Oxy-oil technology has been used at Ovako, Kovehar, Finland since 2000.

**Reference literature**

[208]
6.3.12.3 Gas injection

Description
Since 2002, Voestalpine, Linz, Austria has operated their small blast furnaces 5 and 6 with a simultaneous injection of reduction gas and heavy fuel oil as standard operational procedure with a replacement of 70% of the heavy fuel oil by COG. In 2004, these furnaces averaged an oil injection rate of 45.5 kg/t hot metal and a COG rate of 46.9 kg/t hot metal with a total equivalent coke rate of 477.8 kg/t hot metal. The Eta-CO was 43.5 with about 8% H₂ in the BF gas.

The maximum level for coke oven gas (COG) injection at the tuyère level is thought to be 100 kg/t hot metal. This limit is set by the thermochemical conditions in the furnace. The COG contains residual H₂S and organic sulphur compounds. The real input of COG is much lower (see Table 6.1). The concentration level of these sulphur compounds depends on the level of sulphur in the coals and/or the desulphurisation efficiency of the plant. The use of COG in the BF process as a reductant instead of using it as a fuel elsewhere in the works could result in a reduction in the sulphur emission from the works since a proportion of the sulphur will be captured in the BF slag.

Figure 6.26: Example of the layout for COG injection
[348]

Achieved environmental benefits

Cross-media effects
No data submitted.

Operational data
The replacement ratio for coke oven gas is about 1 kg of gas for 0.98 kg coke or 0.81 kg of heavy oil. Additionally, the replacement of a carbon-rich reductant like coke and heavy oil in the BF process by a carbon-lean reductant like COG leads to an absolute reduction of the CO₂ emissions from the BF process. When COG is used at the blast furnace, it is necessary to substitute this gas that is normally used in reheat furnaces, etc. for BF gas, BOF gas or natural gas. A consequential reduction of SO₂ emissions of between 70 and 90% may then result at these former COG consumers.
A reduction of the hot metal sulphur content may also be possible because COG has a lower sulphur input than heavy oil or coke. The consumption of desulphurisation agents (e.g. lime, CaC_2, Mg) at the pretreatment desulphurisation process of the hot metal can then be reduced. A compressor unit is required for COG injection resulting in an additional energy consumption of about 204 kWh/t COG (based on consumption at a reference plant in 2005).

Applicability
Whilst tuyère injection of COG is also applicable both at new and existing blast furnaces, it is also highly dependent upon the availability of the gas that may be effectively used elsewhere in the integrated steelworks. Direct injection of reducing agents is applicable both at new and existing blast furnaces.

Economics
Driving force for implementation
The main driving forces are both economic and environmental benefits as a result of improved BF operation.

The investment at voestalpine Stahl GmbH for the gas injection plant was about EUR 10 million for a production of about 5000 t hot metal per day. The total specific operational costs are: EUR 1.3/t hot metal or EUR 12/Tm³ COG (EUR 2400000/yr and 200000 Tm³ COG/yr).

Example plants
COG injection into blast furnaces is a technique applied in Europe at Voestalpine, Linz, Austria.

Reference literature
[348]

6.3.12.4 Plastic injection

Description
The maximum level for plastics injection at the tuyère level is thought to be 70 kg/t hot metal. This limit is set by the thermochemical and kinetic conditions in the raceway. Plastics can contain Cl and heavy metals like Hg, Cd, Pb and Zn. The concentration level of these elements in the plastics influences the composition of the gaseous and particulate bound compounds in the BF gas and the dust separation behaviour in the BF gas cleaning system. As a result of this, plastic has to meet certain input criteria for these elements. A small modification of the scrubber parameters allows these concentration levels in the BF gas to be kept comparable to the standard conditions of operation when plastics are not injected.

Achieved environmental benefits
No data submitted.

Cross-media effects
The ratio for plastics is dependant upon the relative amounts of carbon and hydrogen that can be derived from the plastic injected. A kilogram of plastic can replace about 0.75 kg of coke. A reduction of the hot metal sulphur content is possible because plastics have a lower sulphur input than heavy oil or coke. The consumption of desulphurisation agents (e.g. lime, CaC_2, Mg) at the pretreatment desulphurisation process of the hot metal can be reduced.

Depending on the composition of the wastes used (e.g. shredder light fraction), the amount of Cr, Cu, Ni and Mo in the BF may increase.
Chapter 6

Operational data
Voestalpine Stahl, Linz, Austria received final permission for the injection of 220,000 t plastics per year in 2005 and is increasing the capacity up to a level of 70 kg/t hot metal. In 2008 the plastic injection rate was 18 - 25 kg using high-pressurised air. The plastic has to meet certain composition requirements. Table 6.29 provides requirements on the plastics used for injection at Voestalpine.

<table>
<thead>
<tr>
<th>Cl</th>
<th>S</th>
<th>Co</th>
<th>Cr</th>
<th>As</th>
<th>Pb</th>
<th>Ni</th>
<th>Hg</th>
<th>Cd</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;2 %</td>
<td>&lt;0.5 %</td>
<td>1000</td>
<td>500</td>
<td>5</td>
<td>250</td>
<td>500</td>
<td>0.5</td>
<td>9</td>
<td>1000</td>
</tr>
</tbody>
</table>

Figures are all in mg/kg dry plastic

Table 6.29: Requirements for the composition of plastics used for injection into the BF at Voestalpine

[448]

The plastics injection plants in ArcelorMittal, Bremen and ArcelorMittal, Eisenhüttenstadt, both located in Germany, have been in operation for several years. In 2004, the No. 3 furnace at Bremen averaged 52.3 kg/t hot metal while the No. 1 furnace at Eisenhüttenstadt averaged 67.4 kg/t hot metal plastic injection. At present both have stopped the injection of plastics for economical reasons.

Applicability
Direct injection of reducing agents is applicable both at new and existing blast furnaces.

Economics
The investment for the plastics injection plant at voestalpine Stahl GmbH, Linz, Austria was about EUR 20 million for an injection capacity of up to 220,000 t per year. Additional costs will arise for the injection unit maintenance.

Driving force for implementation
For some types of wastes, it is no longer possible to landfill due to the restriction put on the content of hydrocarbons. Therefore, other routes should be found to treat this material.

Example plants
Plastics injection into blast furnaces is a technique applied in Europe at voestalpine, Linz, Austria. It has been reported that four BFs have experience to treat shredder light fraction (~200 kt/yr).

Salzgitter Flachstahl GmbH, Germany started its plastics injection in March 2008.

Reference literature
[11] [65] [132] [238] [348] [390] [399] [401] [423] [424] [448]

6.3.12.5 Direct injection of used oils, fats and emulsions as reducing agents and of solid iron residues

Description
Used oils, fats and emulsions of used oil and water are generated throughout the industry. These residues can be injected into the blast furnace at the tuyère level as a partial substitute for coke and coal. A schematic diagram of the process is given in Figure 6.27 showing a mechanical way to separate the water. Alternative techniques are chemical or thermal splitting.
The crucial point of this procedure is the separation of water, oil and particulate matter in the emulsions to ensure that the injection of water into the blast furnace is tightly controlled. Disc stack centrifuges are used to carry out this operation.

An integral part of this process is to add the water separated in the centrifuge operation to the heavy oil injected to the blast furnace. The level of this water addition can be used to control the raceway adiabatic flame temperature (RAFT) i.e., increasing the level of water addition decreases the RAFT. The economic advantage of using these revert materials is dependent upon a desire to lower the flame temperature in the specific furnace operation.

Oily mill scale residues consist of solid material with a high iron content contaminated with up to 20 % hydrocarbons. The first step in the use of this type of material is often the separation of the oil (degreasing) from the iron-rich solids. In this system, oily mill scale and similar residues are reduced in size (for example by crushing) and mixed with the used oils and the oil phase separated from the emulsion in the centrifuge. The suspension produced is injected into the tuyères with discrete lances. The hydrocarbons act as reducing agents, the iron oxides are reduced to iron and report with the molten steel particles to the hot metal. The substitution ratio of injected ferrous materials to charged burden is about 1.

The injection of material (e.g. oily mill scale) at the tuyère level showed that dioxin and PAH emissions remained well within accepted limits in both cases, confirming the ability to achieve a complete reaction of the oil within the blast furnace raceway.

**Achieved environmental benefits**

The rate of exchange between the separated oil phase and heavy oil is slightly lower than 1 because a total separation of water from the oil phase is not achievable.

The reduction of the coke rate at the blast furnace can be between 3 and 8.5 kg/t hot metal, depending on the amount of injected residues. The direct injection of mill scale at the blast furnace gives a one-to-one substitution of iron ores.
Table 6.30: Injection rates and substitution factors for different materials injected into the tuyères

Cross-media effects
Extensive investigations did not reveal any detrimental cross-media effects. The consumption of heavy oil can be substituted by a similar amount of separated oil phase. The consumption of coke can be reduced by about 3 to 8.5 kg/t hot metal and thus emissions associated with the production of this amount of coke are avoided.

Operational data
No data submitted.

Applicability
Direct injection of residues can be applied to new and existing blast furnaces. It should be noted that the continuous operation of this system is reliant on the logistical concept of delivery and storage of residues. Also, the conveying technology applied is of particular importance for a successful operation.

Economics
The profitability of residues injection is achieved by substituting coke and iron ores and by reducing disposal costs. The capital costs of installing the direct injection of residues is about EUR 4 million - 6 million. The maximum capacity of the voestalpine Stahl GmbH, Linz, Austria, installation is 12 kg residues/t hot metal or 15000 t residues/yr for a blast furnace with a production of about 2500 tonnes hot metal per day.

Driving force for implementation
No data submitted.

Example plants
Direct injection of production residues as described is installed at blast furnaces 5 and 6 of voestalpine, Linz, Austria.

Reference literature
[349]

6.3.13 Energy recovery from top gas pressure

Description
High top pressure blast furnaces provide an ideal opportunity for recovering energy from the large volumes of pressurised top gas which they generate. Energy is recovered by means of an expansion turbine which is installed after the top gas cleaning device.

Achieved environmental benefits
The amount of energy that can be recovered from the top gas pressure depends on the top gas volume, the pressure gradient and the admission temperature. Energy recovery in this way is viable when the BF gas cleaning device and distribution network has a low-pressure drop.
Top gas pressure in modern blast furnaces is approximately 0.25 - 2.5 bar gauge. The pressure of the BF gas collecting main is approximately 0.05 - 0.1 bar. Part of the top gas pressure is "consumed" by the gas cleaning device.

The electricity generated is reported to be as much as 15 MW in a modern blast furnace with a top gas pressure of 2 - 2.5 bar.

Energy savings are estimated at up to 0.4 GJ/t hot metal for a 15 MW turbine. The savings amount to 2% of the gross blast furnace energy demand. Application of top gas pressure recovery at blast furnaces is common in furnaces with high top pressure.

Cross-media effects
No cross-media effects are known.

Operational data
The technique of recovering energy from top gas pressure usually operates automatically without problems. Axial turbines can be used which are more efficient than radial turbines. The critical point is when the turbine has to be shut down and the pressure gradient is transferred to the gas cleaning device. Special safety measures are always taken to avoid damage to the gas cleaning device and/or the collecting main.

It should be noted that the use of turbines requires a thorough cleaning of the as. First of all a high content of alkalis causes technical problems (corrosion).

Applicability
Top gas pressure recovery can be applied at new plants and in some circumstances at existing plants, albeit with more difficulties and additional costs. Fundamental to the application of this technique is an adequate top pressure that must be in excess of 1.5 bar gauge.

At new plants, the top gas turbine and the BF gas cleaning facility can be adapted to each other in order to achieve a high efficiency of both scrubbing and energy recovery.

Economics
The main driving force for installing a top gas pressure recovery turbine is the economic benefits. Profitability of the turbine increases with increasing volume and pressure gradient of the top gas and with increasing energy costs. In a modern blast furnace, a payback period of less than three years is possible, but dependent on local circumstances and top gas pressure, this can be more than 10 years.

Driving force for implementation
No data submitted.

Example plants
Top gas pressure recovery is applied worldwide at modern blast furnaces with a high top gas pressure and volume.

Reference literature
[1] [42] [65] [66] [350]
6.3.14 Energy savings at the hot stoves

Description
The hot stoves are fired with BF gas (often enriched). Several techniques are available to optimise the energy efficiency of the hot stove:

1. use of a computer-aided hot stove operation which prevents unnecessary reserves by adapting the energy supply to the actual demand and which minimises the amount of enriching gas added (in cases where enrichment takes place)
2. Preheating of the fuel in conjunction with insulation of the cold blast line and waste gas flue. Sensible heat from the flue-gas can be used to preheat the fuel media. The feasibility of this depends on the efficiency of the stoves as this determines the waste gas temperature (e.g. at waste gas temperatures below 250 °C, heat recovery may not be a technically or economically attractive option). The heat exchanger preferably consists of a heating oil circuit, for economic reasons. In some cases, imported heat may be used, e.g. sinter cooler heat, if the distances are reasonable. A preheated fuel medium reduces energy consumption. At plants that use enriched blast furnace gas, preheating the fuel could mean that enrichment would not longer be necessary
3. use of more suitable burners to improve combustion
4. Rapid O₂ measurement and subsequent adaptation of combustion conditions.

Achieved environmental benefits
[66] reported the following energy savings:

1. use of computer-aided hot stoves leads to an efficiency improvement of the hot stove of more than 5%. This equals an energy saving of approximately 0.1 GJ/t hot metal.
2. Preheating of the fuel media can lead to an energy saving of approximately 0.3 GJ/t hot metal as well. Significant energy savings are reached by using the combustion gas to preheat the blast furnace gas. The savings from this technique are about 170 MJ/t steel. The emission levels that can be achieved are: NOₓ 20 - 25 g/t hot metal, SO₂ 70 - 100 g/t hot metal, CO₂ 0.4 - 0.5 g/t hot metal.
3. Concerning techniques No. 3 and 4, an additional 0.04 GJ/t hot metal may be saved by improved combustion and adaptation of combustion conditions.

The total energy savings possible by a combination of techniques is of the order of 0.5 GJ/t hot metal.

Cross-media effects
No cross-media effects were reported by [66]. It might be expected that preheating of the fuel media and a reported increase of the flue-gas temperature would lead to higher NOₓ emissions from the hot stoves. The application of modern burners may reduce the NOₓ emissions.

Operational data
No data submitted.

Applicability
The techniques mentioned above for saving energy at the hot stoves are applicable both at new and existing plants.

Economics
These measures might be attractive from an economic point of view because energy consumption is reduced and thus money is saved. The profitability depends on the amount of energy saved and on the investment and operational costs of the measures. Typical installation costs for heat recovery were EUR 6 million in 1997 per set of stoves, i.e. per blast furnace.

Implementation of computer-aided control could require the construction of a fourth stove in the case of blast furnaces with three stoves (if possible) in order to maximise benefits.
Driving force for implementation
The economical benefits connected with increased productivity and reduced energy consumption are the driving forces for the implementation of these techniques.

Example plants
Thyssen Krupp Stahl AG, Duisburg, Germany
Blast Furnace No.7; Corus, Ijmuiden, the Netherlands
ArcelorMittal, Gent, Belgium
AcelorMittal, Gijón, Spain
Ruukki, Finland
Voestalpine, Linz, Austria
Voestalpine, Donawitz, Austria.

Reference literature: [66] [208]
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6.4 Best available techniques for blast furnaces

In understanding this section and its contents, the attention of the reader is drawn back to the Preface of this document and in particular the fifth section of the Preface: ‘How to understand and use this document’. The techniques and associated emission and/or consumption levels, or ranges of levels, presented in this section have been assessed through an iterative process involving the following steps:

- identification of the key environmental issues for blast furnaces in the iron and steel industry
- examination of the techniques most relevant to address those key issues
- identification of the best environmental performance levels, on the basis of the available data in the European Union and worldwide
- examination of the conditions under which these performance levels were achieved; such as costs, cross-media effects, main driving forces involved in implementation of these techniques
- selection of the best available techniques (BAT) and the associated emission and/or consumption levels for this sector in a general sense all according to Article 2(12) and Annex IV to the Directive.

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

On the basis of this assessment, best available techniques, and as far as possible emission and consumption levels associated with their use, are presented in this section that are considered appropriate to the blast furnaces and in many cases reflect current performance of some installations within the sector. Where emission or consumption levels ‘associated with best available techniques’ are presented, this is to be understood as meaning that those levels represent the environmental performance that could be anticipated as a result of the application, for blast furnaces, of the techniques described, bearing in mind the balance of costs and advantages inherent within the definition of BAT. However, they are neither emission nor consumption limit values and should not be understood as such. In some cases it may be technically possible to achieve better emission or consumption levels but due to the costs involved or cross-media considerations, they are not considered to be appropriate as BAT for the blast furnaces. However, such levels may be considered to be justified in more specific cases where there are special driving forces.

The emission and consumption levels associated with the use of BAT have to be seen together with any specified reference conditions (e.g. averaging periods).

The concept of ‘levels associated with BAT’ described above is to be distinguished from the term ‘achievable level’ used elsewhere in this document. Where a level is described as ‘achievable’ using a particular technique or combination of techniques, this should be understood to mean that the level may be expected to be achieved over a substantial period of time in a well maintained and operated installation or process using those techniques.

Where available, data concerning costs have been given together with the description of the techniques presented in the previous Section 6.3. These give a rough indication about the magnitude of costs involved. However, the actual cost of applying a technique will depend strongly on the specific situation regarding, for example, taxes, fees, subsidies and the technical characteristics of the installation concerned. It is not possible to evaluate such site-specific factors fully in this document. In the absence of data concerning costs, conclusions on economic viability of techniques are drawn from observations on existing installations.
In this section for blast furnaces, specific techniques are considered as BAT (including the associated emission and consumption levels). ‘Best Available Techniques’ for a specific installation will usually be the use of one individual techniques or a combination of the techniques and measures listed in this section. Additionally, general BAT elements which can apply for the whole sector, mentioned in Section 2.8, have to be considered.

Where techniques identified individually as BAT can be used in combination, the effects of such combinations should be considered when drawing conclusions on BAT based permit conditions for individual cases.

If not otherwise mentioned, the BAT associated emission levels (BAT-AELs) given in this section are expressed on an annual average basis under standard conditions.

The BAT (including the associated emission and consumption levels) given in this chapter are ‘BAT in a general sense’ (i.e. considered to be appropriate to the sector as a whole). It is intended that they are a reference point against which to judge the current performance of an existing installation or to judge a proposal for a new installation. In this way, they will assist in the determination of appropriate ‘BAT-based’ conditions for the installation or in the establishment of general binding rules under Article 9(8) of the Directive. It is foreseen that new installations can be designed to perform at or even better than the BAT levels presented in this section. It is also considered that existing installations could move towards the BAT levels presented in this section or do better, subject to the technical and economic applicability of the techniques in each case.

While the BAT reference documents do not set legally binding standards, they are meant to give information for the guidance of industry, Member States and the public on achievable emission and consumption levels when using specified techniques. The appropriate permit conditions for any specific case will need to be determined taking into account the objectives of the IPPC Directive and the local considerations.

**Air**

1. BAT for the storage, handling and transport (see Sections 2.6.3 and 2.6.5)

2. BAT is to capture the displaced air during loading from the storage bunker of the coal injection unit and subsequent dedusting by bag filter.

   The BAT-AEL for dust is 20 mg/Nm$^3$, determined as the average over the sampling period (spot measurement, for at least half an hour)

   **Burden preparation (mixing, blending)**

3. BAT is to minimise the dust emissions by appropriate measures and where relevant to extract emissions with a subsequent purification by means of an ESP or bag filter.

   **Charging and conveying of the burden**

4. BAT is to efficiently extract emissions with a subsequent purification by means of an ESP or bag filter.

   **Casting house (tap-holes, runners, torpedo ladles charging points, skimmers)**

5. BAT is to prevent or reduce diffuse dust emissions by applying the following techniques individually or in combination (see Sections 6.3.1 and 6.3.2):
   I. covering the runners
   II. fume suppression using nitrogen while tapping, where applicable
   III. optimising the capture efficiency for diffuse dust emissions and fumes with subsequent off-gas cleaning by means of an ESP or bag filter.
The BAT-AEL for dust is <10 mg/Nm\(^3\), determined as a daily mean value.
The BAT-AEL for dust for new plants is <5 mg/Nm\(^3\), determined as a daily mean value.
The BAT-AEL for diffuse dust emissions is <10 g/t hot metal.

6. BAT is to use tar-free runner linings (see Section 6.3.3).

Blast furnace gas
7. BAT is to minimise the release of blast furnace gas during charging (see Section 6.3.5).

8. BAT is to reduce emissions by applying the following techniques individually or in combination (see Section 6.3.4):
   I. using dry prededusting devices such as:
      Ia. cyclones
      Ib. deflectors
      Ic. ESPs
   II. subsequent fine dust abatement by means of:
      IIa. hurdle-type scrubbers
      IIb. venturi scrubbers
      IIc. annular gap scrubbers
      IId. wet ESP
      IIe. disintegrators
      IIf. any other technique achieving the same removal efficiency.

The BAT-AEL for the cleaned BF gas is a residual dust concentration of <10 mg/Nm\(^3\), determined as the average over the sampling period (spot measurement, for at least half an hour).

The BAT-AEL for the cleaned BF gas is a residual dust concentration of <5 mg/Nm\(^3\), determined as annual mean value.

9. BAT is to re-use the dusts from prededusting in the sinter plant as much as possible.

Hot blast stoves
10. BAT is to use desulphurised process gases.

The BAT-AEL for SO\(_2\) is <200 mg/Nm\(^3\).
The BAT-AEL for dust is <10 mg/Nm\(^3\).
The BAT-AEL for NO\(_x\) is <100 mg/Nm\(^3\).
The BAT-AEL for CO with external combustion is <100 mg/Nm\(^3\).

All determined as daily mean value related to an oxygen content of 3 %.
Chapter 6

Water

Water consumption and discharge

11. BAT for waste water from blast furnace gas scrubbing is to minimise and re-use of scrubbing water as much as possible, i.e. for slag granulation if necessary after treatment with a gravel-bed filter (see Section 6.3.6).

Waste water treatment

12. BAT for waste water from blast furnace gas scrubbing is to use sedimentation and flocculation (coagulation)(see Section 6.3.6).

The BAT-AELs are:

- Suspended solids     <30 mg/l
- TOC                  <50 mg/l
- COD                  <150 mg/l
- Iron                 <5 mg/l
- Lead                 <0.5 mg/l
- Zinc                 <2 mg/l
- Cyanide, easily released <0.4 mg/l
- Toxicity to fish eggs as dilution factor TF <6

The BAT-AELs are based on a qualified random sample or a 24-hour composite sample.

13. BAT for waste water from blast furnace slag granulation (see Section 6.2.2.2).

The BAT-AELs are:

- Suspended solids  <50 mg/l
- TOC   <20 mg/l
- COD   <50 mg/l
- Iron   <5 mg/l
- Lead   <0.1 mg/l
- Zinc   <1 mg/l

The BAT-AELs are based on a qualified random sample or a 24-hour composite sample.

Production residues like wastes and by-products

14. BAT is to prevent waste generation are the following techniques in descending order or priority:
   I. appropriate collection and storage to facilitate a specific treatment
   II. on-site recycling of coarse dust from the BF gas treatment and dust from the cast house dedusting back into the sinter process
   III. hydrocyclonage of sludge with subsequent on-site recycling of the coarse fraction when grain size distribution allows for reasonable separation
   IV. slag treatment, preferably by means of granulation where market conditions allow for it for external use of slag (e.g. in the cement industry or for road construction)
   V. controlled disposal of unavoidable wastes from the blast furnace process.

15. BAT for the handling, storage and transport of solid wastes see general section Section 2.6.4.

Minimising slag treatment emissions

16. BAT is to condense fume if odour reduction is required (see Section 6.3.8).
Chapter 6

Energy

17. BAT is a smooth continuous operation of the blast furnace at a steady state to minimise releases and to reduce the likelihood of burden slips (see 6.3.10).
18. BAT is to use the extracted blast furnace gas as as fuel (see section 6.3.11).
19. BAT is to directly inject reducing agents, e.g. a pulverised coal injection; up to 240 kg/t pig iron is already proven, but higher injection rates could be possible (see Section 6.3.12).
20. BAT is to recover the energy of top blast furnace gas pressure where prerequisites are present (see Section 6.3.13).
21. BAT is to recover the sensible heat from the primary as where prerequisites are present.
22. BAT is to preheat the blast furnace gas by the combustion gas of the hot blast stove (cowper) (see Section 6.3.14).

Noise

(see Section 2.6.9)
7 BASIC OXYGEN STEELMAKING AND CASTING

The replacement of air with oxygen in steelmaking was originally suggested by Henry Bessemer. Since 1950, oxygen has been used in steelmaking irrespective of the specific production method. A prerequisite for the cost-effective use of the basic oxygen furnace (BOF) process on an industrial scale was the availability of the required tonnage of technically pure oxygen, as well as the water-cooled lance technology necessary for introducing the oxygen into the converter.

The first production scale BOF (also called an oxygen converter) was erected in Linz, Austria in 1952 [363].

The BOF process and the electric arc furnace (EAF) have since replaced existing, less energy efficient steelmaking processes such as the Thomas process and open-hearth process (Siemens-Martin process). In the EU the last Siemens-Martin ovens were taken out of operation at the end of 1993. The BOF process and the electric arc furnace are the only processes being used to produce steel in the EU. The BOF process accounts for two thirds of production and the EAF process accounts for the remaining third (EU-27 in 2006. See also Figure 1.2).

Figure 7.1 shows a basic oxygen furnace at the moment of charging hot metal.

![Basic oxygen furnace at the moment of charging hot metal](image)

**Figure 7.1:** Basic oxygen furnace at the moment of charging hot metal [200]

7.1 Applied processes and techniques

The objective in oxygen steelmaking is to burn (i.e. oxidise) the undesirable impurities contained in the hot metal feedstock. The main elements thus converted into oxides are carbon, silicon, manganese and phosphorus [363]. Sulphur content is mainly reduced during pretreatment of the hot metal. The purpose of this oxidation process, therefore, is:

- to reduce the carbon content to a specified level (from approximately 4 - 5 % to typically 0.01 - 0.4 %)
- to adjust the contents of desirable foreign elements
- to remove undesirable impurities to the greatest possible extent.
The production of steel by the BOF process is a discontinuous process which involves the following steps:

- transfer from the BF and discharge
- pretreatment of hot metal (desulphurisation, deslagging)
- transfer, weighting and reladling
- oxidation in the BOF (decarburisation and oxidation of impurities)
- secondary metallurgical treatment
- casting (continuous or/and ingot).

The individual steps and their associated emissions are summarised in Figure 7.2.

![Figure 7.2: The sequence of oxygen steelmaking indicating the individual emission sources](image)

**7.1.1 Transport and storage of hot metal**

Hot metal is supplied from the blast furnace to the steelmaking plant using transfer cars or torpedo ladles. The ladles are lined with corundum, mullite, and bauxite or dolomite brick with an additional insulating interlayer between the steel and the refractory material. The torpedo ladle, a form of hot metal mixer travelling on rails, has become the predominant system. The mixing vessel is supported on either side and can be rotated to discharge its contents. Torpedo ladles are commonly designed with capacities between 100 and 300 tonnes, with the largest units holding up to 400 tonnes. The design of the torpedo ladle minimises heat loss. The fact that the torpedo ladle doubles as a hot metal mixer eliminates the need for a separate hot metal storage system.

The service life of torpedo ladles in normal use varies between 150000 and 400000 tonnes. Desulphurisation in the torpedo ladle shortens its potential utilisation cycle between relinings and requires special care in the selection of refractory materials.

While transporting in an open-top ladle, hot metal is in some cases stored in mixers. These are rotatable horizontal steel containers lined with refractory brick. They serve to compensate for production fluctuations of the blast furnace and the steelmaking plant to equalise the chemical composition of individual blast furnace heats, and to ensure homogeneous temperatures. Modern hot metal mixers have capacities of up to 2000 tonnes.
7.1.2 Pretreatment of hot metal

The aim of the pretreatment is to reduce the content of sulphur, phosphorus and silicon in the hot metal [363].

In Europe, only the desulphurisation step is used when preparing hot metal for the BOF process. De-phosphorising and de-siliconising the feedstock involves costly and sophisticated process technology which appears unwarranted in the foreseeable future, given current requirements. The use of these processes depends on the raw materials used in the blast furnace and the required steel grade [363].

Improved blast furnace metallurgy and a reduction of sulphur input by coke and other reduction agents have resulted in lower hot metal sulphur levels. Today specified sulphur concentrations (typically between 0.001 and 0.020 %) for charging in the converter are commonly adjusted in a hot metal desulphurisation facility located at the steel shop. External desulphurisation also implies benefits in terms of environmental protection. With an upstream blast-furnace process, these generally include reduced consumption of coke and sinter, lower losses of hot metal and improved quality of the metallurgical slag. That finally results in a decrease of consumption of refractory linings and oxygen [363].

Desulphurisation agents are mainly calcium carbide but also lime, lime in conjunction with natural gas, magnesium, calcium oxide and rarely materials containing soda ash.

The most widespread hot metal desulphurisation method used in Europe today is that based on calcium carbide, which has superseded the previous soda process for waste disposal and air quality management reasons. The use of a mixture of calcium carbide, magnesium and lime allows the hot metal to be desulphurised to final levels down to 0.0010 %, regardless of the initial sulphur content. Disadvantages lie in the fairly low exhaustion of the desulphurising agent and the need for intense mixing of the desulphurising agent with the hot metal. One specific benefit is that the process gives rise to a crumbly slag which can be easily removed. The use of magnesium in addition to calcium carbide is approximately just as common as the use of calcium carbide alone [363].

Soda desulphurisation with soda ash is a straightforward process due to the low melting temperature and the resulting easy miscibility of the product with the hot metal. Its drawbacks include the low specificity and the need to find a disposal route for the soda slag produced. The sulphur content of these slags varies between 1 and 15 % and their Na₂O content between 5 and 40 %, depending on the process employed. Recycling soda slag within the plant is an impractical proposition because of its high alkalinity. A cost-efficient alternative recycling method has not been devised to date. When dumped, sodium sulphite decomposes into sodium hydroxide solution and hydrogen sulphide due to the presence of water. The use of soda ash is restricted. Small amounts of soda ash may be utilised to a limited extent during the skimming process.

The desulphurisation process is carried out by a number of different methods and systems. In the more common variants, desulphurisation takes place:

- in the blast furnace launder
- in the pouring stream
- in the transfer ladle, or
- in purpose-designed metallurgical vessels.

Known desulphurisation equipment includes the immersion lance, the siphon ladle, rotating and oscillating vessels, and agitating equipment for use in the ladle. Calcium carbide is most commonly used in conjunction with the immersion lance and the stirring method. Magnesium is added in powdered form in a carrier gas via an immersed lance. The desulphurisation process is performed at separate treatment stations.
Chapter 7

An example of practice is as follows: a desulphurising agent is blown through a lance into the hot metal with the aid of nitrogen or dried air. The sulphur is bound in the slag, which floats to the top of the hot metal. The slag is then removed in the slag separation unit and the liquid iron is fed from the ladle into the weighing pit. If necessary, process agents are added in these pits. In some cases, a second slag removal is performed here using slag scrapers. Mostly the ladle is weighted by crane balance. After weighing, the hot metal is charged into the converter [363]. The difference between the filled ladle and the empty ladle is the accurate weight of the hot metal filled into the converter.

7.1.3 Oxidation in the BOF

In order to meet the objectives mentioned above, undesired impurities are oxidised with subsequent removal of the off-gas or slag. Table 7.1 lists the main oxidation processes occurring in the BOF furnace. Undesirable impurities are removed with the off-gas or the liquid slag. The energy required to raise the temperature and melt the input materials is supplied by the exothermic oxidation reaction, so that no additional heat input is required. On the one hand, scrap or ore have to be added to balance heat. In some BOF and combined blowing processes gaseous hydrocarbons (e.g. natural gas), is injected as tuyère coolant (see Figure 7.4).

<table>
<thead>
<tr>
<th>Carbon elimination</th>
<th>(C) + (O) ↔ CO (off-gas)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(CO) + (O) ↔ CO₂ (off-gas)</td>
</tr>
<tr>
<td>Oxidation of accompanying and tramp elements</td>
<td></td>
</tr>
<tr>
<td>- De-siliconisation</td>
<td>(Si) + 2(O) + 2(CaO) ↔ (2CaO • SiO₂)</td>
</tr>
<tr>
<td>- Manganese reaction</td>
<td>(Mn) + (O) ↔ (MnO)</td>
</tr>
<tr>
<td>- De-phosphorisation</td>
<td>2(P) + 5 (O) + 3 (CaO) ↔ (3CaO • P₂O₅)</td>
</tr>
</tbody>
</table>

Deoxidation

| Removal of residual oxygen through ferro-silicon | (Si) + 2(O) ↔ (SiO₂) |
| Aluminium | 2(Al) + 3(O) ↔ (Al₂O₃) |

Notes: [ ] dissolved in the hot metal. ( ) contained in the slag.

Table 7.1: Main chemical reactions taking place during the oxidation process [200] [363]

The operation of a basic oxygen furnace (BOF) is semi-continuous. A complete cycle consists of the following phases: charging scrap and molten hot metal, oxygen blowing, sampling and temperature recording, and tapping. In modern steelworks, up to 380 tonnes of steel are produced in a 30 - 40 minute cycle. During the process, a number of additives are used to adapt the steel quality and to form slag. During charging and tapping, the converter is tilted. During oxygen blowing, the converter is placed in the upright position [363].

There are several types of reactors used for the basic oxygen steelmaking process. The most commonly used type is the LD converter (Linz-Donawitz) applied for hot metal with low phosphorous content. The converter is a pear-shaped, refractory-lined reactor into which a water-cooled oxygen lance is lowered. Through this lance, pure oxygen (>99 %) from an air separation plant is blown onto the liquid hot metal (see Figure 7.3) [363].
Other types of steelmaking reactors are the OBM (Oxygen Bottom Maxhuette process) known in the English speaking world as the Q-BOP process (see Figure 7.4) and the LWS process (Loire Wendel Sprunch process). These processes differ from the LD-converter in that oxygen and fluxes are blown through submerged tuyères in the furnace bottom [19] [363] [440]. The yellow is duplicated! See the next sentence!

In these converters, oxygen is injected from the bottom through tuyères cooled by hydrocarbons blown into the melt. Combined blowing techniques have also been developed. Where necessary, the LD converter process can be enhanced by “bottom stirring” with argon gas (Ar) or nitrogen (N₂) through porous bricks in the bottom lining in certain phases of the process. The most frequent types are the LBE process (Lance Bubbling Equilibrium process) and the TBM process (Thyssen Blowing Metallurgy process) (see Figure 7.5). Alternatively, bottom tuyères may be used to inject pure oxygen or other gases during the blowing process (LTE, Lance Tuyère Equilibrium, or LD-HC). These combined blowing techniques produce a more intensive circulation of the molten steel and improve the reaction between the oxygen and the molten metal [363].
Table 7.2 gives an overview of numbers of oxygen converters in use in the EU, arranged by process types. Obviously the LD-process is the dominant one.

<table>
<thead>
<tr>
<th>Process</th>
<th>No.</th>
<th>Rated capacity (kt/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1997</td>
<td>2004</td>
</tr>
<tr>
<td></td>
<td>1997</td>
<td>2004</td>
</tr>
<tr>
<td>LD</td>
<td>17</td>
<td>5</td>
</tr>
<tr>
<td>LD with bottom stirring</td>
<td>44</td>
<td>36</td>
</tr>
<tr>
<td>LBE</td>
<td>22</td>
<td>10</td>
</tr>
<tr>
<td>OBM</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>K-OBM</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>EOF</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>TBM</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>LWS</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>LET</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>92</td>
<td>60</td>
</tr>
</tbody>
</table>

Table 7.2: Types, numbers and rated capacities of basic oxygen furnaces (oxygen converters) in operation in the EU

The amount of oxygen consumed depends on the composition of the hot metal (i.e. C, Si, P content).

Progress of the steelmaking process is measured by taking samples of the molten metal. In modern plants, sampling is performed without interrupting the oxygen blowing using a sublance. The same result is obtained by standardising the process procedures and/or by using adequate dynamic modelling and monitoring. Those practices sustain quality, productivity and reduce the fume emissions during former converter tilting. When the steel quality meets the demands, the oxygen blowing is stopped and the crude steel is tapped from the converter into a ladle. The molten steel is then transported, after secondary metallurgy, to the casting machine.
The oxidising reactions are exothermic thus increasing the temperature of the molten iron. Scrap, iron ore or other coolants are added to cool down the reaction and maintain the temperature at approximately 1600 - 1700 °C. Usually, approximately 190 kg/t LS is scrap, but values of 300 kg/t LS and even higher are sometimes reached. The amount of scrap charged depends on the pretreatment given to the hot metal and the required liquid steel tapping temperature [145]. Variations in the market value of scrap and the required steel specifications also have an influence [363].

The gases produced during oxygen blowing (converter gas) contain large amounts of carbon monoxide. In most steelmaking plants, measures have been taken to recover the converter gas and use it as an energy source. Open combustion systems introduce air into the converter flue-gas duct, thus partially or fully combusting the carbon monoxide. In the suppressed combustion system, a skirt is lowered over the converter mouth during oxygen blowing. Thus, ambient oxygen cannot enter the flue-gas duct and the combustion of carbon monoxide is prevented. The CO rich flue-gas can be collected, cleaned and stored for subsequent use as fuel. A main advantage of suppressed combustion is the smaller flue-gas flow since no combustion occurs and no additional air-nitrogen is introduced. This results in higher productivity since oxygen blowing speed can be increased. Both "open combustion" and "suppressed combustion" systems are in use. The heat generated in open combustion is usually recovered in a waste heat boiler [363].

The oxygen steelmaking process also generates considerable quantities of particulate matter during charging of scrap and hot metal, blowing, and during tapping of slag and liquid steel. All steelmaking shops in the EU have taken measures to reduce particulate matter emissions.

During the steelmaking process, BOF slag is formed. Slag control is intended to adjust the composition of the hot metal and to generate slag of desired quality [363]. During slag production and after cooling, several measures are taken depending on the market conditions to influence the quality of the BOF slag (see Figure 7.6). Usually the crystalline slag is crushed and sieved which is part of the production process. Slag can also be treated when still liquid just after having been generated by adding silicium in order to produce very high quality aggregates. Phosphates may also be added to produce agricultural soil conditioner. The technical and chemical properties of the slag make it suitable for applications in civil and hydraulic engineering as well as in agriculture [363]. Sometimes the slag is disposed of in landfills.
## Process-stages

<table>
<thead>
<tr>
<th>Process-stages</th>
<th>Measures to influence the quality</th>
<th>Influenced properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw material preparation</td>
<td>Selection, arrangement and pre-treatment of raw materials relating to the chemical composition of the BOF-slag</td>
<td>Chemical composition, e.g.: CaO, SiO₂, P₂O₅, FeOX, MgO, tracer elements</td>
</tr>
<tr>
<td>Melting process</td>
<td>Selection of appropriate process conditions (O₂ rate, lime and scrap rate)</td>
<td>Temperature, composition of products (e.g., FeO, CaO, CaOₓₙ) volume stability</td>
</tr>
<tr>
<td>Heat treatment</td>
<td>Controlled cooling</td>
<td>Structure, porosity, strength, grain size distribution</td>
</tr>
<tr>
<td>Processing</td>
<td>Crushing, sieving, grading, grading</td>
<td>Grain size shape, grain size distribution</td>
</tr>
</tbody>
</table>

**Figure 7.6:** Treatments of BOF slag

- **Raw material preparation**
  - Selection, arrangement and pre-treatment of raw materials relating to the chemical composition of the BOF-slag
  - Influenced properties: Chemical composition, e.g.: CaO, SiO₂, P₂O₅, FeOX, MgO, tracer elements

- **Melting process**
  - Selection of appropriate process conditions (O₂ rate, lime and scrap rate)
  - Influenced properties: Temperature, composition of products (e.g., FeO, CaO, CaOₓₙ), volume stability

- **Heat treatment**
  - Controlled cooling
  - Influenced properties: Structure, porosity, strength, grain size distribution

- **Processing**
  - Crushing, sieving, grading, grading
  - Influenced properties: Grain size shape, grain size distribution

- **BOF-process**
  - **Lime, additions**
  - **Hot metal**
  - **Scrap**

- **Liquid BOF-slag**
  - **Steel**

- **Converter gas**
  - Treatment of liquid slag with O₂ and SiO₂

- **Cooling on air:** slow cooling on air in slag pits to produce a crystalline material with grain sizes less than 100 mm
  - **Converting, grading to be used as aggregates for road construction**
  - **Grinding to a powdered material (<300 µm) to be used as converter lime (fertiliser)**

- **Weathering to achieve volume stable material**

- **Sieving, grading (<315 µm) to be used as converter lime (fertiliser)**

- **Crushing, sieving, grading (<300 µm) to be used as converter lime (fertiliser)**

- **Crushing, sieving, grading to be used as aggregates for road construction and hydraulic structures**

[116] [363] [365] [397]
7.1.4 Secondary metallurgy

The oxidizing process in the converter is usually followed by post-treatment comprising a number of diverse metallurgical operations. Referred to as "secondary metallurgy," this treatment was developed in response to ever increasing quality requirements and has led to substantial productivity increases by shifting the burden of metallurgical refining processes away from the converter. The main objectives of secondary metallurgy are:

- mixing and homogenising
- adjustment of chemical compositions to close analysis tolerances
- temperature adjustment in time for the downstream casting process
- deoxidation
- removal of undesirable gases such as hydrogen and nitrogen
- improvement of the oxidic purity by separating non-metallic inclusions.

An overview of secondary metallurgy operations is given in Figure 7.7. These steps are performed in the ladle or ladle furnace, in a vacuum system, or in purpose-designed furnaces.

Figure 7.7: Overview of secondary metallurgy operations and cleaning during tapping

Note: VOD is an operation used for the production of stainless steel (see Chapter 8) [200] [363] [365] [440]
An important step in secondary metallurgy is vacuum treatment. This mainly serves to remove gaseous hydrogen, oxygen, nitrogen or residual carbon concentrations from the steel at a vacuum below 0.5 mbar (50 Pa). By vacuum treatment, the mass content of hydrogen and nitrogen can be lowered to 0.0002 % and 0.005 %, respectively, by reducing pressure to 10 mbar (1000 Pa). Today, vacuum treatment operations include the precision decarburisation and deoxidation of unalloyed steels, the decarburisation of chromium-alloy grades, the removal of sulphur and inclusions, as well as various alloying, homogenisation, temperature management and reoxidation prevention steps. Vacuum metallurgy has given us steels of improved purity, lower gas content, and tighter alloying tolerances.

The following vacuum treatment methods are used:

- ladle stand or tank degassing and
- recirculating degassing.

Of these, recirculating degassing is the most common process today, although ladle stand degassing is coming back into widespread use.

In ladle degassing the ladle containing the oxidised metal is placed in a vacuumised container. An input of agitation energy ensures higher reaction speeds and reduces the final concentration of undesirable bath constituents. This agitation may be accomplished by injecting argon through one or more porous plugs in the ladle bottom by homogenising the melt via a lance or by an inductive stirring process.

Depending on individual requirements, it is possible to adjust the temperature of the melt at this stage by applying an appropriate combination of:

1. adding high-purity scrap (cooling scrap) to cool the melts
2. adding aluminium and blowing oxygen to raise the temperature
3. electrical heating by graphite electrodes [363].

Alloying agents are also added to the melt to obtain a precision adjustment of steel composition (e.g. Fe/Ni, Fe/Mo, Fe/Mn, Fe/Cr). These alloys are in solid form or enclosed in a hollow wire which is unwound from a reel system, or else by powder injection via lances. Before the end of the stirring cycle, the oxygen level may be determined with the aid of a special probe and adjusted by adding deoxidants. Throughout the stirring process, the dust/gas mixture rising up from the ladle is drawn off by a movable fume hood [363] [275].

In recirculating degassing, the molten metal is vacuum treated continuously or in separate portions. Depending on the process design, a distinction is made between vacuum lift degassing (DH) and vacuum recirculating degassing (RH).

An important step in secondary metallurgy is vacuum treatment which is mainly performed by two methods; the Ruhrstahl-Heraeus device (RH) or the vacuum tank degasser (VTD). This treatment is used to remove gaseous hydrogen, or residual carbon concentrations from the steel at a vacuum below 0.5 mbar (50 Pa). Using vacuum treatment, the mass content of hydrogen and carbon can be lowered to contents of between 0.0002 and 0.0020 %, respectively. In case of a vacuum tank degasser, it is also possible to noticeably decrease nitrogen and to reach very low levels of sulphur (lower than 10 ppm) thanks to a very strong stirring between slag and metal. Vacuum metallurgy has given us steels of improved purity, lower gas content, and tighter alloying tolerances [532].
7.1.5 Casting

Once the final steel quality has been achieved, the steel is conveyed in a casting ladle to the casting machines. Some years ago, the standard method was to pour the molten steel into permanent moulds (permanent mould or ingot casting) by a discontinuous process. Today, the method of choice is continuous casting, whereby the steel is cast in a continuous strand (i.e. slabs of different sizes, thin strip).

7.1.5.1 Continuous casting

Figure 7.8 shows the schematic diagram of a continuous casting plant.

![Scheme of a continuous casting plant with a soaking furnace and a rolling mill with hot charging](image)

Continuous casting offers several important benefits in comparison to ingot casting: [363]

- energy savings, reduced emissions and reduced water utilisation due to the elimination of slabbing mills and billet mills
- improved working conditions
- high yield rates, in excess of 95 %
- high productivity.

Since continuous casting was first introduced on an industrial scale in the late 1960s, its share in overall EU steel output has risen to approx. 97 %. Worldwide, about 90 % of all steel is now cast by the continuous method. Apart from the traditional ingot casting process, continuous casters have also replaced the blooming-slabbing and semifinishing operations of conventional hot rolling mills. Today, almost all steel grades for rolled products can be handled by the continuous casting route, since the necessary preconditions such as deoxidation and degassing are provided by modern secondary metallurgy.

Various types of continuous casters exist and are referred to as vertical type, bending-and-straightening type, bow type and oval bow type machines, depending on their configuration.

The liquid steel is poured from the converter into a ladle which transports the steel after secondary metallurgy to the "tundish" of the continuous casting machine (CCM). This is an intermediate ladle with controllable outlet. The ladles are preheated prior to accepting a liquid steel charge in order to avoid temperature stratification in the tundish.
When the liquid steel has reached the desired temperature, it is poured into the tundish. From here, it passes to a short water-cooled copper mould in which no air is present and which performs oscillating up and down movements to prevent the steel from sticking. The mould gives the metal the desired shape. Continuous casting is a process which enables the casting of one or a sequence of ladles of liquid steel into a continuous strand of billet, bloom, slab, beam, blank or strip. Mould lubricant is added in powder form or vegetable oil. When the metal leaves the casting mould, a "skin" of solidified steel has formed and a large number of trundles (the "pinch-roll") guide the cast steel with a gentle curve toward a horizontal position. Here, the endless casting is cut in pieces with a torch cutter. Slabs, blooms and billets are cast in this way. In the case of non-self-supporting sections, the red-hot strand, with its solidified surface zone, moves through a number of driven and undriven roll pairs which support its shell against ferrostatic pressure. As the core is still liquid, it is sprayed carefully with water and cooled until fully solidified (secondary cooling). This process prevents cracks in the strand surface zone, which is still fairly thin, and also protects the rolls from overheating. The supporting, conveying and driving elements are commonly rolls equipped with interior and exterior cooling. In the secondary cooling zone, interior roll cooling becomes dispensable as soon as the temperature is reduced sufficiently by the water spray. A number of bearings are connected to an automatic grease lubricating system. Once the strand has fully solidified, it can be cut to size by cutting torches moving with the strand or by shears. The rapid cooling process gives the steel a uniform solidification microstructure with favourable technological properties. The solidification microstructure of the strand can be influenced by downstream air or water cooling.

The shape of the strand is determined by the mould geometry. Current mould types include rectangular, square, round or polygonal sections. For the production of steel shapes, it is possible to use moulds resembling the approximate cross-section of the intended product. Typical strand dimensions in continuous casting vary between 80 x 80 mm and about 310 x 310 mm, 600 mm (round) in billet and 450 x 650 mm in bloom systems, while slab casters produce sizes of up to 350 mm in thickness and up to 2720 mm in width. Billet casters can handle several (currently up to eight) strands at the same time, while the number of strands in slab casting is limited to two.

7.1.5.2 Near net shape casting

Since the end of the 1980s continuous casting has been developed for the manufacturing of flat products. These route can be summarised under the heading 'near net shape casting' which includes thin slab casting, near net shape strip casting also known as direct strip casting (DSC) and thin strip casting. There is actually an installed capacity of about 7 million tonnes of these processes in the EU. The thin strip casting shortens the process from liquid steel to hot rolled sheet, therefore reducing the overall energy demand and increasing material efficiency but requires other secondary metallurgical steps. Typical dimensions for thin slab casting vary between produce sizes of 15 and 50 mm in thickness. Near net shape strip casting leads to a strand thickness of below 15 mm and thin strip casting to less than 5 mm [440].

This process is further discussed in this BREF but it is also included in the Ferrous Metals Processing Industry BREF (see scope section). The decision to build a thin strip casting highly depends on local conditions and the required product quality. In case near net shape strip casting is used, it should be taken into account that special secondary metallurgical steps are needed and therefore the emissions and energy consumption for these treatments in relation with LS production could be higher compared with other processes [363]. Scale formation during this type of casting is typically higher than in the conventional casting [384].
7.1.5.3 Ingot casting

In ingot casting, the liquid steel is cast into casting moulds. Depending on the desired surface quality, degassing agents (such as NaF) can be added during casting in the ingot mould. After cooling, the ingots are taken out of the casting mould and transported to the rolling mills. Subsequently, after preheating, the ingots are rolled into slabs, blooms or billets. In many places, ingot casting has been replaced by continuous casting. In 2004, 3% of steelmaking of EU-15 was produced as ingot casting. For the new Member States EU-10, this percentage is about 4.2%. It is expected that ingot casting will eventually be almost completely replaced by continuous casting except in the case of those products which require ingot casting to achieve the necessary quality, such as producing heavy weights for forging [363].

Ingot casting in EAF is also still applied for some grades and applications.
7.2 Current emission and consumption levels

7.2.1 Mass stream overview and input/output data

Figure 7.9 provides an overview of the input and output mass streams of basic oxygen steelmaking. This overview may be used for the collection of data from a single oxygen steelmaking plant.

---

**Figure 7.9:** Mass stream overview of a basic oxygen steelmaking plant

[200]
Figure 7.10 presents the general process layout of basic oxygen steelmaking and visualises the input and output mass streams.

Figure 7.10: General process layout of basic oxygen steelmaking indicating the individual operations and the input and output mass streams

Subsequently specific input factors and specific emission factors have been determined. Values for these factors are shown in Table 7.3 from basic oxygen steelmaking plants located different EU Member States.

<table>
<thead>
<tr>
<th>Input</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Raw materials</strong></td>
<td><strong>Products</strong></td>
</tr>
<tr>
<td>hot metal</td>
<td>Slabs</td>
</tr>
<tr>
<td>kg/t LS</td>
<td>788 - 931</td>
</tr>
<tr>
<td>scrap</td>
<td>Blooms</td>
</tr>
<tr>
<td>kg/t LS</td>
<td>101 - 340</td>
</tr>
<tr>
<td>iron ore</td>
<td>Billets</td>
</tr>
<tr>
<td>kg/t LS</td>
<td>0.02 - 19.4</td>
</tr>
<tr>
<td>other Fe material</td>
<td>Ingots</td>
</tr>
<tr>
<td>kg/t LS</td>
<td>0 - 60</td>
</tr>
<tr>
<td>coke</td>
<td>Foundry</td>
</tr>
<tr>
<td>kg/t LS</td>
<td>0 - 0.4</td>
</tr>
<tr>
<td>lime</td>
<td>Energy</td>
</tr>
<tr>
<td>kg/t LS</td>
<td>30 - 67</td>
</tr>
<tr>
<td>dolomite</td>
<td>Energy</td>
</tr>
<tr>
<td>kg/t LS</td>
<td>0 - 28.4</td>
</tr>
<tr>
<td>Alloys</td>
<td>BOF gas</td>
</tr>
<tr>
<td>kg/t LS</td>
<td>1.3 - 33</td>
</tr>
<tr>
<td>Primary metallurgy</td>
<td>Sludge</td>
</tr>
<tr>
<td>Steel</td>
<td>MJ/t LS</td>
</tr>
<tr>
<td>kg/t LS</td>
<td>(0) 124 - 335</td>
</tr>
<tr>
<td><strong>Gases</strong></td>
<td><strong>Emissions</strong></td>
</tr>
<tr>
<td>Oxygen</td>
<td>Dust</td>
</tr>
<tr>
<td>m³/t LS</td>
<td>49.5 - 70</td>
</tr>
<tr>
<td>Argon</td>
<td>C[2]</td>
</tr>
<tr>
<td>m³/t LS</td>
<td>0.55 - 1.1</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>Fe</td>
</tr>
<tr>
<td>m³/t LS</td>
<td>2.3 - 18.2</td>
</tr>
<tr>
<td></td>
<td>Cu[6]</td>
</tr>
<tr>
<td></td>
<td>g/t LS &lt;=0.01 - 2.72</td>
</tr>
<tr>
<td>Energy</td>
<td>Pb[6]</td>
</tr>
<tr>
<td>MJ/t LS</td>
<td>44 - 730</td>
</tr>
<tr>
<td>Natural gas</td>
<td>Mn[6]</td>
</tr>
<tr>
<td>MJ/t LS</td>
<td>44 - 730</td>
</tr>
<tr>
<td>Electricity</td>
<td>NO[X]</td>
</tr>
<tr>
<td>MJ/t LS</td>
<td>35 - 216</td>
</tr>
<tr>
<td>COG</td>
<td>CO[2]</td>
</tr>
<tr>
<td>MJ/t LS</td>
<td>0 - 800</td>
</tr>
<tr>
<td>BF gas</td>
<td>CO₂[7]</td>
</tr>
<tr>
<td>m³/t LS</td>
<td>1.84 - 17.6</td>
</tr>
</tbody>
</table>
Chapter 7

<table>
<thead>
<tr>
<th>Input</th>
<th>PAH$^0$</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall steam</td>
<td>MJ/t LS</td>
<td>PCDD/F</td>
</tr>
<tr>
<td></td>
<td>13 - 150</td>
<td>μg I-TEQ/t LS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.043 - 0.094</td>
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<tr>
<td>Compressed air</td>
<td>Nm$^3$/t LS</td>
<td>Production residues</td>
</tr>
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<td></td>
<td>8 - 26</td>
<td>(waste/by-products)</td>
</tr>
<tr>
<td>Desulphur. slag</td>
<td>kg/t LS</td>
<td>3 - 40</td>
</tr>
<tr>
<td>BOF slag</td>
<td>kg/t LS</td>
<td>85 - 165</td>
</tr>
<tr>
<td>Water</td>
<td>m$^3$/t LS</td>
<td>Slag from secondary</td>
</tr>
<tr>
<td></td>
<td>0.8 - 41.7</td>
<td>metallurgy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>kg/t LS</td>
</tr>
<tr>
<td>Spittings</td>
<td>kg/t LS</td>
<td>2.8 - 15</td>
</tr>
<tr>
<td>Dists</td>
<td>kg/t LS</td>
<td>0.75 - 24</td>
</tr>
<tr>
<td>Slag from continuous</td>
<td>kg/t LS</td>
<td>4 - 5.7</td>
</tr>
<tr>
<td>casting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mill scale</td>
<td>kg/t LS</td>
<td>2.3 - 7.7</td>
</tr>
<tr>
<td>Rubble</td>
<td>kg/t LS</td>
<td>0.05 - 6.4</td>
</tr>
<tr>
<td>Waste water</td>
<td>m$^3$/t LS</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.3 - 6.1</td>
</tr>
</tbody>
</table>

Legend: LS = liquid steel (crude steel)

$^1$ A distinction can be drawn between high phosphorus (1.5 - 2.2 % P) and low phosphorus hot metal (0.08 - 0.25 % P).

$^2$ Important alloying additions are: Fe-Ti, Fe-W, Fe-Ni, Fe-V, Fe-Si and Fe-Mo.

$^3$ Sum of products (slabs, blooms, billets or ingots). Some BOF plants operate slab caster in combination with bloom, billet or ingot caster. The output is normalised to 1000 per plant.

$^4$ Zero in the case of non-recovery of BOF gas.

$^5$ High value in case of non-suppressed combustion and heat recovery from flue-gases in the form of steam and hot water; zero in case of quantitative recovery of BOF gas without any heat recovery (no steam generation).

$^6$ Higher value in case of less sufficient secondary dedusting.

$^7$ High value in case of partial to full combustion of the BOF gas - indicative value. Emissions also depend on energy input and individual energy and material.

$^8$ PAH as Borneff 6; data available from two plants only. Data from one plant.

$^9$ Information on PM$_{10}$ and PM$_{2.5}$ are generally not available today.

$^{10}$ The wide range of energy inputs shows the variety of energy management at different sites.

$^{11}$ Slabs are the most common product obtained from the BOF route. Long products such as billet and blooms are very often produced from EAFs.

$^{12}$ The wide range reported is due to the different kinds of gas utilisation.

Information about the determination of the data like sampling methods, analysis methods, time intervals, computation methods and reference conditions is not sufficiently available. Data in the Table are yearly mean values and refer to 2004. Emission data reflect the situation after abatement.

(Figure) Values between brackets represent special conditions or abnormal situations. They are not considered representative of BOF operation.

Table 7.3: Input/output-data from 21 existing basic oxygen steelmaking plants in different EU Member States

[200] [363] [365] [359] [403] [451]

7.2.2 Environmental issues for basic oxygen steelmaking

The basic oxygen steelmaking process is a source of primarily particulate matter and solid wastes/by-products and waste water. When abatement techniques are applied to reduce emissions, cross-media effects occur. Generally the following Sections 7.2.2.1 to 7.2.2.4 below describe the most relevant environmental issues in the oxygen steelmaking process [363].
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7.2.2.1 Emissions to Air

The emissions to air from all of these processes/emission sources are summarised in Table 7.3.

Table 7.4 shows some other air pollutants not appearing in Table 7.3.

<table>
<thead>
<tr>
<th>Air pollutant</th>
<th>Emissions (mg/t LS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO\textsubscript{X}</td>
<td>3790 - 13400</td>
</tr>
<tr>
<td>HF</td>
<td>116 - 760</td>
</tr>
<tr>
<td>CH\textsubscript{4}</td>
<td>215</td>
</tr>
<tr>
<td>Cd</td>
<td>23.35 - 200</td>
</tr>
<tr>
<td>Ni</td>
<td>23.35 - 570</td>
</tr>
<tr>
<td>Zn</td>
<td>662</td>
</tr>
</tbody>
</table>

Values correspond to two EU installations

Table 7.4: Other air pollutants

Following the material flow emissions to air occur from the following process stages.

Hot metal pretreatment
- reladling and deslagging
- hot metal desulphurisation.

BOF operations:
- BOF charging
- BOF oxygen blowing (converter gas or BOF gas generation)
- tapping of liquid steel and slag from BOF (converters).

Secondary metallurgy:
- tapping operations (i.e. ladles, ladle furnaces, converters and other equipment used in secondary metallurgy)
- degassing
- refractory preheating (ladle, tundish, degasser)
- handling of additives
- continuous casting.

Diffuse and fugitive emissions
- diffuse and fugitive emissions occur from all the above-mentioned processes whenever off-gases are not fully captured.

Usually the BOF gas (converter gas) is referred to as primary off-gas. The subsequent extraction and dedusting is indicated as a primary dedusting system. The emissions from all other sources related to the aforementioned BOF steelmaking processes are usually referred to as secondary off-gases and being de-dusted by the secondary dedusting system. Sometimes the emissions from the hot metal pretreatment are extracted and treated separately. Usually they are part of the secondary dedusting system.
7.2.2.1 Emissions from hot metal pretreatment

During reladling, desulphurisation and deslagging, emissions of particulate matter occur. The exhaust air generated in the desulphurisation process, subsequent slag separation and weighing is laden with up to 10000 mg/Nm$^3$ or 1000 g/t steel of particulate matter [76] [19]. An efficient collection of the emissions from hot metal pretreatment can be obtained during these processes applying appropriate hoods and doghouses. The off-gas is and subsequently cleaned by means of wet scrubbers or any other dedusting systems with the same removal efficiency such as bag filters or ESPs (secondary or separate dedusting system) [363].

When the particulate matter is efficiently extracted and subsequently led through a bag filter (or ESP), emissions of less than 10 mg/Nm$^3$ (around 1 g/t LS) can be achieved.

In some cases, calcium carbide has been employed in the desulphurisation process. Where water has been used for cooling purposes in order to prevent dust emissions, severe odour problems have been observed. The reason for this was the formation of H$_2$S and organic sulphides which were probably formed by sulphur and residual carbide. By the use of calcium oxide instead of calcium carbide, the slag can be cooled in the air with significantly fewer odour problems.

Since January, 2006 SO$_2$ emissions have also been monitored continuously. Recent daily average emission values of SO$_2$ are in the range of 20 - 100 mg/Nm$^3$ (see Figure 7.17). About 85% of the half-hour average SO$_2$ values are below 100 mg/Nm$^3$ (reference period 1/2007 - 5/2007); however, single values are significantly higher (up to 340 mg/Nm$^3$) [424].

7.2.2.1.2 Emissions from BOF operations

- BOF charging
- slopping during oxygen blowing
- tapping of liquid steel and slag from BOF (converters)
- BOF oxygen blowing.

The emissions from charging, blowing and slopping during the blowing of the BOF (converter) and the tapping of liquid steel and slag are of major relevance and are described in more detail here:

Secondary ventilation and dedusting systems at BOF operations:
Particulate matter is emitted during all of the above-mentioned processes as charging of scrap and hot metal, oxygen blowing and during the tapping from the BOF. During charging or tapping operations, the converter is tilted. A so-called secondary ventilation and dedusting system, is often installed to abate the particulate matter emissions that occur. The secondary ventilation system usually consists of a canopy hood just above the converter in a tilted position and a doghouse around the remaining 3/4 of the converter. During blowing, the secondary system extracts most of the emissions that are not captured by the primary ventilation system. Subsequent treatment of the evacuated gases is usually performed by means of a bag filter or an ESP.

Primary ventilation and dedusting systems at BOF operations:
During oxygen blowing, converter gas is released from the converter. This gas contains carbon monoxide (CO) and large amounts of particulate matter (mainly consisting of metal oxides, including heavy metals), relatively small amounts of sulphur oxides (SO$_2$) and nitrogen oxides (NO$_X$). In addition, very small amounts of PCDD/F and PAH are emitted (see Table 7.3).
Generally, two systems can be used to recover energy from the converter gas:

a. partial/full combustion
b. suppressed combustion.

a. In the full (or open) combustion system, the process gas from the converter furnace is combusted in the flue-gas duct. An opening between the converter furnace and the primary (or converter gas) ventilation allows the entrance of ambient air and thus allows for a partial or full combustion of the converter gas. In this case, the process gas contains approximately 15 - 20 kg particulate matter per tonne of liquid steel and approximately 7 kg carbon monoxide per tonne of liquid steel. Energy is recovered by using the sensible heat in a waste heat boiler. Note that open combustion systems have a large flow (2000 - 3000 Nm³/t LS) compared to suppressed combustion systems (50 - 100 Nm³/t LS). This is due to the introduction of air into the BOF gas (converter gas) duct.

b. When suppressed combustion is applied, a retractable water-cooled skirt is lowered over the mouth of the converter. In this way, carbon monoxide combustion in the flue-gas duct is suppressed and the carbon monoxide can be recovered. The absence of nitrogen (given that air is excluded) means higher oxygen blowing speeds are possible and thus process time is reduced.

The chosen type of recovery influences the emissions.

BOF gas (converter gas) must be classified as a lean gas in terms of its calorific value and Wobbe index, but belongs to the group of rich gases when considered in terms of its combustion properties (and particularly, its combustion temperature). The composition of the converter gas varies with the process used, the recovery method and, specifically, the oxygen volume (see Table 7.5).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Average value</th>
<th>Variation range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO</td>
<td>(vol - %)</td>
<td>72.5</td>
<td>55 - 80</td>
</tr>
<tr>
<td>H₂</td>
<td>(vol - %)</td>
<td>3.3</td>
<td>2 - 10</td>
</tr>
<tr>
<td>CO₂</td>
<td>(vol - %)</td>
<td>16.2</td>
<td>10 - 18</td>
</tr>
<tr>
<td>N₂ + Ar</td>
<td>(vol - %)</td>
<td>8.0</td>
<td>8 - 26</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Characteristic</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>(kg/Nm³)</td>
<td>1.33</td>
<td>1.32 - 1.38</td>
</tr>
<tr>
<td>Gross calorific value</td>
<td>(kJ/Nm³)</td>
<td>9515</td>
<td>7100 - 10100</td>
</tr>
<tr>
<td>Net calorific value</td>
<td>(kJ/Nm³)</td>
<td>9580</td>
<td></td>
</tr>
<tr>
<td>Theoretical flame temperature</td>
<td>(°C)</td>
<td>2079¹</td>
<td></td>
</tr>
<tr>
<td>Specific air demand (wet)</td>
<td>(Nm³/Nm³)</td>
<td>1.81</td>
<td>1.34 - 1.90</td>
</tr>
<tr>
<td>Specific off-gas quantity (wet)</td>
<td>(Nm³/Nm³)</td>
<td>2.43</td>
<td></td>
</tr>
</tbody>
</table>

¹ Combustion gas figures refer to conditions downstream of the gasholder at a temperature of 15 °C, a gauge pressure of 60 mbar, barometer level 1013 Pa and a humidity of 100 %.

² With total humidity and 0 °C.

Table 7.5: Composition and characteristics of BOF gas

Figure 7.11 shows the CO content (a key parameter for the utilisation of BOF gas) as a function of oxidation time in the case of suppressed combustion. On account of its low CO content and for safety reasons, the BOF gas generated during the start and the end of blowing (a few minutes each) is not collected but flared after dedusting [363].
Particulate matter is usually removed from BOF gas by means of venturi scrubbers but also by dry or wet electrostatic precipitators. When suppressed combustion is employed, the venturi scrubbers may achieve a particulate matter concentration of 5 - 10 mg/Nm$^3$ in the grid gas (higher concentrations up to 50 mg/Nm$^3$ are also possible amongst others depending on the particulate size distribution). This corresponds to 1 g/t LS. The iron content of the particulate matter recovered is 42 - 75 %. The particulate matter in the grid gas is emitted at the site of incineration of the grid gas [363]. Before and after blowing the comparatively small collected off-gas flow is flared off as shown in Figure 7.23.

When full combustion is employed, particulate matter emissions to the atmosphere are in the range of 25 - 100 mg/Nm$^3$ after treatment. As a result of the much higher flue-gas flow of open combustion systems, this Figure corresponds to particulate matter emissions of up to 180 g/t LS. Table 7.6 summarises the emissions to air from a BOF.
<table>
<thead>
<tr>
<th>Component</th>
<th>Specific emission value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Flow of primary (BOF gas) ventilation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Full combustion</td>
<td>65000 - 300000</td>
<td>Nm³/h</td>
</tr>
<tr>
<td></td>
<td>2000 - 3000</td>
<td>Nm³/t LS</td>
</tr>
<tr>
<td></td>
<td>50 - 120</td>
<td>Nm³/t LS</td>
</tr>
<tr>
<td>• Suppressed combustion</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Particulate matter from oxygen blowing</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• unabated</td>
<td>15 - 20</td>
<td>kg/t LS</td>
</tr>
<tr>
<td>• after primary (BOF gas) dedusting</td>
<td>0.3 - 55</td>
<td>g/t LS</td>
</tr>
<tr>
<td>• Filtered dust/sludge</td>
<td>12 - 23</td>
<td>kg/t LS</td>
</tr>
<tr>
<td><strong>Flow of secondary ventilation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1300 - 4800</td>
<td>Nm³/t LS</td>
</tr>
<tr>
<td></td>
<td>300000 - 3441000</td>
<td>Nm³/h</td>
</tr>
<tr>
<td><strong>Particulate matter from charging and tapping</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• unabated</td>
<td>200 - 1000</td>
<td>g/t LS</td>
</tr>
<tr>
<td>• after secondary dedusting</td>
<td>2 - 60</td>
<td>g/t LS</td>
</tr>
<tr>
<td>• not caught by enclosure</td>
<td>25 - 100</td>
<td>g/t LS</td>
</tr>
<tr>
<td><strong>Particulate matter from secondary dedusting</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Filtered dust/sludge</td>
<td>0.1 - 1.2</td>
<td>kg/t LS</td>
</tr>
<tr>
<td><strong>(Heavy) metals</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al</td>
<td>0.60 - 0.68</td>
<td>g/t LS</td>
</tr>
<tr>
<td>As</td>
<td>0.00 - 0.02</td>
<td>g/t LS</td>
</tr>
<tr>
<td>Cd</td>
<td>0.07 - 0.20</td>
<td>g/t LS</td>
</tr>
<tr>
<td>Cr</td>
<td>0.00 - 0.04</td>
<td>g/t LS</td>
</tr>
<tr>
<td>Cu</td>
<td>0.04</td>
<td>g/t LS</td>
</tr>
<tr>
<td>Fe</td>
<td>2.8 - 83</td>
<td>g/t LS</td>
</tr>
<tr>
<td>Hg</td>
<td>0.00 - 0.02</td>
<td>g/t LS</td>
</tr>
<tr>
<td>Mg</td>
<td>1.45 - 2.40</td>
<td>g/t LS</td>
</tr>
<tr>
<td>Mn</td>
<td>2.7 - 60</td>
<td>g/t LS</td>
</tr>
<tr>
<td>Pb</td>
<td>1.5 - 2.9</td>
<td>g/t LS</td>
</tr>
<tr>
<td>Zn</td>
<td>8.2</td>
<td>g/t LS</td>
</tr>
<tr>
<td><strong>Sulphur oxides (SO₂)</strong></td>
<td>0.4 - 5.5</td>
<td>g/t LS</td>
</tr>
<tr>
<td><strong>Nitrogen oxides (NOₓ)</strong></td>
<td>5.0 - 20</td>
<td>g/t LS</td>
</tr>
<tr>
<td><strong>Carbon monoxide (CO)</strong></td>
<td>7.0 - 16</td>
<td>kg/t LS</td>
</tr>
<tr>
<td><strong>Hydrogen fluoride</strong>*</td>
<td>0.008 - 0.01</td>
<td>g/t LS</td>
</tr>
<tr>
<td><strong>PAH (Borneff 6)</strong></td>
<td>0.08 - 0.16</td>
<td>mg/t LS</td>
</tr>
<tr>
<td><strong>PCDD/F</strong></td>
<td>&lt;0.001 - 0.11</td>
<td>µg I-TEQ/t LS</td>
</tr>
</tbody>
</table>

Legend: LS = (crude) liquid steel  
* whenever fluorspar (CaF₂) is added as a flux in hot metal desulphurisation, emissions of fluorides may be much higher.

Table 7.6: Specific emission values to air from a basic oxygen furnace with suppressed combustion; after abatement, if there is no other indication

[65] [365] [451]

Note that gradations between suppressed and full combustion exist; some plants employ full combustion while other plants employ partially suppressed combustion and other plants still fully suppress BOF gas combustion. In some cases, the BOF gas is not recovered but flared. Nowadays, there is a tendency towards suppressed combustion and subsequent BOF gas recovery. This makes a large gas tank for a continuous use with controlled quality necessary. There also has to be local use of the recovered gas. The absence of these in some cases means that there are still basic oxygen steelmaking plants in the EU whithout BOF gas recovery [363].

The lance hole is an important aspect in particulate matter emissions. As the oxygen lance needs to be retractable, particulate matter in the flue-gas duct may escape through the lance hole reaching the building atmosphere. Shielding and blowing of steam or inert gas can prevent these emissions. PAH emissions can be reduced by using tar-free refractories.
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7.2.2.1.3 Other emissions in the BOF process including secondary metallurgy and continuous casting

- tapping operations (i.e. ladles, ladle furnaces, converters and other equipment used in secondary metallurgy)
- degassing
- refractory preheating (ladle, tundish, degasser)
- handling of additives
- continuous casting.

Some of the mentioned processes are connected with the secondary ventilation and dedusting system.

Dust releases from the various processes are in the range of 1 - 275 g/t LS [38]. Emissions to air after abatement are in the range of 0.1 - 50 g/t LS.

Concerning the production of leaded steel (see Section 7.3.5) emissions occur during the addition of lead into the ladle containing liquid steel. The resulting off-gas is sucked off and normally treated in a bag filter especially for this waste gas to achieve low residual dust contents (<5 mg/Nm³). But the ladle itself is not gas tight and thus there are also fugitive emissions which are not caught but can be of considerable significance. Information on flow and lead emissions is not available. Such Pb emissions are typical for BOF plants for long products with Pb alloyed steels for automatic computerised numerical control machines [363].

7.2.2.1.4 Diffuse and fugitive emissions from the BOF processes

Diffuse and fugitive emissions occur from all of the above-mentioned processes whenever the emissions are not fully captured. Diffuse emissions should in any case be avoided as much as possible. For this reason, the primary and, in particular, the secondary extraction system should be optimised. Usually the evacuation flow of secondary dedusting systems is quite high. The most efficient measure to prevent or reduce diffuse emissions and to limit the needed extraction flows is to capture the emissions as close as possible to the emissions source. A less efficient option would be to include an additional extraction device at the roof to reduce these emissions. As seen in Table 7.7, big gas volumes have to be treated with comparatively low emission concentrations. However, worldwide a few plants worldwide apply roof extraction.

Diffuse emitted particulates are partially deposited in the production halls or are being emitted via openings in the roof from open doors and windows.

Today, no standardised measurement technique for roof emissions exists so that the estimation of these emissions widely varies. In Table 7.7 the results of measurements according to VDI 2467 part 7 for the emitted dust via the roof are shown. Although an efficient secondary ventilation and dedusting system is used with hoods close to the emissions sources and an extraction flow of 300000 - 1000000 m³/h a considerable amount of dust is still emitted via the roof openings. Concerning the average steel production, the specific dust emissions are approximately 100 g/t. In general, roof emissions are estimated to be in the range of 8 - 120 g/t liquid (crude) steel. Some process conditions e.g. slopping from the converter can result in temporarily higher emission values. The actual emissions depend mainly on the capture efficiency and the charging sequence of scrap and hot metal [363].
Table 7.7: Measurements of roof emissions from basic oxygen steelmaking

From one plant it is reported that the emissions that are emitted diffusely via the roof from reladling and desulphurisation are 4 tonnes and from the charging and tapping of the converter and from secondary metallurgy are 56 tonnes [359].

7.2.2.2 Waste water

The relevant sources of waste water are the following:

Water is used for the following purposes:

- scrubbing water from BOF gas treatment
- scrubbing water from wet dedusting of desulphurisation
- water from vacuum generation
- water from direct cooling from continuous or ingot casting.

According to the water management which is looking for an optimal treatment of all waste water information on the flow and treated waste water of single production steps often are not available because therefore the mixture of different waste water streams are treated together (see Section 2.4) [363].

Waste water from BOF gas treatment

BOF gas is treated either wet or dry. In the case of wet cleaning, waste water is produced which is normally recycled after treatment. This treatment is very often performed in two steps: separation of coarse particles (>200 μm grain size) followed by sedimentation in circular settling tanks. Flocculating agents are added to improve sedimentation.

The purpose of electrical flocculation is to eliminate small and slowly settling particles by means of an electrical field. Particles with the same polarity tend to repel each other, thus decelerating the sedimentation process. In electrical flocculation, the surface of the particles is discharged when passing the electrical field which approves the agglomeration of particles.

The electrical flocculation system consists of several segments that are installed in the middle of the settling tank near the waste water inlet. Each segment consists of one anode and four cathode pipes. A DC current is conducted from the anode to the cathodes via the waste water, thus generating an electrical field.
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The capacity of settling tanks is remarkably increased and no chemical flocculants are needed. The process also has an anti-scaling effect which prevents sedimentation of particles on the surfaces of the settling tank [363].

The sludge is dewatered by means of rotary vacuum filters, chamber filter presses or centrifuges. Representative data about flow and quality of the treated waste water discharged from the circuit (overflow) are not available.

Waste water from vacuum generation

For the vacuum treatment the usual specific process water flow from vacuum generation ranges from 5 - 8 m³/t LS vacuum treated. In a few cases, the specific process water demand is higher; in one case 41 m³/t LS (see Table 7.3). This water is almost fully recycled. It should be mentioned that not all of the liquid steel has to be vacuum treated. Therefore, the weighted specific overall waste water output from vacuum treatment is 1.3 m³/t LS. Data on composition and treatment or recycling are not available [363] [365] [471]. Usually this waste water is treated together with other streams from the rolling mill(s).

Waste water from continuous casting

Emissions to water from continuous casting machines are generated by the direct cooling system. This is used for direct cooling of slabs, blooms, billets and the machines. The waste water contains mill scale (1 - 3 g/l) and oil/grease. This water is very often treated together with waste water from rolling mills. The amount of waste water strongly depends on local conditions and water management. The specific water demand for continuous casting is usually between 5 and 35 m³/t LS [495]. The amount of waste water which can arise from continuous casting is up to 2 m³/t LS.

7.2.2.3 Process residues such as wastes and by-products

The various solid residues resulting from basic oxygen steelmaking are compiled with their specific quantities in Table 7.8 [363], and show the results of an inquiry from European oxygen steelmakers.

<table>
<thead>
<tr>
<th>Generated solid material (waste/by-product/residues)</th>
<th>Specific quantity (range) (kg/t LS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desulphurisation slag</td>
<td>3 - 21</td>
</tr>
<tr>
<td>BOF slag</td>
<td>85 - 165</td>
</tr>
<tr>
<td>Slag from secondary metallurgy</td>
<td>9 - 15</td>
</tr>
<tr>
<td>Slag from continuous casting</td>
<td>4.0 - 5</td>
</tr>
<tr>
<td>Splittings</td>
<td>2.8 - 15</td>
</tr>
<tr>
<td>Fine and coarse dust</td>
<td>0.75 - 24</td>
</tr>
<tr>
<td>Mill scale from continuous casting</td>
<td>2.3 - 6.4</td>
</tr>
<tr>
<td>Rubble</td>
<td>0.05 - 6</td>
</tr>
</tbody>
</table>

Table 7.8: Kind and specific quantity of solid residues resulting from oxygen steelmaking [363] [365]

From this table the following percentages can be derived: BOF slag, (approx. 80 %), desulphurisation slag (approx. 10 %), slag from the secondary metallurgy (approx. 7 % and slag from continuous casting (approx. 3 %) [363].

The slag from basic oxygen converters (BOF) make up the largest share as shown in Table 7.9.
Steel slags | Amount (ktonnes) | %
---|---|---
BOF slag | 9424 | 87.3
Secondary steel slag including desulphurisation and secondary metallurgy | 1368 | 12.7
Total | 10792 | 100

Data from 2004 and related to the following EU countries: AT, BE, DE, DK, ES, FR, FL, LU, NL, UK, S, Slo

Table 7.9: Production of BOF and secondary steel slags

Desulphurisation slag
Desulphurisation slag is a heterogeneous slag which is only partially melted. The composition of desulphurisation slags strongly depends on the used desulphurisation agents. An example of the composition of such a slag is presented in Table 7.10.

<table>
<thead>
<tr>
<th>CaO</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>MgO</th>
<th>Total Fe</th>
<th>Metallic Fe</th>
<th>MnO</th>
<th>P₂O₅</th>
<th>Cr₂O₃</th>
<th>Free CaO</th>
<th>S</th>
<th>CaO/ SiO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>27.0</td>
<td>18.0</td>
<td>8.0</td>
<td>10.0</td>
<td>20.0</td>
<td>15.0</td>
<td>≤0.5</td>
<td>≤0.2</td>
<td>≤0.1</td>
<td>≤5</td>
<td>≤4</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Table 7.10: Chemical composition of slag from hot metal desulphurisation in (wt - %)

The relatively high sulphur content and unsatisfactory mechanical properties do not make desulphurisation slag ideal for re-use. They are normally recycled to the sinter mix of the integrated steelworks or partially used for landfill construction or for noise protection barriers. They are also landfilled (see Figure 7.12) [363]. New investigations for using the slag as sulphur containing soil conditioners are successful, so there could be a new application for this kind of slag.

![Landfilled 41 % On-site recycling 37 % Sold 21 % External use 1 %](image)

Figure 7.12: Fate of slag from hot metal desulphurisation in the EU

BOF slag
The chemical composition of BOF slag depends on the processes employed (see Table 7.11).
### Table 7.11: Examples of chemical composition of BOF slags

<table>
<thead>
<tr>
<th>Process</th>
<th>LD/AC</th>
<th>LD1</th>
<th>LD2</th>
<th>LD3</th>
<th>LD4</th>
<th>AOD1</th>
<th>AOD2</th>
<th>AOD3</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaO</td>
<td>50.0</td>
<td>50.0</td>
<td>52.4</td>
<td>51.4</td>
<td>44.2</td>
<td>53.0</td>
<td>51</td>
<td>56.7</td>
</tr>
<tr>
<td>Free CaO</td>
<td>≤7</td>
<td>≤10</td>
<td>8.2</td>
<td>4.8</td>
<td>≤0.2</td>
<td>≤5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SiO₂</td>
<td>9.0</td>
<td>15.0</td>
<td>12.6</td>
<td>14.8</td>
<td>23.7</td>
<td>28.0</td>
<td>30</td>
<td>30.7</td>
</tr>
<tr>
<td>CaO/SiO₂</td>
<td>4</td>
<td>2.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>≤2</td>
<td>≤2</td>
<td>1.6</td>
<td>1.3</td>
<td>1.6</td>
<td>3.0</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>MgO</td>
<td>≤3</td>
<td>≤3</td>
<td>3.1</td>
<td>4.1</td>
<td>2.1</td>
<td>5.0</td>
<td>7.7</td>
<td>5.5</td>
</tr>
<tr>
<td>Total Fe</td>
<td>12.0</td>
<td>16.0</td>
<td></td>
<td></td>
<td>≤2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metallic Fe</td>
<td>≤1</td>
<td>≤1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FeO</td>
<td></td>
<td></td>
<td>12.6</td>
<td>12.7</td>
<td>12.2</td>
<td>0.5</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td></td>
<td></td>
<td>11.7</td>
<td>10.8</td>
<td>11.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MnO</td>
<td>2.0</td>
<td>≤4</td>
<td>4.3</td>
<td>4.9</td>
<td>2.4</td>
<td>≤1</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Cr₂O₃</td>
<td>≤1</td>
<td>≤1</td>
<td>0.4</td>
<td>0.31</td>
<td>0.16</td>
<td>≤2</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>TiO₂</td>
<td></td>
<td></td>
<td>0.5</td>
<td>0.9</td>
<td>0.7</td>
<td>0.9</td>
<td>0.39</td>
<td></td>
</tr>
<tr>
<td>V₂O₅</td>
<td></td>
<td></td>
<td>0.33</td>
<td>0.29</td>
<td>0.12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P₂O₅</td>
<td>15.0</td>
<td>≤2</td>
<td></td>
<td></td>
<td></td>
<td>≤0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>≤1</td>
</tr>
</tbody>
</table>

Legend:
- LD/AC = Linz-Donawitz/Arbed-CRM process
- LD = Linz-Donawitz process (four examples)
- AOD = Argon Oxygen Decarburisation process (three examples)

### Table 7.12: Three examples of the range of mineral constituents of converter slags

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Tricalcium silicate</th>
<th>Dicalcium silicate</th>
<th>Dicalcium iron oxide</th>
<th>Spinel</th>
<th>Wüstite</th>
<th>Lime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formula</td>
<td>3CaO·SiO₂</td>
<td>2CaO·SiO₂</td>
<td>2CaO·Fe₂O₃</td>
<td>MeO·Me₂O₃</td>
<td>FeO</td>
<td>CaO</td>
</tr>
<tr>
<td>LD slag 1</td>
<td>0</td>
<td>40</td>
<td>30</td>
<td>0</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>LD slag 2</td>
<td>20</td>
<td>35</td>
<td>25</td>
<td>0</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>LD slag 3</td>
<td>0</td>
<td>70</td>
<td>0</td>
<td>20</td>
<td>10</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: Values in wt- %

The mineral composition of these slags is different and are very site-specific as shown in Table 7.12.

Most of the BOF slag is used as an aggregate in road construction as base/sub-base, in asphalt mixtures and in water way construction (in hydraulic engineering, e.g to stabilise shores). But there is also a percentage of BOF slag that is still put to landfill due to market conditions.

Steel slag can also partially be used as a lime source in the sinter mix or directly in the blast furnace burden or in the BOF as well (internal use). This is partly restricted due to the limited amount of phosphorus allowed in the hot metal. A considerable amount of slag is still used as a fertiliser and a liming agent in agriculture because of the relatively high free CaO content.
Slags from secondary metallurgy

The composition of secondary metallurgy slag is quite different and a very wide range of compositions can be found because they depend on the production technology and on the kind of steels produced.

The slag from secondary metallurgy represents a small proportion of residues from steel shops as shown in Table 7.9.

The mineral composition of secondary slags is different and is site-specific as shown in Table 7.12 and Table 7.13.

### Secondary metallurgy slag

<table>
<thead>
<tr>
<th>Name</th>
<th>Mineral</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beta dicalcium silicate</td>
<td>larnite</td>
<td>$\beta$-Ca$_2$SiO$_4$</td>
</tr>
<tr>
<td>Gamma dicalcium silicate</td>
<td>ingesonite</td>
<td>$\gamma$-Ca$_2$SiO$_4$</td>
</tr>
<tr>
<td>Calcium magnesium silicate</td>
<td>bredigite</td>
<td>Ca$_2$Mg(SiO$_4$)$_4$</td>
</tr>
<tr>
<td>Calcium fluoride silicate</td>
<td>cuspidine</td>
<td>Ca$_4$F$_2$Si$_2$O$_7$</td>
</tr>
<tr>
<td></td>
<td>spinels</td>
<td>Me$^{2+}$(Me$^{3+}$)$_2$O$_4$</td>
</tr>
<tr>
<td>Calcium aluminium oxide</td>
<td>mayenite</td>
<td>Ca$_{12}$Al$<em>6$O$</em>{33}$</td>
</tr>
<tr>
<td>Magnesia</td>
<td>periclase</td>
<td>MgO</td>
</tr>
<tr>
<td>Calcium oxide</td>
<td>lime</td>
<td>CaO</td>
</tr>
</tbody>
</table>

**Me**: Combination of metals with valence 2 and 3 (e.g. Mg$^{2+}$, Al$^{3+}$)

### Table 7.13: Major mineral constituents secondary metallurgical slags

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Lower limit (w/w %)</th>
<th>Upper limit (w/w %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaO</td>
<td>20</td>
<td>65</td>
</tr>
<tr>
<td>FeO</td>
<td>0.1</td>
<td>20</td>
</tr>
<tr>
<td>SiO$_2$</td>
<td>1</td>
<td>40</td>
</tr>
<tr>
<td>MgO</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>0.5</td>
<td>40</td>
</tr>
<tr>
<td>P$_2$O$_5$</td>
<td>&lt;0.01</td>
<td>1</td>
</tr>
<tr>
<td>Mn</td>
<td>0.03</td>
<td>7.7</td>
</tr>
<tr>
<td>Ti</td>
<td>0.02</td>
<td>3</td>
</tr>
<tr>
<td>Cr</td>
<td>&lt;0.01</td>
<td>2.6</td>
</tr>
<tr>
<td>F</td>
<td>&lt;0.01</td>
<td>10</td>
</tr>
<tr>
<td>S tot.</td>
<td>&lt;0.05</td>
<td>4</td>
</tr>
</tbody>
</table>

### Table 7.14: Secondary steelmaking slags

Figure 7.13: Fate of BOF slags in the EU [30]
Dust and sludge from BOF gas treatment

Coarse dust comes from the first dedusting step and fine dust from the second one. There are different systems for separating coarse and fine dust. This can be done in the process itself, e.g. by separate capture separation of the dust of the consecutive dedusting steps or by treatment of the dust/sludge afterwards e.g. coarse sludge can be recovered in a pre-settling tank and fine sludge in a second settling tank. The composition of coarse dust can be seen from Table 7.15 in comparison with the one for fine dust. The composition of coarse sludge and fine sludge has the similar relations.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Coarse dust</th>
<th>Fine dust</th>
<th>Primary dedusting</th>
<th>Secondary dedusting</th>
<th>Sludge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Fe</td>
<td>30 - 85</td>
<td>54 - 70</td>
<td>38 - 85</td>
<td>32 - 63</td>
<td>48 - 70</td>
</tr>
<tr>
<td>Metallic Fe</td>
<td>72</td>
<td>20</td>
<td>Only poor information of the metallic content</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CaO</td>
<td>8 - 21</td>
<td>3 - 11</td>
<td>5.7 - 40</td>
<td>3.7 - 35</td>
<td>3.0 - 17</td>
</tr>
<tr>
<td>Zn</td>
<td>0.01 - 0.4</td>
<td>1.4 - 3.2</td>
<td>0.1 - 1.5</td>
<td>0.5 - 13</td>
<td>0.2 - 4.1</td>
</tr>
<tr>
<td>Pb</td>
<td>0.01 - 0.04</td>
<td>0.2 - 1.0</td>
<td>0.05 - 0.4</td>
<td>0.09 - 0.8</td>
<td>0.04 - 0.14</td>
</tr>
<tr>
<td>S</td>
<td>0.02 - 0.06</td>
<td>0.07 - 0.12</td>
<td>0.02 - 1.3</td>
<td>0.1 - 1.1</td>
<td>0.03 - 0.35</td>
</tr>
<tr>
<td>C</td>
<td>1.4</td>
<td>0.7</td>
<td>0.1 - 6.5</td>
<td>1.0 - 8</td>
<td>0.7 - 4.6</td>
</tr>
</tbody>
</table>

*) Values up to 8.5 wt-% are possible

Table 7.15: Composition of coarse and fine dust and sludge in (wt-%)

The coarse dust after preparation is usually returned to the oxygen steelmaking process or is recycled to the sinter strand or to cold bonded briquettes for use in blast furnaces. In the EU a smaller percentage is sent to landfill (see Figure 7.14).

![Figure 7.14: Fate of dust from dry BOF gas treatment](30) [363]

Table 7.15 indicates that fine dust compared to coarse dust contains significantly larger amounts of lead and zinc. The main source of these heavy metals is usually scrap charged to the BOF. In some cases it is possible to control the lead and particularly the zinc input with the scrap. However, it has been noticed that the availability of scrap with low content of zinc (e.g. less than 1 %) has decreased continuously during the last years. Because of the zinc content, very often the fine dust or sludge cannot be recycled but is put to landfill (see Figure 7.14) [363].

Spittings

Spittings occur from slopping caused by extreme foaming in the converter during blowing. The spittings have a high content of iron which is separated and recycled to the sinter plant. The rest of the slag (with less iron) is normally landfilled [363].

Mill scale from continuous casting

These by-products are normally recycled to the sinter strand [363].
### Table 7.16: Composition of mill scale

<table>
<thead>
<tr>
<th>Parameter</th>
<th>wt- %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe_total</td>
<td>33 - 72</td>
</tr>
<tr>
<td>Fe_metallic</td>
<td>Only poor information of the metallic ferrous content.</td>
</tr>
<tr>
<td>CaO</td>
<td>0.4 - 16</td>
</tr>
<tr>
<td>C</td>
<td>0.1 - 0.8</td>
</tr>
<tr>
<td>Oil</td>
<td>8</td>
</tr>
</tbody>
</table>

The total amount of dust/sludge and mill scale from oxygen steelmaking was 2.23 million tonnes in 2004 (covering the 86 % of the EU-15 production).

![Diagram showing use of dust/sludge and mill scale from oxygen steelmaking](image)

**Figure 7.15: Use of dust/sludge and mill scale from oxygen steelmaking**

**Rubble**

Rubbles are mainly spent refractories. There are no representative data available on the fate of these solid wastes/by-products. In some steelworks it is partly recycled to the BOF or re-used for the production of new refractory material. In other cases, it is put to landfill [363].

#### 7.2.2.4 Energy consumption

**Basic oxygen furnace (BOF)**

In the BOF (converter), fuel is consumed to preheat and dry the converters after relining and repair. This thermal energy consumption totals approximately 0.051 GJ/t LS. Electricity consumption is estimated at 23 kWh/t LS or 0.08 GJ/t LS. This figure includes the production of oxygen and the operation of the converters.

The process gas from the converter contains large amounts of carbon monoxide (CO) and is hot. When the energy from the BOF gas is recovered (waste heat recovery and/or BOF gas recovery), the basic oxygen furnace becomes a net producer of energy. In a modern plant, energy recovery can be as high as 0.7 GJ/t LS.

**Continuous casting**

Fuel consumption for preheating the ladle containing liquid steel is estimated at 0.02 GJ/t LS. Electricity consumption of the casting machines is estimated at 0.04 GJ/t LS [65].
Chapter 7

7.3 Techniques to consider in the determination of BAT

This section sets out techniques considered generally to have potential for achieving a high level of environmental protection in the industries within the scope of the document. Management systems, process-integrated techniques and end-of-pipe measures are included, but a certain amount of overlap exists between these three when seeking the optimum results.

Prevention, control, minimisation and recycling procedures are considered as well as the re-use of materials and energy.

Techniques may be presented singly or as combinations to achieve the objectives of the IPPC Directive. Annex IV to this Directive lists a number of general considerations to be taken into account when determining BAT and techniques within this section will address one or more of these considerations. As far as possible, a standard structure is used to outline each technique, to enable comparison of techniques and an objective assessment against the definition of BAT given in the IPPC Directive.

The content of this section is not an exhaustive list of techniques and others may exist or be developed which may be equally valid within the framework of the IPPC and BAT.

The standard structure used to outline each technique is shown in Table 7.17.

<table>
<thead>
<tr>
<th>Type of information considered</th>
<th>Type of information included</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Technical description of the technique (including drawings, schematics if necessary)</td>
</tr>
<tr>
<td>Achieved environmental benefits</td>
<td>Main environmental benefits (including energy, water, raw material savings, as well as production yield increases, energy efficiency, etc.) addressed by the technique</td>
</tr>
<tr>
<td>Cross-media effects</td>
<td>Main environmental side effects and disadvantages to other media caused by using the technique. Details of the environmental effects of the technique in comparison with others</td>
</tr>
<tr>
<td>Operational data</td>
<td>Data on consumption and emission levels from operational plants using the technique (including any reference conditions and monitoring methods used). Any other relevant information on how to operate, maintain and control the technique</td>
</tr>
<tr>
<td>Applicability</td>
<td>Indication of the type of plants in which the technique may be applied, considering, e.g. plant age (new or existing), plant size (large or small), techniques already installed and type or quality of product</td>
</tr>
<tr>
<td>Economics</td>
<td>Information on costs (both investment and operational) and any possible savings (e.g. reduced raw material or energy consumption, waste charges) or revenues including details on how these costs/savings or revenues have been calculated/estimated</td>
</tr>
<tr>
<td>Driving force for implementation</td>
<td>Local conditions or requirements which lead to, or may stimulate, implementation. Information on reasons other than environmental ones for implementation (e.g. increase in productivity, safety)</td>
</tr>
<tr>
<td>Example plants</td>
<td>Reference to (a) plant(s) in which the technique is applied and from which information has been collected and used in writing the section</td>
</tr>
<tr>
<td>Reference literature</td>
<td>Literature or other reference material (e.g. books, reports, studies, websites) that was used in writing the section and that contains more details on the technique</td>
</tr>
</tbody>
</table>

Table 7.17: Information breakdown for each technique described in this section
7.3.1 Particulate matter abatement from hot metal pretreatment

Description
During the three stages of hot metal pretreatment (desulphurisation, slag separation, and hot metal transfer and weighing), particulate matter emissions occur. The specific dust emission factor (before abatement) varies from 110 - 830 g/t LS [38]. These emissions are captured (see Figure 7.16) and are usually treated by means of bag filters. The desulphurisation stands are largely of the enclosed type. Key dust recovery measures include the use of ladle lids, controlled introduction of desulphurising agents, integrated deslagging operations, use of an enclosure with an extraction system and the installation of a door moving in the process (see Figure 7.16).

![Diagram of dust arrestment at a hot metal desulphurisation stand](image)

Figure 7.16: Dust arrestment at a hot metal desulphurisation stand
[38]

Extracted gases are loaded with up to 10000 mg/Nm³ of dust. In some cases, dry electrostatic precipitators are applied.

An important feature is the evacuation efficiency of the ventilation system. The position of the suction hoods has to be optimised in order to achieve a good extraction efficiency. Flue-gas flow for standalone dedusting is in the range of 30000 - 1 million Nm³/h. With standalone dedusting systems one may better control dedusting capacities and re-use different types of collected dusts. Today, in some plants, the dedusting of desulphurisation stand is part of a centralised secondary dedusting system and cannot be separately characterised. These systems have a flow capacity of between 300000 and 2200000 Nm³/h. In some cases, the necessary extraction capacity can be adjusted based on different process conditions.

Achieved environmental benefits
When the particulate matter is efficiently extracted and subsequently led through a bag filter (or ESP), emissions of less than 10 mg/Nm³ (around 1 g/t LS) can be achieved.
A dedusting unit in Voestalpine Stahl Linz, Austria has an extraction volume of about 1 million Nm³/h and handles extraction points from hot metal pretreatment, hot metal desulphurisation, slag separation, hot metal handling and one ladle furnace. Emissions of dust are measured continuously. The annual average dust emissions level in 2004 was 7.1 mg/Nm³. Recent daily average dust emission values are in the range of 0.2 - 1 mg/Nm³. Since 2006 SO₂ emissions are monitored continuously, too. Daily average emission values of SO₂ measured over a period of 3 month in 2007 are in the range of 20 - 100 mg/Nm³. Monitoring data for both dust and SO₂ emissions over a period of three months are shown in Figure 7.17. However, single values are up to 340 mg/Nm³.

Cross-media effects
The suction pumps consume energy and solid waste is generated which can be recycled into the sintering process (high Fe content). However, this will generate a higher sulphur emissions of the sintering process. The composition of the dust from the hot metal desulphurisation unit is dependent heavily on the desulphurisation agent used.

Operational data
Both bag filters and ESPs can be operated without problems.
Applicability
Particulate matter abatement from hot metal pretreatment can be applied at both new and existing plants.

Economics
Investments for the application of this technique are approximately EUR 10 million. For the example the currency was converted into Ecu in 1996 and for the review into EUR.

Driving force for implementation
The main driving forces have been the emission limit values or other legal requirements.

Example plants
Particulate matter abatement during hot metal pretreatment is practised at many plants around the world.

Reference literature
[19] [65] [363] [409] [424]

7.3.2 Primary dedusting

Description
During oxygen blowing, BOF gas is generated. This gas is loaded with a large amount of particulate matter. When the BOF gas is recovered for use as a fuel (see Section 7.3.11), the gas should meet certain requirements. When BOF gas is combusted in the flue-gas duct, the flue-gas is emitted and should meet local emission standards. Nowadays, most plants recover the BOF gas as a fuel. Full combustion systems introduce ambient air in the primary ventilation system to combust the BOF gas. This leads to a large flue-gas flow (2000 - 3000 Nm$^3$/t LS); suppressed combustion systems only generate BOF gas (50 - 100 Nm$^3$/t LS) (see Table 7.6). This results in significant differences in the dimensions of the primary dedusting facilities. The reduced waste gas flowrate characterising the suppressed combustion method results in a higher raw gas mass concentration, so that the efficiency of the dust recovery system must be increased for an identical clean gas dust load. From a dust recovery point of view, therefore, the suppressed combustion principle allows the use of dedusting systems designed for smaller volumetric flowrates which must nevertheless achieve higher dust recovery rates.

Primary dedusting is usually performed by venturi-type scrubbers (approximately 60 % of the plants) or dry and wet electrostatic precipitators. Prior to the venturi or the ESP, coarse particulates are usually removed by means of a deflector, etc.

Special attention should be paid to the emission of particulate matter through the oxygen lance hole. Emissions from this hole can be as large as 50 g/t liquid steel. Emissions can be abated by means of a movable "mill stone", which covers the hole during oxygen blowing and/or injection of inert gas (N$_2$/CO$_2$) or steam in the lance hole to dissipate the particulate matter. Other designs of lance hole seals are also efficiently combined with lance cleaning devices.

Achieved environmental benefits
Dry dedusting and suppressed combustion: By applying an ESP, residual dust concentrations in the BOF gas may be reduced to as little as 10 mg/Nm$^3$ (equivalent to 0.5 - 1.0 g/t LS), at any rate below 50 mg/Nm$^3$. Before the gas is treated in the ESP, coarse dust is removed in a deflection zone and the gas is conditioned in an evaporation cooler.

Dry dedusting and open combustion: Dust emissions of the BOF gas may be reduced to 20 - 50 mg/Nm$^3$. 
Chapter 7

**Scrubbing and suppressed combustion:** Applying a wet system first, coarse particles are removed in a wet separator, then fine particles are removed by venturi scrubbers. The particulate matter concentration in the BOF gas after scrubbing is usually between 15 and 50 mg/Nm$^3$, but can also be less than 10 mg/Nm$^3$.

**Scrubbing and open combustion:** When BOF gas is combusted in the flue-gas duct and cleaned by means of venturi scrubbers, the residual dust content is between 10 and 50 mg/Nm$^3$.

<table>
<thead>
<tr>
<th></th>
<th>Scrubber and wet ESP</th>
<th>Wet separator and Bag filter</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM</td>
<td>32.5</td>
<td>&lt;20</td>
</tr>
<tr>
<td>CO</td>
<td>15</td>
<td>2</td>
</tr>
<tr>
<td>NO$_x$</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Hg</td>
<td></td>
<td>0.002</td>
</tr>
<tr>
<td>Cd, Ti</td>
<td>0.003</td>
<td></td>
</tr>
<tr>
<td>As, Co, Ni, Se, Te</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Pb, Cr, Cu, Mn, V</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>Pb</td>
<td></td>
<td>0.3</td>
</tr>
<tr>
<td>PCDD/F</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>HF</td>
<td>&lt;0.5</td>
<td></td>
</tr>
</tbody>
</table>

Notes: Values are in mg/Nm$^3$ except for PCDD/F that are in ng/Nm$^3$. Values are annual averages.

Table 7.18: Achievable levels when using different air abatement techniques [407]

**Cross-media effects**
The extracted dusts and sludges may contain high concentrations of zinc, thus hampering their re-use. The use of zinc-poor scrap may enable recycling of the BOF sludge/dust to the sinter plant. Plants using dry ESPs may hot briquette the solid waste and recycle the briquettes directly into the steelmaking process (see Section 7.3.8).

In addition, wet dedusting implies the generation of a contaminated waste water flow.

Furthermore, the operation of a dedusting device consumes energy. In a suppressed combustion system, this would correspond to 0.001 - 0.005 GJ/t steel for a venturi scrubber and <0.001 GJ/t steel for a dry ESP.

In an open combustion system, this would correspond to 0.04 to 0.15 GJ/t liquid steel for a venturi scrubber and <0.005 GJ/t steel for a dry ESP.

**Operational data**
No data submitted.

**Applicability**
Primary dedusting can be applied at both new and existing plants. Some plants apply dry ESPs. For instance, at Voestalpine Stahl GmbH, Linz, Austria, the steel plant was retrofitted with a dry dedusting system to replace an existing wet one.

**Economics**
- investments for primary dedusting are between EUR 24 million and 40 million for a 1 Mt/yr steelmaking plant
- operational costs are from EUR 2 - 4/t LS.

For the examples the currency was converted into Ecu in 1996 and for the review into EUR.
Driving force for implementation
In order to recover BOF gas by suppressed combustion, highly efficient purification is necessary. In the case of non-recovery or recovery by combustion of BOF gas, the BOF gas should be treated in order to meet existing emission limit values.

Example plants

- dry ESP and suppressed combustion:
  - ThyssenKrupp Steel AG, Duisburg, Germany
  - LD Melt Shop 3, Voestalpine Stahl GmbH, Linz, Austria
  - Salzgitter AG, Salzgitter, Germany
- dry ESP and open combustion:
  - ArcelorMittal Ruhrott GmbH, Duisburg, Germany
- scrubbing and suppressed combustion
  - Oxygen steel plants; many European steel plants, e.g. Corus, Ijmuiden, the Netherlands
  - ArcelorMittal, Krakow, Poland.

Reference literature
[19] [65] [66] [76] [363] [404] [407] [471]

7.3.3 Collection and abatement of secondary emissions

Description
Up until the early 1970s, oxygen steelmaking plants were built without secondary dust collection equipment. As a result, most of today's secondary and subordinate primary source dust collecting installations are retrofits. The efficiency of such systems is highly dependent on local conditions. These play a particularly important role when it comes to the choice and design of the recovery system (enclosures, hoods, etc.). Determination of the waste gas flowrates often depend on local conditions and on the available space for installing piping systems, together with the possible size of the pipe cross-sections. For both new and existing installations, it is virtually impossible to determine recovery efficiency in advance with any degree of certainty. Any evaluation attempt is further complicated by the extreme difficulty in measuring the results. Even an optimum design and high waste gas flowrates for a technical complete waste gas collection will not guarantee that a 100% capture rate can be consistently achieved on a long-term basis throughout the oxygen steelmaking process. Changing or atypical operating conditions and environmental factors, such as unusual airflows in plant buildings, may lead to the release of unrecoverable dust streams which will escape as unavoidable secondary emissions through the roof monitors.

Secondary emissions are typically generated by the following operations:

- hot metal pretreatment such as reladling, deslagging and desulphurisation of hot metals (see Section 7.3.1)
- BOF charging and tapping of liquid steel and slag from BOF (converters) and ladles
- secondary metallurgy and tapping operations
- handling of additives
- ingot and continuous casting (see Section 7.3.5).

The emissions from these sources related to the aforementioned BOF steelmaking processes are usually referred to as secondary off-gases and are de-dusted by the secondary ventilation and dedusting system. Sometimes the emissions from the hot metal pretreatment are extracted and treated separately; usually they are part of the secondary dedusting system.
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Estimates of the quantity of secondary emissions vary between 2 and 200 g/t LS where the capture ratio of the secondary dedusting system is between 93 and 99.6% [363]. BOF charging and tapping operations contribute the most to these dust emissions. The given range differs from the figures given in Table 7.3 due to a limited number of plants which have been included in the inquiry. One explanation for this and for the broad scatter range may be found in the fact that secondary emissions are difficult to delimit with any degree of certainty and the recovery measures employed are often not adequately known. This results in a grey zone of overlap between data on substances released and data on actual emissions following the implementation of appropriate off-gas capture and cleaning steps.

Hot metal pretreatment such as reladling of hot metal
The transfer of hot metal from the torpedo ladle to the charging ladles takes place in enclosed stands. An integrated control room arrangement permits direct monitoring of the transfer process. The hot metal ladle travels below mill floor level on a transfer car. This car carries a front sealing shield which seals off the vault at the hot metal pouring point, thereby forming an enclosed chamber. Where full enclosure is not feasible it is possible to mount a fume hood over the ladle.

Hot metal pretreatment such as deslagging of hot metal
For the deslagging process, the ladle carrying the hot metal is tilted into its deslagging position while supported by a crane or a tilting cradle. The free cross-section of the hoods is restricted by suitable interior members to achieve higher intake velocities. The hoods can be of a travelling type so that they can serve several deslagging positions. The deslagging stands are normally separated by partitions which permit just enough travel for this operation. The openings are closed by sealing shields fitted on the car.

BOF charging and tapping of liquid steel and slag from BOF (converters) and ladles
During the charging of hot metal and scrap and the tapping of the BOF (converter), emissions of particulate matter occur. The primary ventilation system is in full operation only during oxygen blowing when the BOF converter is in a vertical position. The generated emission during charging and tapping are captured by the secondary extraction system. Charging and tapping take only a few minutes which makes about 10% of the tap to tap time.

The secondary ventilation that forms the BOF operations usually consists of a canopy hood just above the converter mouth in a tilted position and a doghouse around the remaining 3/4 of the converter (see Figure 7.18). The canopy hood is preferably placed as close to the BOF as possible. In some existing plants, the construction does not enable a canopy hood close to the BOF. In this case, the canopy hood may be installed near the roof, resulting in lower efficiency, depending on conditions such as the size of the hood and the extracted volume or local flow conditions in the hall.
Figure 7.18: Collection of secondary emissions during charging of hot metal to the BOF [38]; the same system is used for the charging of scrap

The flue-gas flow from secondary dedusting is in the range of 300000 - 3441000 Nm$^3$/h and cleaning is usually performed by means of a bag filter, although dry electrostatic precipitators are also used. Some examples of design ratings of secondary dedusting systems are summarised in Table 7.19.

<table>
<thead>
<tr>
<th>Plant</th>
<th>Capacity of vessel</th>
<th>BOF number</th>
<th>Numbers of heat per month</th>
<th>Waste gas volume (Nm$^3$/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OX 1</td>
<td>112</td>
<td>2</td>
<td>1658</td>
<td>1250000</td>
</tr>
<tr>
<td>OX 2</td>
<td>125</td>
<td>3</td>
<td>1983</td>
<td>372000</td>
</tr>
<tr>
<td>OX 3</td>
<td>156</td>
<td>3</td>
<td>1107</td>
<td>3441000$^{11}$</td>
</tr>
<tr>
<td>OX 4</td>
<td>240</td>
<td>2</td>
<td>866</td>
<td>300000</td>
</tr>
<tr>
<td>OX 5</td>
<td>295</td>
<td>2</td>
<td>2322</td>
<td>1300000</td>
</tr>
<tr>
<td>OX 6</td>
<td>330</td>
<td>2</td>
<td>974</td>
<td>1000000</td>
</tr>
<tr>
<td>OX 7</td>
<td>264</td>
<td>3</td>
<td>1885</td>
<td>2119457</td>
</tr>
<tr>
<td>OX 8</td>
<td>325</td>
<td>3</td>
<td>1698</td>
<td>720000</td>
</tr>
<tr>
<td>OX 9</td>
<td>330</td>
<td>3</td>
<td>1125</td>
<td>393500</td>
</tr>
</tbody>
</table>

$^{11}$ This plant has two independent secondary dedusting systems and the given value is the addition of the two systems.

Table sorted by total vessel capacity (Capacity of vessel * BOF number)

Table 7.19: Data from applied secondary dedusting systems and characteristics for the charging and tapping of emissions [363] [365]
Chapter 7

### Table 7.20: Data for one plant showing specific secondary dedusting system characteristics [404]

<table>
<thead>
<tr>
<th>Location</th>
<th>Dedusting capacity (%)</th>
<th>Filtering area (m²)</th>
<th>Capacity (m³/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melt shop dedusting</td>
<td>98</td>
<td>942</td>
<td>1500000</td>
</tr>
<tr>
<td>Dedusting of desulphurisation stage</td>
<td>100</td>
<td>7668</td>
<td></td>
</tr>
<tr>
<td>Ladle heating furance dedusting</td>
<td>99</td>
<td>2799</td>
<td></td>
</tr>
</tbody>
</table>

Secondary metallurgy and tapping operations
No data submitted.

Handling of additives
No data submitted.

**Achieved environmental benefits**

Emissions are mainly influenced by the efficiency with which the particulate matter generated during charging and tapping is evacuated.

**Table 7.21: Achievable degree of dust collection from secondary off-gases in basic oxygen steelmaking plants** [38]

<table>
<thead>
<tr>
<th>Hot metal pretreatment</th>
<th>BOF operation (Converter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relading station</td>
<td>Hot metal pretreatment</td>
</tr>
<tr>
<td>94 - 99 %</td>
<td>94 - 99 %</td>
</tr>
<tr>
<td>Hot metal charging</td>
<td>Scrap charging</td>
</tr>
<tr>
<td>24 - 64 %</td>
<td>84 - 94 %</td>
</tr>
<tr>
<td>Blowing</td>
<td>89 - 99 %</td>
</tr>
<tr>
<td>Tapping of LS and slag</td>
<td>49 - 55 %</td>
</tr>
</tbody>
</table>

Presuming that 100 % degree of collection represents technically achievable; the lower value refers to what is generally and the higher value to what is maximum achievable.

### Table 7.22: Achieved emission levels [407]

<table>
<thead>
<tr>
<th></th>
<th>ESP</th>
<th>Bag filter</th>
<th>Scrubber and wet ESP</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM</td>
<td>6</td>
<td>&lt;10</td>
<td>13</td>
</tr>
<tr>
<td>Pb, Cr, Cu, Mn, V</td>
<td>0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCDD/F</td>
<td>0.03</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: Values are in mg/Nm³ except for PCDD/F that are in ng. Values are annual averages.

**Cross-media effects**

During secondary dedusting, 0.5 kg of solid waste per tonne of liquid steel is generated (up to 1.2 kg/t LS). Re-use of this iron-rich solid waste depends largely on the zinc content. Some plants may be able to re-use it and others have to dispose of it.
The operation of a ventilation and particulate matter cleaning device requires energy. Secondary ventilation requires an evacuation capacity of approximately 300000 - 3441000 Nm³/h. In one example, effective energy consumption is reported to be 13 MJ/t LS when a bag filter is applied. Other values reported are 0.72 - 7.2 MJ per 1000 Nm³ treated. The energy consumption mainly depends on the pressure drop and the capacity of the associated fan. The specific energy consumption for secondary dedusting is relatively high compared to other dedusting operations (see Figure 7.21).

![Figure 7.19: Specific energy input for dedusting operations in integrated steelworks](image)

Because of high evacuation rates, secondary dedusting systems can significantly contribute to noise emissions. Therefore, additional measures for noise protection such as concrete housing for the fans, extra insulation in the filter and damper in the chimney may be necessary.

**Operational data**
Both bag filters and ESPs can be operated without problems. The most difficult aspect of secondary dedusting is evacuation efficiency, prevention of explosion in the ducts and the recycling of the solid wastes generated.

**Applicability**
Secondary dedusting can be applied at new and existing plants. In existing plants, the design of the plant may restrict the possibilities for proper evacuation.

**Economics**
Total investments for the collection and abatement of secondary emissions techniques were EUR 29 million in 2004, including noise protection measures.

Operational costs depend highly on the electricity price for the electricity consumption of 13 MJ/t LS. Additional costs for maintenance e.g., of the filter, are necessary. The costs were estimated in 1996 to be in the range of EUR 0.8 - 4/t LS.
Capital costs for the dedusting of secondary off-gases: EUR 10 million - 30 million. Implementing complete dedusting of secondary off-gases costs up to EUR 30 million in an existing steelmaking plant with a production of 5 Mt liquid steel (reference plant: ArcelorMittal, Gent, Belgium).

**Driving force for implementation**
The main driving force has been the prevention of visual emission during tapping and charging and better working conditions in the converter bay with an additional driving force being the need to contribute to an increased reliability of the charging cranes.

**Example plants**
Most European and worldwide I&S plants apply secondary dedusting.

The BOF plant of Voestalpine, Linz, Austria consists of three BOF converters, each with a capacity of 158 t liquid steel. Total capacity of the BOF plant is 5.2 million tonnes liquid steel per year. At the beginning of 2006, the existing secondary dedusting unit 2.1 (extraction volume of 0.8 million Nm³/h) was extended by the installation of unit 2.2 (extraction volume of max. 1 million Nm³/h). The secondary dedusting therefore consists of two separate blowers and filters handling the air extracted from a variety of extraction points including the charging and tapping of converters, the converter aisle and the charging hall (see Figure 7.20). The system ensures that even in the event that one dedusting system fails, the cleaning of the off-gases is assured. In this way, in the event of a system failure, the relevant emissions can be captured by the other secondary dedusting system. Consequently, a reduction of about 370 t/yr in dust emissions or about 300 t/yr in PM₁₀ emissions can be achieved. According to the permit of the environmental impact assessment, an operational availability of at least 97% has to be aimed at for each secondary dedusting unit.

Figure 7.20 shows the new secondary dedusting concept in the steel plant with the already existing secondary dedusting system 2.1 and the recently installed secondary dedusting system 2.2 with their respective technical key figures.
Dust emissions of dedusting units 2.1 and 2.2 are measured continuously. The annual average emission value for unit 2.1 was 3.7 mg/Nm³ in 2004, but for unit 2.2, the annual average values were not available. Recent daily average emission values are in the range of 0.3 - 10 mg/Nm³ for unit 2.1 and about 0.5 mg/Nm³ for unit 2.2, with single values of up to 4 mg/Nm³. Emissions of heavy metals and PCDD/F are measured discontinuously. Monitoring data for both units over a period of three months are shown in Figure 7.21.

<table>
<thead>
<tr>
<th>Filter unit 1</th>
<th>Flow</th>
<th>Filter unit 2</th>
<th>Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total flow amount</td>
<td>1 million Nm³/h</td>
<td>Total flow amount</td>
<td>1 million Nm³/h</td>
</tr>
<tr>
<td>Hot metal charging</td>
<td>1</td>
<td>Tapping</td>
<td>0.2</td>
</tr>
<tr>
<td>Scrap charging</td>
<td>0.3</td>
<td>Ladle furnace</td>
<td>0.12</td>
</tr>
<tr>
<td>Oxygen blowing</td>
<td>0.18</td>
<td>Conditioning stand</td>
<td>0.06</td>
</tr>
<tr>
<td>Discharge</td>
<td>0.35</td>
<td>Roof fume exhaust system</td>
<td>0.6</td>
</tr>
<tr>
<td>Slag splashing</td>
<td>0.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fan power</td>
<td>2680 kW</td>
<td></td>
<td>2680</td>
</tr>
<tr>
<td>Filter unit characteristics</td>
<td>9 chambers</td>
<td>10850 m²</td>
<td>10 chambers</td>
</tr>
</tbody>
</table>

Table 7.23: Technical key figures of a system

[361]

![Figure 7.21: Daily average emission values of the BOF plant/secondary dedusting at Unit 2 of Voestalpine Stahl-, Austria](image)

[424]
7.3.4 General techniques prevent or reduce diffuse and fugitive secondary emissions

General techniques to prevent diffuse and fugitive emissions from the relevant BOF process secondary sources are:

1. Independent capture and use dedusting devices for each sub-process in the BOF shop which helps to optimise capture efficiency and encourage re-use possibilities
2. Use of reagents, like lime instead of calcium carbide in the desulphurisation process that leads to a decrease in PM and odour emissions and a different (more useful) composition of the generated slag
3. Maintaining the lid on when the hot metal ladle is not in use, allowing them to cool less and therefore form fewer bears; this leads to lower emissions of PM. Besides that, hot metal ladles should be undone of bears on a regular basis. When the hot metal ladle is not in use the lid should be on it, than they cool less and therefore fewer bears are formed. This leads to less emission of PM. Besides that hot metal ladles should be undone of bears on a regularly basis
4. Maintaining the hot metal ladle in front of the the converter for approximately two minutes after putting the hot metal into the converter to capture the smoke that may be emitted
5. Computer control and optimisation of the steelmaking process so that slopping (i.e. when the slag foams to such extent that it flows out of the vessel) is prevented or reduced
6. Slopping during tapping can be reduced by limiting elements that cause slopping and the use of anti-slopping agents
7. Take measures to prevent the forming of ladle skull in the hot metal ladle
8. Prevention of smoking ladles by covering ladles as much as possible and cleaning ladles
9. Prevent visible emissions from appearing from the mill stone (the stone between the doghouse of the converter and the lance hole closing the free space through the lance hole)
10. Closure of doors from the room around the converter during oxygen blowing
11. Computer control and optimisation
12. Correct management of the desulphurisation installation to prevent air emissions
13. Total enclosure of the desulphurisation installation; evacuation of the air through a dust collection system
14. Continuous measurement of dust emissions from secondary dedusting systems
15. Continuous monitoring of dust emissions at the roof
16. When the dust emissions that are emitted through the roof are continuously measured by an optical measurement system, changing of or not normal operating conditions that can occur and lead to increase of the dust emissions are observed by the system and the installation owner can take measures quicker to adjust these conditions. The measuring principle that can be used is a transmission type. The transmitter transmits a light, this light is reflected by a reflector. The particulate matters in the light tube absorb the light. The transmitter (receiver) measures the effect of the particulate matter in the light tube. With this method concentrations of 3 to 200 mg/Nm\(^2\) can be measured. By setting an alarm concentration of particulate matter changes are measured and an alarm is given.
17. The use of a roof extraction system
Achieved environmental benefits
To 10. Closed doors at the converter during blowing leads to a decrease of the emission of particulate matter by 20 %;

To 18. Dust emission from the LD process, excluded primary, can be reported for each heat and also summarised as monthly averages. In the case of poor performances of the secondary dedusting system, prompt action can be taken.
The PM\textsubscript{10} emissions in the surrounding of the plant can be reduced.

In one specific case with the application of technique No. 2, 3, 4, 10 and 11 the following specific emission factors have been achieved.

<table>
<thead>
<tr>
<th>Emissions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof emissions from torpedo tapping</td>
<td>$\leq 0.14$ kg/HM tapping</td>
</tr>
<tr>
<td>Roof emissions from charging BOF converters</td>
<td>$\leq 10$ g/t HM</td>
</tr>
</tbody>
</table>

Table 7.24: Secondary emissions from hot metal transfer [359]

Cross-media effects
No data submitted.

Operational data
No data submitted.

Applicability
No data submitted.

Economics
No data submitted.

Driving force for implementation
No data submitted.
Continuous monitoring provides the option for early corrective action which can also have economical benefits.

Example plants
No. 18: SSAB Oxel"sound AB, Sweden
Corus, Ijmuiden, the Netherlands
No. 17: Voelstalpine Linz, Austria, since beginning of 2006.

Reference literature
[208] [359] [360] [361] [359] [404] [409] [412]

7.3.5 Dust abatement for ingot and continuous casting

Description
Ingot casting shrouds should be used to protect the molten stream from oxygen contamination and reduce fume production to an insignificant level. If significant fume generation cannot be avoided, then fume collection and abatement should be used. As in the case of continuous casting, dedicated fume extraction equipment and cleaning is essential for leaded steels.

The oxy-gas cutting equipment used when cutting stainless steel is fed with iron powder. This produces sufficient brown fume to justify fitting fume extraction and abatement equipment, such as bag filters.
When casting leaded steels or when making lead additions, the top of the ladle and tundish can be covered. Careful consideration of injection plant design is required to minimise the risk of releasing lead fume. Fume collection should be provided around the mould area and for the secondary steelmaking unit itself, with extraction to a bag filter dedicated to treating lead-bearing fume.

If oxygen lancing is used to clear the nozzle, the fume should be confined and extracted, together with the other lead-bearing fumes. All dusts from leaded steel casting should be captured by dedicated bag filter systems.

**Achieved environmental benefits**

<table>
<thead>
<tr>
<th></th>
<th>Ingot and continuous casting</th>
<th>Continuous casting</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Ni</td>
<td>$&lt;0.002$</td>
<td>0.014</td>
</tr>
<tr>
<td>Cr,Mn,V</td>
<td>$&lt;0.004$</td>
<td>0.016</td>
</tr>
<tr>
<td>Ni,Cr,Mn,V</td>
<td>$&lt;0.006$</td>
<td>0.03</td>
</tr>
<tr>
<td>Cr(VI)</td>
<td>$&lt;1$</td>
<td>0.014</td>
</tr>
</tbody>
</table>

Notes: Units are in mg/Nm$^3$ and are annual averages. Stainless steel production maximum values are based on half-hourly average values.

**Cross-media effects**
No data submitted.

**Operational data**
No data submitted.

**Applicability**
The given achieved emission values are taken from a casting installation in an EAF plant with stainless steel production only and with the application of bag filters. In principle, applicable to BOF plants for stainless steel production which have comparable conditions.

**Economics**
No data submitted.

**Driving force for implementation**
No data submitted.

**Example plants**
Bag filter at casting installations are applied in two German EAF plants for stainless steel production.

Used in United Kingdom.

**Reference literature**
[240] [407]
7.3.6 Treatment of waste water from wet dedusting

Description
In most oxygen steelmaking plants, scrubbers are used to reduce emissions to air from the primary gas flow (BOF gas) (see Section 7.3.11). This potentially transfers pollution from air to water so the waste water generated is usually recycled and treated before discharge.

The water from the scrubbers mainly contains suspended solids; zinc and lead being the main heavy metals present.

A large part of the suspended solids in the scrubbing water circuit can be removed by means of hydrocyclonage and/or precipitation. After pH correction, most of the water can be recycled.

The bleed can be treated by means of precipitation and/or filtration prior to discharge.

Achieved environmental benefits
In Table 7.26 examples are given for the specific emissions to water from wet dedusting systems at oxygen steelmaking plants.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Suppressed combustion systems</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Corus IJmuiden, NL\textsuperscript{1}</td>
</tr>
<tr>
<td>Discharge flow</td>
<td>\text{m}^3/\text{t LS}</td>
</tr>
<tr>
<td>Suspended solid</td>
<td>\text{g/LS}</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>\text{mg/LS}</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>\text{mg/LS}</td>
</tr>
</tbody>
</table>

\textsuperscript{1} Emissions at Corus IJmuiden, the Netherlands relate to 1994 values.

Table 7.26: Examples for the specific emissions to water from wet dedusting facilities at oxygen steelmaking plants

[65]

The most effective measures for minimising waste water discharge are:

1. Increasing the recirculation rate of the scrubbing water:
   a high recirculation can be achieved by means of a two-stage sedimentation in the scrubbing water flow with carbon dioxide (CO\textsubscript{2}) injection prior to the second sedimentation step, in order to enhance precipitation of carbonates. Note that the injection of CO\textsubscript{2} is only possible in systems operating suppressed combustion

2. Treating the bleed:
   although efficient recirculation can be achieved, a bleed is necessary to avoid accumulation of certain minerals/salts. The bleed contains suspended solids (including zinc, lead, etc.) as the most important pollutant. The bleed is treated by sedimentation and filtration.

Cross-media effects
Sludge is generated during hydrocyclonage and/or the sedimentation of the suspended solids in the scrubbing water circuit. This sludge can be 100 % recycled within the iron and steelmaking process if the zinc input via the scrap is strictly limited. At many other steelmaking plants in the world, the sludge cannot be used and is stored or disposed of.

Dust emissions may increase if it is recycled in the sintering plant.

Operational data
No data submitted.
Applicability
A high recirculation efficiency and further treatment can be applied both at new and existing plants.

Economics
No data submitted.

Driving force for implementation
No data submitted.

Example plants
High degree of recirculation and treatment of bleed:
Corus, Ijmuiden, the Netherlands; ArcelorMittal, Gent, Belgium; ThyssenKrupp Stahl, Duisburg, Germany; ArcelorMittal, Cleveland, United States.

Reference literature
[65] [138] [363]

7.3.7 Treatment of waste water from continuous casting

Description
Water is used in continuous casting machines for direct cooling of the slabs, blooms and billets. A contaminated water flow is therefore generated. In many cases, this waste water is treated together with waste water streams from the rolling mills. After treatment, the water is recirculated.

The casting mould and the inner part of the rollers are usually cooled with water in a closed circuit and are not considered here.

The main pollutants are suspended solids and oil. The main measures to reduce discharges to water are a high rate of recirculation along with sedimentation and/or filtration of the bleed. Skimming tanks can be used to remove oil.

The spray water is commonly precipitated by sand filtration prior to or after cooling in an evaporative cooling tower. Sand filtration helps to ensure low levels of particulate and oil contamination to achieve satisfactorily prolonged operation of the secondary spray nozzles of the casting machine. The bleed from the open circuit to control the level of dissolved solids should be taken from downstream of the sand filtration plant to minimise the discharge of suspended solids and any oil/grease contamination. To prevent the clogging of the sand filter, oil skimming should be installed before the sand filters.

Achieved environmental benefits
In Table 7.27 examples are given for specific emissions to water from continuous casting.
### Table 7.27: Overview of specific emissions to water from direct cooling systems at continuous casting

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Corus IJmuiden, NL</th>
<th>Stelco Lake Erie Works, Ontario, Canada</th>
<th>ArcelorMittal, Indiana Harbour Works, IN, US</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discharge flow</td>
<td>0.04</td>
<td>1.4</td>
<td>0.076</td>
</tr>
<tr>
<td>Recirculation rate</td>
<td>98</td>
<td>78</td>
<td>99</td>
</tr>
<tr>
<td>Suspended solid</td>
<td>0.8</td>
<td>26</td>
<td>1.4</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>&lt;1</td>
<td>-</td>
<td>8.0</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>&lt;1</td>
<td>-</td>
<td>8.7</td>
</tr>
<tr>
<td>Oil</td>
<td>20</td>
<td>2000</td>
<td>160</td>
</tr>
</tbody>
</table>

Note:
1) Data refer to 2004
2) Data for 2007 indicates a trend downwards

### Cross-media effects

The sedimentation steps generate an iron-containing sludge which can be recycled into the sinter plant or by direct injection via tuyères in the blast furnace.

### Operational data

No data submitted.
Applicability
A high recirculation rate and a treatment of the bleed can be applied at both new and existing plants.

Economics
No data submitted.

Driving force for implementation
No data submitted.

Example plants
ArcelorMittal, Indiana Harbour Works, Indiana, United States
Corus, Ijmuiden, the Netherlands
ArcelorMittal, Gent, Belgium
Voestalpine Stahl, Linz, Austria.

Reference literature
[65] [362] [363] [240]

7.3.8 Cold briquetting

Description
A cold briquetting plant consists of the following units:

- input material handling, storage and protective screening
- pre-drying of filter cakes
- mixing and dosing of binders
- briquetting
- screening of fines
- curing and storage of briquettes for internal use.

The various residues as received from the iron and steel works have to be stored separately so that a controlled mix for the briquette can be obtained. The main residues utilised for cold BOF briquette production are: BOF sludge, BOF/BF dusts, mill scales, BOF slag fines.

These materials are mixed together with two alloying elements: hydrated lime and molasses.

The homogenised mixture is fed to the briquette press by gravity and the briquettes produced are screened using a vibrating screen.

The briquettes have to be stored in a sheltered area under cover (roof) for curing to achieve high-strength briquettes. The cold briquettes produced are recycled in the BOF plant.

Achieved environmental benefits
Iron-bearing material are recycled thus reducing the material amount to landfill which saves primary raw material and its costs and avoids costs for dumping or waste processing.

Cross-media effects
No cross-media effects are known. Bag filters generate a solid waste which is recycled into the briquetting plant.

Operational data
The emissions are de-dusted with a bag filter. A dust concentration of 10 - 20 mg/Nm³ in the waste gas after abatement is achievable.
Applicability
Cold briquetting can be applied both at new and existing plants. However, it should be noted that its applicability depends on-site-specific factors.

Economics
The total investment cost for one cold briquetting plant of 150000 t/yr is about EUR 7 million - 8 million.

Driving force for implementation
No data submitted.

Example plants
Three years of industrial experience in ILVA Steelworks, Taranto, Italy.

Reference literature
[208] [363] [423]

7.3.9 Dust hot briquetting and recycling with recovery of high zinc concentrated pellets for external re-use

Description
Whenever a dry ESP is applied as a means of cleaning of the BOF gas resulting from oxygen blowing, solid dust is generated. This dust has a high iron content (40 - 65 %) and can be used as a valuable raw material when the dusts are pressed to briquettes. Although coarse dust and fine dust are briquetted in the same plants, they are charged separately on account of their different properties (see Table 7.15). Briquettes from coarse dust contain about 70 % metallic iron and can be used as a substitute for scrap in the BOF. Briquettes from fine dust have about 7 % metallic iron and can be used as a supplement for cooling ore [2]. Hot-briquetting is performed in a hot-briquetting plant (see Figure 7.22). First the dusts are heated up to 750 °C in a moving bed reactor by hot air and autothermic reactions. In the second step, briquettes are formed in a cylindrical press.

Figure 7.22: Facility for briquetting dust from basic oxygen steelmaking plants [38]
Recycling dust progressively enriches the zinc concentration. When the dust briquettes have reached an average zinc content of at least 17% by weight, they are transported to external reprocessors for zinc recovery. For technical and economical feasibility, a zinc content of 20 to 24% has to be realised for zinc recovery, i.e., by mixing input materials.

As the zinc in the dust within this closed system is very unevenly distributed, dusts with zinc contents significantly above 17% by weight also find their way into the cycle outlined here. This leads to considerable quantities of zinc being carried in the cycle unnecessarily, and being repeatedly reduced, vaporised, oxidised and briquetted in every successive cycle.

This sawtooth pattern of successive enriching and elimination of the dusts leads to a greatly fluctuating briquette charge in the BOF. This, in turn, not only influences the metallurgical work (slagging, build up of dust accretions in the waste gas duct) but also has a significant impact on the thermal balance (hot metal/scrap). Regular analytic control is needed in order to ensure that the quality of the steel and slag produced is not impaired by any undue increase in the Zn content.

In order to optimise the process an on-line technique for determining the level of zinc in dust in real time has been developed. This technology is referred to as LIBS (laser-induced breakdown spectroscopy). The device continuously measures the zinc content of the dust on the conveyor. Knowing the zinc content of the dust means it can be selected – where appropriate – for removal, pelletising and transporting it to the reprocessor.

Figure 7.23 gives a schematic overview of the optimised dust cycle at an oxygen steelmaking plant.

![Figure 7.23: Schematic overview of measures to optimise the recycling of dusts from the BOF](image)

The reason for pelletising fine dust is that even by employing bonding agents it cannot be briquetted. Moreover, pellets generally better meet customer requirements such as analysis, storage stability, freedom from dust, transportability and ease of handling. Moreover, the dust pellets can be optimised for further processing by adding reducing agents, other additives, etc.
Hot briquetting and the generation of pellets with a high zinc content for external re-use are described. Technically it is possible to extract the non-ferrous metals from this sludge and dust, after which the valuable cleaned solids containing iron can be recycled into the ironmaking process. The non-ferrous metals extracted can be further processed by the non-ferrous metals industry.

The following methods have been applied:

- rotating hearth furnace processes
- fluidised bed processes
- circulating fluidised bed reactors
- high turbulence mixer processes
- plasma processes
- multi-role oxygen cupola furnaces.

External processes for zinc-rich sludge/dust exist on a commercial scale. This technique has become more and more common.

**Achieved environmental benefits**

When applying dust hot briquetting and recycling, the landfilling of solid wastes is avoided and valuable raw materials are saved. The amount of dust processed is approximately 10 - 20 kg per tonne of liquid steel produced. The overall iron yield is increased by approximately 1 %. A recycling rate of dusts of 100 % can be achieved.

**Cross-media effects**

The hot-briquetting plant requires energy but saves raw materials.

**Operational data**

No data submitted.

**Applicability**

This method is applicable when a dry electrostatic precipitation is used to clean the BOF gas. Some experiences have shown that recovery of zinc by briquetting is not a solution in wet dedusting sytems because of unstable sedimentation in the settling tanks caused by the formation of hydrogen (from a reaction of metallic zinc and water). Due to these safety reasons, the zinc content in the sludge should be limited to 8 - 10 %.

In the future it may be possible to treat sludges from venturi scrubbers as well, but this would require extra energy for the evaporation of water.

**Economics**

No data submitted.

**Driving force for implementation**

The main driving forces are limited possibilities and high costs of dust disposal.

**Example plants**

LD 3 Steelmaking plant, Voestalpine Stahl GmbH, Linz, Austria (at this plant the recovery of zinc in the form of pellets for external re-use is practised);
Steel Plant Kwangyang Works, POSCO Iron and Steel Company, Republic of Korea;
Steel Plant Baoshan Iron and Steel Company, People's Republic of China;
Dneprovsky Metallurgical Combinate (DK), Ukraine
LD 1, LD 2 steelmaking plants, Thyssen Krupp Stahl AG, Duisburg, Germany
BHP, Newcastle, Australia.

**Reference literature**

[2] [57] [116] [154] [363]
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7.3.10 Lowering the zinc content of scrap

Description
A high zinc content in the blast furnace has an adverse effect on correct operation. Therefore, recycling of material with a high zinc content is restricted. The dusts and sludges collected from the BOF gas dedusting device may contain relatively high concentrations of heavy metals, especially zinc (Zn) (see Table 7.15). This zinc mainly originates from the scrap charged into the basic oxygen furnace. The release of zinc can fluctuate strongly from one cast to another, according to the type of external scrap loaded and the blowing conditions. The same problem, but to a lesser extent, applies to lead (Pb), cadmium (Cd).

In order to meet dust recycling requirements, scrap with a low zinc content may be used. This excludes scrap containing galvanised products.

Achieved environmental benefits
At some plants a strict policy on the use of scrap with a low zinc content is practised. The sludge from BOF gas dedusting has a zinc content of approximately 0.1 - 0.3 %, which allows 100 % recycling of the dust in the sinter plant.

Cross-media effects
This solution should be seen as a local solution. The overall effect is probably zero, because large amounts of galvanised steel are produced worldwide which will lead to the generation of sludges with a relatively high zinc content when the steel becomes available as scrap in the steelmaking process. At most BOFs, zinc is mainly emitted from the converter in the first few minutes of oxygen blowing.

Operational data
Operates without problems.

Applicability
Application is possible at both new and existing plants. However, this measure strongly depends on the availability of scrap which is low in Zn, Pb and Cd and the economics of using this type of scrap. It is therefore not applicable in all cases and strongly depends on the scrap market. In the aforementioned example plant of Corus the process is based on a low zinc content of the scrap. Zinc coated scrap is not used because of the recycling of dust from the BOF in the BF.

Economics
Scrap with a low zinc content is more expensive and increases the cost price per tonne LS produced. It is expected that scrap with a low zinc content will become increasingly hard to obtain. On the other hand, the use of low zinc scrap enables the recycling of the BOF gas cleaning sludges and dusts.

Driving force for implementation
No data submitted.

Example plants
Corus, IJmuiden, the Netherlands; British Steel, Scunthorpe, United Kingdom.

Reference literature
[13] [65] [105] [363] [409]
7.3.11 Energy recovery from the BOF gas

Description
Recovering energy from the BOF gas measure involves making efficient use of both the sensible heat and the chemical energy in the BOF gas. Previously, most of the chemical energy was dissipated by flaring.

BOF gas produced during oxygen blowing leaves the BOF through the converter mouth and is subsequently caught by the primary ventilation. This gas has a temperature of approximately 1200 °C and a flowrate of approximately 50 - 100 Nm³/t steel. The gas contains approximately 70 - 80 % carbon monoxide (CO) when leaving the BOF and has a heating value of approximately 8.8 MJ/Nm³.

Generally, two systems can be used to recover energy from the BOF gas:

1. Combustion of BOF gas in the converter gas duct and subsequent recovery of the sensible heat in a waste heat boiler to produce steam;
   - This BOF gas can be fully or partially combusted by allowing ambient air into the gas duct of the primary ventilation system. Thus, the sensible heat and the total gas flow in the primary ventilation system increases and more steam can be generated in the waste heat boiler. The amount of air admixed with the BOF gas determines the amount of steam generated.
   - In a complete steelmaking cycle (approx. 30 - 40 minutes), oxygen blowing lasts for approximately 15 minutes. Steam generation, which is directly related to oxygen blowing, is therefore discontinuous.

2. Suppression of BOF gas combustion and buffer of the BOF gas in a gasholder for subsequent use;
   - BOF gas combustion in the primary ventilation system can be suppressed by preventing the supply of ambient air from going into the system. This is usually done by lowering a water-cooled retractable skirt over the mouth of the converter. In this way, the carbon monoxide is retained and the BOF gas can be used as an energy source at other locations. The gas is cleaned to meet grid gas requirements and can be stored in a gasholder. A waste heat boiler may be installed to recover the sensible heat which is present in the non-combusted BOF gas.
   - It should be noted that BOF gas is not collected during the start and the end of blowing on account of its low CO content. During these periods, which last a few minutes, it is flared instead (see Figure 7.11).

There is currently a trend toward suppressed combustion followed by BOF gas recovery. There are two main reasons for this:

- suppressed combustion reduces the quantity of flue-gas and thus reduces the cost of fans and dust removal. The reduced waste gas flowrate typical of suppressed combustion results in a raw gas with a higher mass concentration. Thus for an identical clean gas dust concentration, a more efficient dust recovery system must be used (see also Section 7.3.2).
- large volumes of steam are obtained from full combustion systems. However, as the steam is produced discontinuously, it cannot always be fully utilised. The use of recovered BOF gas with suppressed combustion is much more flexible. The use of BOF gas in conjunction with blast furnace gas and coke oven gas as a third gas phase furnace product brings substantial advantages if it allows for the replacement of considerable amounts of primary energy resources, such as natural gas. At some plants, the BOF gas is primarily used in upgrading the blast furnace gas [66]. Coke oven gas and natural gas are only admixed in the mixing stations as a second and third priority (cascade control) [66].

Table 7.29 shows the benefits and drawbacks of suppressed combustion designed for air/fuel ratios below 0.1.
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<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced volumetric waste gas flowrate</td>
<td>Complex equipment technology with regard to safety engineering standards</td>
</tr>
<tr>
<td>Larger dimensions of gas-carrying components to achieve more uniform velocities in the hoods</td>
<td>Need for additional components</td>
</tr>
<tr>
<td>Reduced energy consumption of the waste gas fan</td>
<td>Additional safety engineering measures needed</td>
</tr>
<tr>
<td>Reduced water requirement for off-gas cooling</td>
<td></td>
</tr>
<tr>
<td>Design of dust recovery systems for smaller volumetric off-gas flowrates</td>
<td></td>
</tr>
<tr>
<td>Off-gas utilisation possibility</td>
<td></td>
</tr>
<tr>
<td>Reduced gas release from effervescent melt conditions due to the arrangement of sealing skirts of different designs</td>
<td></td>
</tr>
</tbody>
</table>

Table 7.29: Advantages and disadvantages of suppressed combustion with particular consideration of BOF gas utilisation

[38]

The BOF gas composition in case of suppressed combustion is shown in Table 7.6. When full combustion is applied, the CO content is much lower and CO₂ content is correspondingly higher.

**Achieved environmental benefits**

In Table 7.30, examples are given for steam generation in waste heat boilers at basic oxygen steelmaking plants of Thyssen Stahl AG, Germany.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Ruhrort</th>
<th>Beeckerwerth</th>
<th>Bruckhausen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>(t LS/cast)</td>
<td>4 x 140</td>
<td>3 x 250</td>
<td>2 x 380</td>
</tr>
<tr>
<td>Air introduction factor*</td>
<td>-</td>
<td>&gt;2.0</td>
<td>0.4</td>
<td>0.15</td>
</tr>
<tr>
<td>Flue-gas flow</td>
<td>(Nm³/t LS)</td>
<td>250</td>
<td>115</td>
<td>87</td>
</tr>
<tr>
<td>Steam generation</td>
<td>(kg steam/t LS)</td>
<td>380</td>
<td>130</td>
<td>80</td>
</tr>
</tbody>
</table>

*Notes: the air introduction factor indicates how much air is introduced in the flue-gas duct. I.e.: Factor 2 means that the amount of introduced air is two times the amount of the original BOF gas.

Table 7.30: Steam generation at basic oxygen steelmaking plants of Thyssen Stahl AG

[66]

Energy recovery from a full combustion system with a waste heat boiler is reported to be 80 % of the total outgoing heat. When suppressed combustion is applied, only 10 - 30 % (0.1 - 0.3 GJ/t LS) of the total energy output is recovered in the waste heat boiler [66]. Another 50 - 80 % is recovered as chemical energy (CO) in the BOF gas, depending on the air introduction factor. When the gas is flared and thus not recovered, this energy is lost.

Total energy recovery when applying suppressed combustion, BOF gas recovery and a waste heat boiler for the use of sensible heat can be as high as 90 % [1; 66].

When BOF gas is recovered, energy savings amount to 0.35 - 0.7 GJ/t LS, compared to flaring. The leak-free OG system, which was developed by Nippon Steel Corporation, leads to an energy saving of 0.98 - 1.08 GJ/t LS and an increased molten steel production of 0.4 % compared to flaring.
Cross-media effects
Recovering BOF gas requires proper cleaning of the crude gas in order to meet the grid gas requirements. When full combustion is applied, the flue-gas is directly emitted to the atmosphere. Overall emissions to air are reduced when suppressed combustion is applied. In addition, the (much) larger flue-gas flow from full combustion systems implies more expensive and relatively less efficient particulate matter abatement.

The energy recovery may result in savings primarily of energy sources.

Recovery of BOF gas is potentially hazardous and requires strict safety precautions (explosions, carbon monoxide leakage, etc.).

Operational data
No data submitted.

Applicability
Both waste heat recovery and BOF gas recovery by suppressed combustion can be applied at new and existing plants.

Economics
The investment required in 2007 was EUR 30.5 million for an ongoing project consisting of a gasholder of 80000 m³, blower fans, gas ducts, three way valves in the off-gas systems, security measures, erection and engineering, etc. 80% of the BOF gas will be recovered resulting in an annual energy savings of 2600 TJ/yr = approx. EUR 12/GJ investment cost. Payback is about five years taking into account the savings in the purchase of natural gas, CO₂ emission credits, reduced flare losses, sales of gas to the electricity producer, reduced steam production and the exploitation costs.

Driving force for implementation
No data submitted.

Example plants
Energy recovery by means of full combustion systems or suppressed combustion systems is widely applied at oxygen steel plants around the world. There is a tendency towards suppressed combustion systems, mainly because of logistic advantages compared to full combustion systems.

Reference literature
[1] [66] [65] [363]

7.3.12 On-line sampling and steel analysis

Description
Oxygen steelmaking is a batch process. Every charge of hot metal has to be refined until the required steel quality is achieved. In order to monitor progress, samples are taken from the steel bath for analysis. The results of the analysis are used to determine the additional time of oxygen blowing needed to achieve the required steel quality.

The latest dynamic modelling and monitoring systems reach a precision that makes sampling during blowing unnecessary. A control sample is then taken during the pouring period. This technique reduces the emissions due to sampling to zero.
It used to be necessary to interrupt oxygen blowing and tilt the BOF in order to take the sample. This was a time-consuming process and it increased emissions from the BOF. In a modern plant, samples are taken on-line during oxygen blowing by means of a sub-lance or similar devices. This enables the refining process to continue while the samples are being analysed. This shortens production cycle times and so increases productivity. Emissions are lower compared to the previous sampling method as the position of the BOF is not changed.

**Achieved environmental benefits**
Production time per batch is reduced so productivity is increased. Emissions to air are reduced as it is not necessary to tilt the BOF.

**Cross-media effects**
No cross-media effects are known.

**Operational data**
No data submitted.

**Applicability**
Can be applied at all new plants. Existing plants need a retrofit in order to install this sampling system.

**Economics**
Costs are probably reduced as a result of the higher productivity.

**Driving force for implementation**
No data submitted.

**Example plants**
Most European plants apply on-line sampling and dynamic modelling.

**Reference literature**
[65] [363]

### 7.3.13 Increase energy efficiency in the steel shop by automatisation

**Description**

a. The automatic ladle-lid system
Steel ladles are used for secondary treatments and transporting of liquid steel from the BOF converters to continuous casting. In normal practice, the ladles are not covered during ladle treatments and transportation, but a lid is commonly used to prevent extra heat losses during continuous casting. After casting and ladle maintenance, the ladles in operation are heated with burners, typically with coke oven gas or natural gas to keep them hot for next heat.

At Raahe Steelworks, eight to nine ladles are in operation simultaneously. The ladles are equipped with lids which are removed only during the tapping of the BOF and during ladle treatments. No burners are needed to keep the ladles hot after ladle maintenance. BOF converters and secondary metallurgy stations are equipped with lid stands where the lid is automatically placed or removed on/off the ladle depending on the process stage. The system is a "hinged lid" system, which also enables slag tapping after casting without removing the lid.
b. Automated BOF tapping practice.

By utilising the available SUB-lance system, steel temperature and a carbon content estimate can be obtained without having to tilt the converter into a horizontal position. Hence, tapping can be commenced within 2 - 3 minutes after the end of blow, depending on the time for post-stirring. In 2004 approximately 75 % of the heats were tapped within three minutes. The tapping sequence, initiated by the operator, consists of the following automated steps:

- steel tapping
- slag coating, and if necessary also slag splashing
- slag tapping.

An infrared camera, which can distinguish between steel and slag, is used to determine when slag enters the tap stream and when to automatically terminate steel tapping.
Achieved environmental benefits

Energy efficiency is improved (improved temperature control) and there is less dust formation.

a. Because less heat is lost during ladle cycle time, the average tapping temperature has decreased by 10 °C. Lower tapping temperatures enable an 8 kg/t higher scrap rate at the BOF with no extra fuel added and thus higher productivity. Another possibility is to produce steel with 8 kg/t less hot metal which is equivalent of 15 kg/t reduction in CO₂ emissions. The deviation of tapping temperatures is 4 °C lower, which is significant for stable process control. Steel temperatures are more stable during the whole steelmaking process, which reduces interrupted casts at continuous casting. The ladles are practically free of steel and slag sculls. No extra energy is needed at ladle maintenance areas, which allows the use of coke oven gas at other applications in the steelworks. The lids reduce dust emissions and direct heat radiation from steel ladles during transportation. Refractory wear of converters and ladles is slightly improved.

b. The automated tapping practice has several major environmental benefits;
- it lowers the aimed tapping temperature for steel by some 15 °C. This allows for an increased scrap ratio, hence a decreased hot metal ratio in the charge. With a 15 °C lower tapping temperature, it is possible to reduce the hot metal ratio with some 9 kg per tonne of crude steel, equivalent to a possible total reduction in CO₂ production at the plant of around 16 kg CO₂ per tonne of crude steel.
- by avoiding tilting the converter into a horizontal position for sampling after the end of blow, the emission of hot gases and dust are reduced.
- with accurate timing of termination of the steel tap, less steel is left in the converter and tapped together with slag into the slag pot. Less steel in the slag pot results not only in a stabilised process yield, but also in fewer dust emissions when the pots are emptied.
- a higher degree of slag coating leads to a longer lining life and reduces the need for ceramic materials. A rough estimate is that automated tapping, in itself, has led to a 20 % increase in lining life.

The energy efficiency is not only improved by an overall increase in productivity due to shorter times between steel tapping, but also by a reduced tapping temperature, which can be utilised for an increase in scrap recirculation, as well as by an improved steel yield.

Cross-media effects
No negative cross-media effects have been recorded with this new practice.

Operational data
No data submitted.

Applicability
a) The automatic ladle lid system is basically applicable to all steel plants. The lids can be very heavy because they are made out of refractory bricks. The capacity of the cranes and the design of the whole building constricts the applicability in existing plants. There are different technical designs for implementing the system into the particular conditions of a steel plant.

b) The practice is easily applicable at any BOF plant which is equipped with systems for the fast and accurate recording of the temperature and carbon content of the steel at the end of blow, as well as for slag detection during tapping.

Economics
a) The automatic lid system gives the steel maker a significant reduction in production costs.

b) The economic benefits are mainly related to an increased productivity, decreased maintenance costs and reduced refractory wear.
Driving force for implementation

a) The driving forces for the implementation of this technique are increased production, better process control with improved yield, increased energy efficiency and cost savings.

b) Increased productivity and increased scrap consumption result in the case of the automated BOF tapping practice. The driving forces for an increased degree of automation of the tapping practice include:

- stabilising and increasing steel production and increased time utilisation
- improved process control
- improved working environment
- increased lining life.

Example plants

a and b) Ruuki-Finland.
b) Lulea Works – Sweden. Automation of the BOF tapping practice at SSAB Tunnplåt AB’s steel plant in Luleå was gradually introduced during the late 1990s. The first step was the implementation of quick and direct tapping (QDT), followed by automation of the whole tapping sequence, including the tapping of slag.

Reference literature

[208]

7.3.14 Direct tapping from BOF

Description

Normally, expensive facilities like SUB-lance or DROP IN sensor-systems are used to be able to tap without waiting for a chemical analysis of the samples taken (direct tapping). Koverhar has developed a practice to achieve direct tapping without such facilities. In the practice, the carbon is directly blown down to 0.04 % and simultaneously the bath temperature to a reasonable low target. Before tapping, both the temperature and oxygen activity are measured for further actions.

The reblow rate at the Ovako Koverhar plant is today approximately 5 %.

Achieved environmental benefits

Through direct tapping, increased energy efficiency is achieved and positive environmental impacts are seen.

The advantages of direct tapping practice are mainly to increase energy efficiency. The bath cooling after blowing has reduced with 20 °C. At the same time, the tap-to-tap time is shortened by 20 %. That means a significant increase in productivity. Because of an improved thermal economy, the volume of scrap has increased by 5 % compared to non-direct tapping practices. This means a reduction of CO₂ emission by approximately 15 kg/t.

The lining life is increased by about 10 %. Because of the increased lining life and larger amount of recirculated material (scrap) a reduced environmental impact is also achieved.

Cross-media effects

No data submitted.

Operational data

No data submitted.
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Applicability
The practice is principally applicable in BOF plants with certain preconditions. The realising of the practice without extra facilities means several years of developmental work.

For succeeded direct tapping are some preconditions are needed, like a suitable hot metal analyser and slag stopping facilities. The availability of a ladle furnace makes the practice easier to realise.

Economics
The economic benefits are connected with increased productivity, reduced energy consumption and reduced refractory ware.

Driving force for implementation
Increased energy efficiency is the driving force for implementation.

- increased productivity
- cost savings
- reduced environmental impact.

Example plants
Ovako, Koverhar, Finland. Direct tapping has been in use since 2001 for almost all steel grades and concerns nearly all steel qualities except some special steels. The share of direct tapping is today 99 % of all melts.

Reference literature
[208]

7.3.15 Near net shape strip casting

Description
Near net shape strip casting means the continuous casting of steel to strips with a thicknesses of less than 15 mm. The casting process is combined with direct hot rolling, cooling and coiling of the strips without an intermediate reheating furnace used for conventional casting techniques, e.g. continuous casting of slabs or thin slabs. Therefore, strip casting represents a technique for producing flat steel strips of different widths and thicknesses of less than 2 mm.

The casting process can be divided into different techniques. All of them are characterised by moving moulds without the use of casting powder. Twin roll strip casting as a vertical casting techniques and direct horizontal strip casting (which used to be called direct strip casting) are the ones with the greatest industrial interest.

An overview of twin roll, and direct horizontal strip casting and further techniques is given in [472], see Figure 7.26.
Achieved environmental benefits

The achievable benefit for energy savings is essentially based on the fact that reheating is not necessary as well as on the reduced work for hot rolling. In comparison to conventional slab casting, additional energy for reaching the temperature necessary for hot rolling is not needed. Calculations with respect to energy consumption have already been done in the past. The relationship between energy consumption and the different casting techniques is given in Figure 7.27 [472] along with the main process steps. A re-evaluation of the energy demand for strip casting is part of a running BMBF project [474].
Cross-media effects
No cross-media effects were reported.

Operational data
Data on consumption levels are not available.

Applicability
The strip casting technique is applicable both at new and existing steel plants. The relatively small space needed (approx. length 100 m) offers the potential to integrate a strip caster when retrofitting.

The casting process can be applied to both types of steel plants, BOF and EAF. Further metallurgical techniques are related to the steel grades, but not to the strip casting process.

Economics (horizontal strip casting)
There are three main economic incentives for establishing the strip casting technique: the capital costs, the energy savings and the required area. Additionally, the technique is useful for a wide range of steel grades and the production capacity of a one line casting rolling machine is approx. 1.5 million tonnes/yr.

Driving force for implementation
The driving forces for the implementation are multifaceted:

• material forces: horizontal strip casting prevents impact due to the bending and straightening of the product. In particular, it is advantageous to produce grades with critical ductility properties at a high temperature by applying this technique. High alloyed steel grades (specifically those with a high AL content) are processable because no interaction with casting powder occurs

• economic and environmental forces: the main economic reasons are hot charging of strips without reheating and reduced hot rolling work. Both arguments lead to decreased emissions.

Example plants
Strip casters (twin-roll caster) are operational at plants of ThyssenKrupp Nirosta (400000 t/yr), Nucor Crawfordsville (400000 t/yr) and Nippon. Upcoming projects are at Nucor Castrip Blytheville (Arkansas), US (500000 t/yr) and Posco Postrip Pohang, Korea (600000 t/yr) [475]. The scheduled start-up for an industrial horizontal strip caster with a capacity of 500000 t/yr is 2010.

Reference literature
[472] [473] [474] [475]
7.4 Best available techniques for basic oxygen steelmaking and casting

In understanding this section and its contents, the attention of the reader is drawn back to the Preface of this document and in particular the fifth section of the Preface: ‘How to understand and use this document’. The techniques and associated emission and/or consumption levels, or ranges of levels, presented in this section have been assessed through an iterative process involving the following steps:

- identification of the key environmental issues for basic oxygen steelmaking and casting in the iron and steel industry
- examination of the techniques most relevant to address those key issues
- identification of the best environmental performance levels, on the basis of the available data in the European Union and worldwide
- examination of the conditions under which these performance levels were achieved; such as costs, cross-media effects, main driving forces involved in implementation of these techniques
- selection of the best available techniques (BAT) and the associated emission and/or consumption levels for this sector in a general sense all according to Article 2(12) and Annex IV to the Directive.

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

On the basis of this assessment, best available techniques, and as far as possible emission and consumption levels associated with their use, are presented in this section that are considered appropriate to basic oxygen steelmaking and in many cases reflect current performance of some installations within the sector. Where emission or consumption levels ‘associated with best available techniques’ are presented, this is to be understood as meaning that those levels represent the environmental performance that could be anticipated as a result of the application, for basic oxygen steelmaking, of the techniques described, bearing in mind the balance of costs and advantages inherent within the definition of BAT. However, they are neither emission nor consumption limit values and should not be understood as such. In some cases it may be technically possible to achieve better emission or consumption levels but due to the costs involved or cross-media considerations, they are not considered to be appropriate as BAT for basic oxygen steelmaking. However, such levels may be considered to be justified in more specific cases where there are special driving forces.

The emission and consumption levels associated with the use of BAT have to be seen together with any specified reference conditions (e.g. averaging periods).

The concept of ‘levels associated with BAT’ described above is to be distinguished from the term ‘achievable level’ used elsewhere in this document. Where a level is described as ‘achievable’ using a particular technique or combination of techniques, this should be understood to mean that the level may be expected to be achieved over a substantial period of time in a well maintained and operated installation or process using those techniques.

Where available, data concerning costs have been given together with the description of the techniques presented in the previous Section 7.3. These give a rough indication about the magnitude of costs involved. However, the actual cost of applying a technique will depend strongly on the specific situation regarding, for example, taxes, fees, subsidies and the technical characteristics of the installation concerned. It is not possible to evaluate such site-specific factors fully in this document. In the absence of data concerning costs, conclusions on economic viability of techniques are drawn from observations on existing installations.
Chapter 7

In this section for **basic oxygen steelmaking**, specific techniques are considered as BAT (including the associated emission and consumption levels). ‘Best Available Techniques’ for a specific installation will usually be the use of one individual techniques or a combination of the techniques and measures listed in this section. Additionally, general BAT elements which can apply for the whole sector, mentioned in Section 2.8, have to be considered.

Where techniques identified individually as BAT can be used in combination, the effects of such combinations should be considered when drawing conclusions on BAT based permit conditions for individual cases.

If not otherwise mentioned, the BAT associated emission levels (BAT-AELs) given in this section are expressed on an annual average basis under standard conditions.

The BAT (including the associated emission and consumption levels) given in this chapter are ‘BAT in a general sense’ (i.e. considered to be appropriate to the sector as a whole). It is intended that they are a reference point against which to judge the current performance of an existing installation or to judge a proposal for a new installation. In this way, they will assist in the determination of appropriate ‘BAT-based’ conditions for the installation or in the establishment of general binding rules under Article 9(8) of the Directive. It is foreseen that new installations can be designed to perform at or even better than the BAT levels presented in this section. It is also considered that existing installations could move towards the BAT levels presented in this section or do better, subject to the technical and economic applicability of the techniques in each case.

While the BAT reference documents do not set legally binding standards, they are meant to give information for the guidance of industry, Member States and the public on achievable emission and consumption levels when using specified techniques. The appropriate permit conditions for any specific case will need to be determined taking into account the objectives of the IPPC Directive and the local considerations.

### Air

1. **BAT for the storage, handling and transport** (see Sections 2.6.3 and 2.6.5)

2. **BAT for the BOF process** is to prevent mercury emissions by avoidance of raw materials and auxiliaries which contains mercury as far as possible (see Section 2.6.3).

   **Hot metal pretreatment** (i.e. preheating of vessels, desulphurisation, dephosphorisation, deslagging, hot metal transfer processes and weighing)

3. **BAT for these processes** is to minimise diffuse dust emissions by means of integrated techniques (see Section 7.3.1) and an efficient dust extraction system with subsequent off-gas cleaning by means of an bag filter or an ESP.

The **BAT-AEL** for dust is <10 mg/Nm³, determined as daily mean value.
4. BAT is to apply the use of fume suppression with inert gas during the reladling of hot metal from the torpedo ladle (or hot metal mixer) to the charging ladle in order to minimise fume/dust generation.

**BOF gas recovery during oxygen blowing and primary dedusting**

5. BAT is to extract the BOF gas during blowing as much as possible and to clean it by applying the following techniques in combination (see Section 7.3.2):
   I. use of a suppressed combustion process
   II. prededusting to remove coarse dust by means of dry separation techniques (e.g. deflector, cyclone) or wet separators
   III. dust abatement by means of:
       IIIa. dry dedusting (ESP or bag filter) for new and existing installations
       IIIb. wet dedusting (i.e. wet ESP or scrubber) for existing installations

The BAT AEL is <20 mg/Nm³ for I, II and IIIa.

The BAT AEL is <30 mg/Nm³ for I, II and IIIb.

Both, determined as the average over the sampling period (spot measurement, for at least half an hour).

6. BAT in case of full combustion is to reduce the dust emissions by applying the following techniques individually (see Section 7.3.2):
   I. dry dedusting (ESP or bag filter) for new and existing installations
   II. wet dedusting (i.e. wet ESP or scrubber) for existing installations

The BAT AEL is <20 mg/Nm³ for I.

The BAT AEL is <30 mg/Nm³ for II.

Both, determined as the average over the sampling period (spot measurement, for at least half an hour).

7. BAT is to minimise the dust emissions from the oxygen lance hole by applying the following techniques individually or in combination (see Section 7.3.2):
   I. covering the lance hole during oxygen blowing
   II. inert gas injection into the lance hole to dissipate the particulate matter
   III. use of other alternative sealing designs combined with lance cleaning devices.

8. BAT for the BOF is to prevent mercury emissions by avoidance of raw materials and auxiliaries which contains mercury as far as possible (see Section 2.6.3).

Secondary dedusting (including preheating of vessels, slopping during oxygen blowing, hot metal and scarp charging, tapping of liquid steel and slag from BOF

9. BAT for the collection of secondary dust emissions during these processes is an efficient extraction of emissions with a collection efficiency of >95 % by applying appropriate hoods and doghouses and subsequent off-gas cleaning by means of a bag filter or ESP or any other technique with the same removal efficiency (see Section 7.3.3).

The BAT-AEL for all dedusted off-gases is a residual dust content of <10 mg/Nm³ in case of bag filter and of <20 mg/Nm³ in case of ESP, both determined as daily mean value.
Chapter 7

Secondary dedusting (including secondary metallurgy and continuous casting)

10. BAT for the collection of secondary dust emissions for these processes is an efficient extraction of emissions with subsequent off-gas cleaning by means of bag filter or any other technique with the same removal efficiency (see Section 7.3.3, 7.3.4 and 7.3.5).

The BAT-AEL for these operations is 10 mg/Nm³, determined as daily mean value.

Slag treatment emissions

11. BAT for on-site slag processing is to reduce dust emissions by the following techniques individually or in combination (see Section 8.3.3):
   I. Efficient extraction of dust emissions from slag crusher and screening devices with subsequent off-gas cleaning.

   The BAT-AEL is <20 mg/m³, determined as the average over the sampling period (spot measurement, for at least half an hour).
   II Transport of untreated slag by shovel loaders
   III. Extraction or wetting of conveyor transfer points for broken material
   IV. wetting of slag storage heaps
   V. use of water fogs when broken slag is loaded

Water

Water consumption, treatment and discharge

12. BAT is to dry BOF gas cleaning where prerequisites are present.

13. BAT for waste water from BOF primary dedusting is to minimise and re-use of scrubbing water as much as possible, i.e. for slag granulation (see Section 7.3.6).

14. BAT is to minimise the waste water discharge from continuous casting by applying the following techniques in combination (see Sections 7.2.2.2, 7.3.6 and 7.3.7):
   I. removal of solids by sedimentation and/or filtration
   II. removal of oil in skimming tanks or any other effective device
   III. recirculation of cooling water and water from vacuum generation much as possible.

   The BAT-AELs for waste water from continuous casting machines are:
   - TOC <10 mg/l
   - Iron <5 mg/l
   - Zinc <1 mg/l
   - Nickel <0.5 mg/l
   - Total chromium <0.5 mg/l
   - Total Hydrocarbons <5 mg/l
   - Toxicity to fish eggs as dilution factor TF <2

   The BAT-AELs are based on a qualified random sample or a 24-hour composite sample.

15. BAT for waste water from BOF is to use sedimentation and flocculation (coagulation) (see Sections 7.3.6 and 7.3.7).

   The BAT-AEL for waste water in general is:
   - Suspended solids <20 mg/l

   The BAT-AELs are based on a qualified random sample or a 24-hour composite sample.
Chapter 7

Production residues like wastes and by-products

16. BAT is to prevent waste generation by applying the following techniques in descending order or priority (see Section 7.2.2.3):
   I. appropriate collection and storage to facilitate a specific treatment
   II. on-site recycling of coarse dust from BOF gas treatment, dust from secondary dedusting and mill scale from continuous casting back to the steelmaking processes
   III. on-site recycling of BOF slag in various applications
   IV. slag treatment, preferably by means of granulation where market conditions allow for it for external use of slag (e.g. in the cement industry or for road construction)
   V. use of filter dusts and sludge for external recovery of non-ferrous metals such as zinc in the non ferrous metals industry (see Section 7.3.9)
   VI. use of a settling tank for sludge with subsequent recycling of coarse fraction in the sinter/blast furnace or cement industry when grain size distribution allows for a reasonable separation
   VII. controlled disposal of unavoidable wastes from the basic oxygen furnace process.

17. BAT for the handling, storage and transport of solid wastes see general Section 2.6.4.

Energy

18. BAT is to collect, clean and store BOF gas for subsequent use as a fuel. In some cases, it may not be economically feasible or, with regard to appropriate energy management, not feasible to recover the BOF gas by suppressed combustion. In these cases, the BOF gas may be combusted with the generation of steam. The kind of combustion (full or suppressed combustion) depends on the local energy management (see Section 7.3.11).

19. BAT is to optimise the process by applying an automated BOF tapping practice and automatic ladle-lid systems. The latter technique is limited to new plants (see Section 7.3.13).

20. BAT is to reduce energy consumption by applying a continuous near net shape strip casting (see Section 7.3.15).

Noise

(see Section 2.6.9)
8 ELECTRIC ARC STEELMAKING

8.1 Applied processes and techniques

The direct smelting of materials which contain iron, such as scrap is usually performed in electric arc furnaces (EAF) which play an increasingly important role in modern steelworks concepts (see Figure 1.2). Today the percentage of electric arc furnace steel of the overall steel production in the EU-25 is 38 % [373]. With 61 % in Italy and 77 % in Spain, the production of EAF steel is significantly higher than steel production via the blast furnace/basic oxygen furnace route (not considering Member States having exclusively EAF steel production).

The major feedstock for the EAF is ferrous scrap, which may be comprised of scrap from inside the steelworks (e.g. offcuts), cut-offs from steel product manufacturers (e.g. vehicle builders) and capital or post-consumer scrap (e.g. end-of-life products). Direct reduced iron (DRI) is also increasingly being used as a feedstock due both to its low gangue content, variable scrap prices and lower content of undesirable metals (e.g. Cu). Ferroalloys may be used as additional feedstock in more or less large quantities to adjust the desired concentrations of non-ferrous metals in the finished steel. As in the BOF, a slag is formed from lime to collect undesirable components in the steel [373] [417].

Figure 8.1 shows an EAF plant. In this case the building containing a twin shell EAF is totally enclosed in order to minimise dust, and gaseous and noise emissions.

![Electric arc furnace plant](image)

An EAF is usually charged with scrap by metal baskets (charging boxes) hanging over the open kiln vessel as can be seen in Figure 8.2.
An overview of the electric steelmaking process is given in Figure 8.3.

Figure 8.2: Electric arc furnace charging

Figure 8.3: Overview of the processes related to electric arc furnace steelmaking
With respect to the end-products, distinction has to be made between production of ordinary, so-called carbon steel as well as low alloyed steel and high alloyed steels/stainless steels. In the EU, about 88% of steel production is carbon or low alloyed steel [373].

For the production of carbon steel and low alloyed steels, the following main operations are performed:

- raw materials handling, pretreatment (if any) and storage [373]
- furnace charging
- EAF scrap melting
- steel and slag tapping
- ladle furnace treatments for quality adjustment
- slag handling
- casting.

For high alloyed and special steels, the operation sequence is more complex and tailor made for the end-products. In addition to the mentioned operations for carbon steels, various ladle treatments (secondary metallurgy) are carried out, such as:

- desulphurisation
- degassing for the elimination of dissolved gases like nitrogen and hydrogen
- decarburisation (AOD or VOD).

### 8.1.1 Raw materials handling and storage

Scrap metal is stored normally outside on large, uncovered and often unpaved ground. The ferrous scrap metal is loaded into baskets by magnets or grabs. Scrap is purchased based on specific international specifications which minimise non-metallic inclusions. The handling minimises any rogue non-magnetic material like stones, wood or non-ferrous metals from entering the process. Some types and quality of scrap during metal storage and handling operations may lead to the deposit of residual materials on the ground, as well as to the deposition of heavy metals and hydrocarbons.

Depending upon the types and qualities of scrap being processed, handling operations may also lead to inorganic (dust) and organic emissions under certain weather conditions. Some types of scrap may also give rise to noise emissions during handling [442].

Some scrap sorting is carried out to reduce the risk of including hazardous contaminants. In-house generated scrap can be cut into handleable sizes using oxygen lancing. The scrap may be loaded into charging baskets in the scrapyard or may be transferred to temporary scrap bays inside the melting shop. In some cases, the scrap is preheated in a shaft or on a conveyor (see scrap preheating). Radioactivity present in the incoming scrap may be an issue in some cases. Please refer to Section 2.3.1 [417].

Other raw materials including fluxes in lump and powder, powdered lime and carbon, alloying additions, deoxidants and refractories are normally stored under cover. Following delivery, handling is kept to a minimum and, where appropriate, dust extraction equipment may be used. Powdered materials can be stored in sealed silos (lime should be kept dry) and conveyed pneumatically or kept and handled in sealed bags.
Chapter 8

8.1.2 Scrap preheating

Over the past several years more and more new as well as existing EAF have been equipped with a system for preheating the scrap by the off-gas in order to recover energy. Scrap preheating has been used successfully over 40 years in countries with high electricity costs, such as Japan. Such preheating is performed either in the scrap charging baskets or in a charging shaft (shaft furnace) added to the EAF or in a specially designed scrap conveying system allowing continuous charging during the melting process (e.g. the Consteel and ESC process). In some cases even additional fossil energy is added in the preheating process [373].

The shaft technology has been developed in steps. In 1988 Fuchs System Technik GmbH, now SIMETAL, started a development to overcome the shortfalls of the scrap bucket preheaters and opted for direct charging of the scrap into a shaft that was positioned on the roof of the EAF. With the single shaft furnace at least 50 % of the scrap can be preheated [125].

A further modification is the double shaft furnace which consists of two identical shaft furnaces (a twin shell arrangement) which are positioned next to each other and are serviced by a single set of electrode arms. The scrap is partly preheated by off-gas and partly by side wall burners.

A very efficient shaft furnace design is the finger shaft furnace. The finger shaft design uses a unique scrap retaining system with fingers which allow the preheating of 100 % of the scrap amount [162]. The first basket is preheated during the refining of the previous heat and the second during melt down of the first one. In 1994 the first Finger Shaft Furnace started up at Hylsa in Monterrey. Through the utilisation of the furnace off-gas during the heat cycle, scrap can be preheated to a temperature of approximately 800 °C prior to the final melting in the furnace vessel. This means considerable energy and cost savings with a substantial reduction in tap-to-tap times.

A recent development of the scrap preheating process is the COSS technology which combines the benefits of the SHAFT Systems – high scrap preheating – with those of the CONSTEEL process – the continuous scrap feeding. [450]

8.1.3 Charging

The scrap is usually loaded into baskets together with lime or dolomitic lime which is used as a flux for the slag formation. Carbon-bearing materials are also charged for the needs of the metallurgical work to be performed in the furnace. At some plants, lump coal is also charged in order to adjust the carbon content. Even though this has not been confirmed up to now by emissions measurements, this may result in relevant emissions of benzene (as well as toluene and xylenes). The furnace electrodes are raised into top position, the roof is then swung away from the furnace for charging. It is normal to charge about 50 - 60 % of the scrap initially with the first scrap basket; the roof is then closed and the electrodes lowered to the scrap. Within 200 - 300 mm above the scrap, they strike an electric arc. After the first charge has been melted, the remainder of the scrap is added from a second or third basket [373] [417] [422].

The amount of scrap charging into the EAF is directly proportional to the size of the furnace. For example, one EAF of 6.7 meters diameter charge around 60 tonnes of scrap [417] [422].

A proprietary available system is known as the shaft furnace which allows part of the scrap to be charged into a vertical shaft integrated into the furnace roof and thus prevents the opening of the furnace roof halfway through the melting process. The scrap present in the shaft is preheated by the hot gases coming from the furnace [373].
Another new charging system that has been adopted by some operators is the Consteel Process where the scrap is continuously fed via a horizontal conveyor system into the arc furnace. This also allows the scrap to be preheated by the furnace off-gas flowing in countercurrent.

### 8.1.4 Electric arc furnace melting and refining

During the initial period of melting, the applied power is kept low to prevent damage from radiation to the furnace walls and the roof from whilst allowing the electrodes to bore into the scrap. Once the arcs have become shielded by the surrounding scrap, the power can be increased to complete melting. Oxygen lances and/or oxy-fuel burners are more and more used to assist in the early stages of melting. Fuels include natural gas and oil. Furthermore, oxygen may be brought to the liquid steel by specific nozzles in the bottom or side wall of the EAF.

Oxygen in electric furnace steelmaking has become increasingly considered over the last 30 years not only for metallurgical reasons but also for increasing productivity requirements. The purpose of using oxygen is manifold:

- the combined injection of oxygen and granular carbon allows for the generation of a foamy slag thanks to the generation of CO bubbles. The “foamy slag” technique, which is now of general use in carbon steelmaking, improves the shielding of the furnace walls from the radiation of the arc and allows for an improved energy transfer from the arc into the steel bath [417]
- for metallurgical reasons, oxygen is used for decarburisation of the melt and removal of other undesired elements such as phosphorus and silicon
- oxygen is also injected into the top of the furnace for “post-combustion” in order to react with CO and hydrocarbons before the fumes leave the furnace with the aim of keeping as much of the heat as possible of the heat generated by the exothermic reactions within the furnace [373].

Oxygen injection results in an increase in gas and fume generation from the furnace. CO and CO$_2$ gases, extremely fine iron oxide particles and other product fume are formed. In case of post-combustion, the CO content is below 0.5 vol- % [373].

Argon or other inert gases may be injected into the melt to provide bath agitation and temperature balancing. The slag-metal equilibrium is also improved by this technique.

Fumes and gases generated from the melting operation are processed in a flue-gas treatment plant which includes collection and treatment devices aiming at reducing pollutant emissions.

### 8.1.5 Steel and slag tapping

Slag may need to be removed during heating and oxidising at the end of the heat prior to tapping. The furnace is tilted backwards towards the slagging door and the slag runs off or is raked into a pot or on the ground below the furnace resulting in dust and fume generation.
8.1.6 Secondary metallurgy

Carbon steel
Secondary metallurgy is carried out on the molten steel after the tapping of the primary steelmaking furnace up to the point of casting. It is typically carried out at ladle treatment stations while the molten steel stays in the ladle. These treatment stations are generally comprised of an arc-heating unit (ladle furnace) which allows an adjustment of the final temperature of the liquid steel for the casting operation. The treatment includes the addition of deoxidising agents and alloying elements in order to adjust the chemical composition of the finished steel. In some cases vacuum treatment units are used for achieving special requirements regarding the concentration of elements such as hydrogen, nitrogen and oxygen of finished steel. In order to achieve a good homogenisation, inert gases (Ar or N₂) are injected into the ladle for stirring purpose. Some minor ladle treatment stations are based on inert gas or powder injection equipment. Fig 8.4 shows a block diagram with a multitude of possible secondary metallurgy treatments. Depending on the type of steel produced, one or more of such treatments are applied. Some of those treatments are applied to the steel while it is in the ladle, others need a separate treatment vessel. Some treatments are made under vacuum, others with inert gas rinsing [373].
Figure 8.4: Secondary metallurgy/ladle treatments

[147]
In the case of production of leaded steel, off-gases containing lead have to undergo special treatment (see information under secondary metallurgy in basic oxygen steelmaking).

**Stainless steel**

The secondary metallurgy of stainless steel may be performed either under vacuum in the ladle (VOD process – Vacuum Oxygen Decarburisation) or in a separate metallurgical vessel called an AOD (Argon Oxygen Decarburisation) converter and a subsequent ladle treatment. Depending on the steel grades to be produced, some operators apply a combination of both AOD and VOD [373].

A flow diagram of a stainless steel melt shop with an AOD converter is shown at Figure 8.5.

![Flow diagram of a stainless steel melt shop with an AOD converter](image)

**Alloys steel**

The secondary metallurgy of alloy steels which contain (besides carbon) substantial quantities of alloying elements but do not rank in the stainless steel category consist generally of a ladle furnace and, if required, a vacuum treatment, depending on the steel grades produced.

During most of the processes of secondary metallurgy, slags are used to capture the non-metallic compounds generated during the treatment [373].

**8.1.7 Slag handling and processing**

If slag is collected in a slag pot at the EAF, it needs to be poured into outside slag basins for solidification. The cooling of the slag may be enhanced by water sprays.

If the slag is poured on the floor, it is pre-crushed after solidification using excavators or shovel loaders and brought to an outside storage area.
After a certain period of time the slag is processed in crushing and screening devices in order to give it the desired consistency for its further use in construction. During this operation any metallic particles contained in the slag are separated magnetically and physically and recycled into the steelmaking process. Recovering metals from slags is particularly sensitive for metals with a high commercial value. Slag breaking and metal recovery can create dust emissions [373].

Sometimes water is used to cool down the slag during slag tapping which improves the microstructure, achieving better mechanical properties. This "black electric kiln" slag is processed to street and road building material, while the "white slag" from open basins can be used, e.g. as a lime fertiliser [417] [422].

8.1.8 Casting

For the purpose of controlled solidification of EAF steel, basically the same techniques apply as for BOF steel. The descriptions in Section 7.1.5 apply.

While the general trend is to supersede ingot casting by continuous casting, ingot casting will continue to be applied for some types of specialty steels produced in EAF steelmaking facilities.
Chapter 8

8.2 Present consumption and emission levels

8.2.1 Mass stream overview and input/output data

Figure 8.6 provides an overview for the input and output of electric arc furnaces. This overview may be used for the collection of data from an electric arc furnace.

Subsequently specific input factors as well as specific emission factors have been determined. Such factors are presented in Table 8.1. The data are derived from various sources mentioned in the footnotes.
### Input/output data for electric arc furnaces within the EU

<table>
<thead>
<tr>
<th>Input</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw materials</td>
<td>Products</td>
</tr>
<tr>
<td>metallic input:</td>
<td>Liquid steel (LS) kg</td>
</tr>
<tr>
<td>Scrap</td>
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<tr>
<td>Pig iron</td>
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<tr>
<td>Liquid hot metal(^1)</td>
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<td>DRI (HBI)</td>
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<td>Graphite electrodes</td>
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</tr>
<tr>
<td>Refractory lining</td>
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<tr>
<td>Alloys:</td>
<td>Off-gas flow Million Nm(^3)/t LS</td>
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<tr>
<td>Carbon steel</td>
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<td>Energy</td>
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<td>Fuels (natural gas &amp; liquid fuels)</td>
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</tr>
<tr>
<td>Water</td>
<td>50 - 1500</td>
</tr>
<tr>
<td>Production residues (waste/ by-products)</td>
<td>1454 - 2693</td>
</tr>
<tr>
<td>Slag from furnace kg/t</td>
<td>50 - 1500</td>
</tr>
<tr>
<td>Slag from ladle kg/t</td>
<td>1 - 42.8</td>
</tr>
<tr>
<td>Ducts kg/t</td>
<td>1 - 42.8</td>
</tr>
<tr>
<td>Waste refractories kg/t</td>
<td>1 - 42.8</td>
</tr>
<tr>
<td>Noise dB(A)</td>
<td>90 - 133</td>
</tr>
</tbody>
</table>

**Legend:** LS = liquid steel

\(^1\) Hot metal is only used in very special cases (about 275 kg/t LS), then the quantity of scrap is lower.

\(^2\) Typically lime is not used but in few cases dolomite alone is used or combinations of dolomite and lime (e.g. weight proportion 63/37).

\(^3\) Steam is generally not used withing the EAF steelmaking, except for plants with secondary metallurgy with vacuum treatment DRI (direct reduced iron); hot metal are only used in special cases.

\(^4\) No consistent database, some results represent the total of 16 EPA PAH, others only a section of them.

\(^5\) No consistent database, values represent different selections of PCBs (32 of them refer to the above-mentioned Ballschmiter PCBs, 2 to WHO-TEQ, 1 to SUM-WHO and 2 without further indication).

Notes: Some measuring methodologies might vary importantly from country to country and from plant to plant. Not all the emitted substances are measured at all plants. The measuring programmes vary greatly depending on permit requirements. Data has been compiled from information provided by EAF melt shop operators (carbon steel, alloy steel and stainless steel) representing 37.4 Mt of steel produced. This represented close to 50 % of the total EAF steel production in the EU in 2004 in 11 different EU countries.
By far the main iron source for an EAF is scrap. Hot metal and DRI are used by a rather small number of operators, generally in a rather sporadic fashion. Thus, it is difficult to indicate representative ranges. DRI and hot metal might be used to adjust composition – low residuals – for some particular steel grades. In some instances, the input of DRI or hot metal might also be due to economic reasons. HBI is basically hot briquetted DRI. It is better suited for handling and transportation and less exposed to atmospheric oxidation.

The emission factors indicated in Table 8.1 are the result of a survey. The wide ranges observed for some of the emission factors may have the following origins:

- differences in the performance of environmental protection equipment
- differences in the emission limit values prescribed by national or local authorities
- differences in the quality of measurements – frequency, precision, sampling, laboratory methodologies, etc.
- differences in the input material
- differences in the plant characteristics
- type of steel produced (metals emissions)
- plant productivity.

8.2.2 Environmental issues for electric arc furnace steelmaking process

The electric arc steelmaking process is a source of primarily particulate matter and solid wastes/by-products. Energy consumption also plays an important role for EAF steelmaking. When abatement techniques are applied to reduce emissions, cross-media effects occur. Generally, Sections 8.2.2.1 to 8.2.2.4 below describe the most relevant environmental issues in the EAF process.

8.2.2.1 Emissions to air

8.2.2.1.1 Collection of primary emissions

Primary off-gases represent approximately 95% of total emissions from an EAF [22]. Most of the existing plants extract the primary emissions by the 4th hole (in the case of three electrodes – AC furnace) (see Figure 8.7) or by the second hole (in the case of one electrode – DC furnace). Thus 85 - 90% of the total emissions during a complete cycle “tap-to-tap” can be collected [22]. There are still few plants which do not have a 4th hole but a “doghouse”; a complete enclosure of the furnace with adequate gas extraction [373].

8.2.2.1.2 Collection of secondary emissions

Off-gases are generated during scrap handling, charging and tapping as well as those escaping from the furnace openings, like fumes (i.e. electrode openings and doors) are captured by a canopy hood generally located above the furnace. They may contain all of the pollutants described under primary emissions.

The most recent furnaces are often installed inside buildings with closed upper parts and a powerful extraction at the roof top. Depending on the dimensions of the building and the capacity of the furnace, the flowrate of the extraction system can exceed 1 million m³/h [373].
Figure 8.7 shows the three types of off-gas collection systems.

- EAF with extraction of primary off-gas at the furnace (4th hole) and a canopy hood for the collection of the secondary off-gas flow, installed in a building with open roof sections.
- EAF with doghouse collecting all the fumes from the furnace to one exhaust system, installed in a building with open roof sections.
- EAF with extraction of primary off-gas at the furnace (4th hole) installed in a building with a totally closed roof that collects the secondary off-gas flow.

Figure 8.7: Collection systems at EAF
based on [373] [471]

If secondary metallurgy is carried out in the same building as the EAF, these emissions can also be collected by canopy hoods and roof extractions [373].

Table 8.2 summarises the qualitative efficiencies to collect emissions from the main operations of electric arc furnace steelmaking.

<table>
<thead>
<tr>
<th>Sources of emissions</th>
<th>Charging</th>
<th>Melting (in EAF)</th>
<th>Tapping</th>
<th>Secondary Metallurgy ¹</th>
<th>Continuous Casting ¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collection system</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4th hole</td>
<td>no</td>
<td>yes</td>
<td>no</td>
<td>yes, if also equipped</td>
<td>n.a.</td>
</tr>
<tr>
<td>Hood</td>
<td>yes, partly</td>
<td>yes</td>
<td>yes, partly</td>
<td>yes, if also equipped</td>
<td>yes, if also equipped</td>
</tr>
<tr>
<td>Doghouse</td>
<td>only if closed ²</td>
<td>yes</td>
<td>yes</td>
<td>yes, if also equipped</td>
<td>n.a.</td>
</tr>
<tr>
<td>Total building evacuation</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

¹) If located in the same building.
²) Usually the doghouses are not closed during charging as they obstruct the access to the EAF.

Table 8.2: Systems for the collection of emissions from EAF plants
[22] [373]
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Figure 8.8 shows the percentages of the four existing emission collection systems in the EU, indicating that only one third of the plants have a 4th hole for the collection of primary emissions. 4th hole in this context means an additional hole in the roof of an EAF in order to extract the off-gas. In the case of a single electrode (usually there are three), this additional hole is called second hole. A doghouse is a specific housing of the EAF.

Figure 8.8: Percentage of existing dust collection system in 51 EAF in the EU

[471]

With respect to micropollutants like organochlorine compounds, especially PCDD/F, the contamination of secondary off-gases (mainly the leakages from EAF) contribute to overall emissions. In order to minimise total PCDD/F emissions, secondary emissions also have to be taken into account, thus strengthening the need for total building excavation.

8.2.2.1.3 Primary and secondary emissions and treatment

Off-gas from primary and secondary collection in EAF contains dust, metals, nitrogen and sulphur oxides and organic matter (e.g. VOC, chlorobenzenes, PCBs, PAH and PCDD/F). Organic matter emissions mainly depend on the scrap quality. Some scrap contain paints, oils and other organic substances [367].

Information about secondary emissions is limited. From charging the EAF usually 0.3 - 1 kg dust/t LS and from tapping 0.2 - 0.3 kg dust/t LS are emitted (emissions before abatement) [22]. For fume leakages during EAF operation, dust emission factors between 0.5 - 2 kg dust/t LS are reported [30].

Emission factors as a sum of the aforementioned three sources (charging, tapping, fume leakages) are between 1.4 and 3 kg dust/t LS before abatement [30]. This can be considered a confirmation that primary emissions are about ten times higher than secondary emissions.

Generally the treatment of different off-gas flows (i.e. primary and secondary emissions) is performed in the same device, mostly in bag filters [373]). Only in a few cases are ESPs and wet scrubbers applied.
### Table 8.3: Emission concentrations of air emissions from the EAF process after abatement [407] [424]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Bag filter</th>
<th>Electrostatic precipitator</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM</td>
<td>0.5 - 5</td>
<td>1.8</td>
<td>mg/Nm³</td>
</tr>
<tr>
<td>CO</td>
<td>88 - 256</td>
<td></td>
<td>mg/Nm³</td>
</tr>
<tr>
<td>NOx</td>
<td>0.97 - 70</td>
<td></td>
<td>mg/Nm³</td>
</tr>
<tr>
<td>SOx</td>
<td>8 - 17</td>
<td></td>
<td>mg/Nm³</td>
</tr>
<tr>
<td>Metals:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hg</td>
<td>0.016 - 0.019</td>
<td>&lt;0.0003</td>
<td>mg/Nm³</td>
</tr>
<tr>
<td>Total (including Sb, Pb, Cr, CN,F,Cu, Mn, V, Se, Te, Ni, Co, Sn)</td>
<td>0.006 - 0.022</td>
<td>0.01 - 0.07</td>
<td>mg/Nm³</td>
</tr>
<tr>
<td>Cr (except Cr (VI))</td>
<td>0.013</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mn</td>
<td>0.036</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ni</td>
<td>0.003</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PAH</td>
<td>&lt;0.00001</td>
<td>&lt;0.001</td>
<td>mg/Nm³</td>
</tr>
<tr>
<td>PCDD/F</td>
<td>0.0015 - 0.1&lt;sup&gt;2&lt;/sup&gt;</td>
<td></td>
<td>ng/Nm³</td>
</tr>
<tr>
<td>HF</td>
<td>0.085 - 0.2</td>
<td></td>
<td>mg/Nm³</td>
</tr>
<tr>
<td>HCl</td>
<td>3 - 5.4</td>
<td></td>
<td>mg/Nm³</td>
</tr>
<tr>
<td>Cl₂</td>
<td>&lt;3</td>
<td></td>
<td>mg/Nm³</td>
</tr>
</tbody>
</table>

Notes: Values are annual averages and relate to the central dedusting system. PAH contains benzo(a)pyrene and dibenzo-(a,h)-anthracene.  
<sup>1</sup> ESP applied in stainless steel production.  
<sup>2</sup> Upper end of the range relates to measurements carried out in 1997.

### Dust

The off-gas contains 10 - 30 kg dust/t liquid carbon steel or low alloyed steel and 10 – 18 kg dust/t in case of high alloyed steel before abatement. The composition of the dust can be seen from the analysis of the dust separated from the off-gas in the bag filters or electrostatic precipitators (ESP) (see Table 8.11). Most of the heavy metals are mainly associated with particulate matter and, thus, are removed to a large extent from the off-gas with the dust abatement. Those heavy metals present in the gas phase, e.g. mercury, are not eliminated by filtration or ESP [373].

The range of dust emission factors after abatement can be seen in Table 8.1. About 96 % of the dust belongs to PM<sub>10</sub> [288] [491]. The range is quite wide (three orders of magnitude), indicating a big difference in collection and abatement efficiency. In terms of concentration, the emissions are between 0.5 - 50 mg dust/Nm³ (the majority of the installations are at the lower end of the range). Normally these emission factors or emission concentrations include secondary dust emissions because primary and secondary emissions are very often treated in the same equipment [373] [366].

### Heavy metals

Some emissions in Table 8.1 show wide ranges. Higher values can be of high environmental relevance. Zinc is the metal with the highest emission factors. Chromium and nickel emissions are, for obvious reasons, generally higher in the manufacturing of stainless steel [373]. In three EU EAF plants, emissions factors for arsenic between 0.025 and 14 g/t have been measured [288] [403].
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Mercury emissions can strongly vary from charge to charge depending on scrap composition/quality [137] [144]. Mercury emissions in the sector are expected to decline due to the progressive phasing out of mercury following the full implementation of several directives already in place, such as the 'End of life vehicles' Directive, the 'Waste from electric and electronic equipment' Directive and the restriction of hazardous substances in the electric and electronic equipment as well as the batteries Directive [422]. Nevertheless, relevant exceedings of mercury ELVs have been observed, indicating that mercury-bearing components still occur in the scrap sources, and apparently they are not always removed from the shredder input. Emissions factors for mercury of 170 mg/t LS, despite efforts to reduce mercury in purchased scrap, have been observed on an annual basis and seem to be fairly similar for steel, based on domestic and imported scrap [492].

**Sulphur and nitrogen oxides**
The SO$_2$ emissions mainly depend on the quantity of coal and oil input but are not of high relevance. NO$_X$ emissions also do not need special consideration.

**Other inorganic compounds**
[288]
Fluoride, chloride are some examples.

**VOC**
VOC emissions may result from organic substances adhering to the raw materials (e.g. solvents, paints) charged to the furnace. In the case of the use of natural coal (anthracite), compounds such as benzene may degas before being burnt off [373].

**Polycyclic aromatic hydrocarbons (PAH)**
The emission factors for PAH are also relatively high (9 - 970 mg/t LS - see Table 8.1) but there are not many reported measurements. PAH are also already present in the scrap input [120] but may also be formed during EAF operation. The expectation that PAH adsorb to the filter dust to a high extent (also depending on the off-gas temperature) could not be confirmed by investigations in Luxembourg, where PAH emissions remained unchanged before and after abatement in a bag filter which achieved low residual dust contents (<5 mg/Nm$^3$) as a daily mean value [167]. The PAH profile is dominated by the more volatile two or three ring PAHs such as naphthalene, acenaphthene, anthracene and phenanthrene [388].

**Persistant organic pollutants (POP)**
Since the nineties increasing note has been taken of persistant organic pollutants. Analytical results are only available for a limited number of compounds. Organochlorine compounds, such as chlorobenzenes, PCB and PCDD/F have been measured.

There is a strong correlation between the concentrations of PCDD/F and WHO-12 PCBs, with the I-TEQ of PCDD/F being approximately 16.5 times higher than that of WHO-12 PCBs. This suggests that the formation mechanisms of PCBs and PCDD/F are linked [388].

Chlorobenzenes have been determined at several EAF operations (0.2 - 12 mg/t LS – see Table 8.1). From measurements at one EAF plant, it is known that hexachlorobenzene is present in the emitted off-gas [373].

**Polychlorinated biphenyls (PCB)**
PCB emissions have been detected and measured at some EAF's. These measurements showed that different congeners have been determined. Values as low as 0.01 mg/t LS and as high as 5 mg/t LS have been reported. In addition, it is not known yet whether PCB can be formed 'de novo' during the process and/or within the off-gas devices. These uncertainties show that it is difficult if not impossible to draw general conclusions on the formation and decomposition processes of PCB in EAF off-gases.
PCB may be present in the scrap input which could be the dominant source for the measured emissions [120]. Regulations, for example as end-of-life electric equipment management have greatly helped to prevent the introduction of items containing PCB (for instance small capacitors in several technical devices like washing machines, (hair)dryers, cooker hoods, oil burners, fluorescent lamps, etc). One investigation has shown that PCBs are practically not abated in bag filters [167]. A recent study performed in Sweden has shown a correlation between dioxin-like PCBs and PCDD/F but has also shown that the emission of PCBs in terms of WHO-TEQ is far less important than the emission of PCDD/F [373].

In general, it has been concluded that typical off-gas cleaning systems (e.g. filters, ESP, scrubbers) are more efficient at removing PCDD/F emissions than PCBs. The compound specific differences can be explained by differences in volatility between the congeners of the three compound groups. The variability in efficiency may be also due to the differences in the dust separation efficiency, gas temperature and adsorption properties of the dust [370].

The main contributor to the WHO-12 I-TEQ was PCB 126. Other PCB congeners found are PCBs 28, 52, 101, 138, 153 and 180 [388].

Polychlorinated dibenzo-p-dioxins and furans (PCDD/F)
During the thermal treatment of scrap containing paints, oils (e.g cutting oils), PVC (polyvinyl chloride) or other organic substances, PCDD/F are released or produced during waste gas treatment and emitted into the atmosphere along with the furnace fumes [367]. These emissions are especially important during the beginning of the scrap melting phase at the EAF, when the temperatures are still low. Even if downstream process temperatures are sufficiently high to destroy the PCDD/F, the PCDD/F generated during that initial phase will have an influence on its downstream generation [375] [388].

PCDD/F are generated as well by the combustion at low temperatures (250 - 500 °C) of organochlorinated compounds catalysed by metals (e.g. Cu and to a less extent Fe) that may be present in the charge as well as by 'de novo' synthesis. Findings indicate that the temperature profile is more important than the mean temperature in determining the PCDD/F concentration in the waste gas [388]. Regarding PCDD/F, there are many measurements available showing emission factors between 0.04 - 6 µg I-TEQ/t LS ([442]see Table 8.1). Concentrations between 0.02 and 9.2 ngTEQ/Nm3 have been measured [367]. Figure 8.9 presents an example of the distribution of PCDD/F homologues in the raw and cleaned off-gas of an EAF. The PCDD/F homologues with four and five chlorine atoms dominate.

![Figure 8.9: Distribution of PCDD/F homologues in the off-gas of a twin shell EAF with scrap preheating before and after abatement](image)

With respect to the absolute PCDD/F emissions, there is a correlation between off-gas temperature (see Figure 8.10) and dust content (see Figure 8.11) [366] [375].
Figure 8.10: Correlation of PCDD/F emissions and temperature of the off-gas after abatement in a bag filter of an EAF

[167]

Figure 8.10 indicates that as long as the clean gas temperature is below 75 °C, PCDD/F emissions will stay below 1 ng I-TEQ/Nm³. The physical explanation of this pertains to the decrease of volatility of PCDD/F with decreasing temperature [126]. At low temperatures, PCDD/F increasingly tends to adsorb to the filter dust.

Figure 8.11: Correlation of residual dust content and PCDD/F concentrations after abatement in a bag filter in the off-gas of an EAF at temperatures below 85 °C

[23] [106]

The observation that there is a close connection between dust and PCDD/F emissions has to be related to off-gas temperature. The dust content itself mainly depends on the dimension and quality of the bag filter but also on the relative humidity in the off-gas which can be high in case of off-gas quenching or location near the sea (see Figure 8.12).
PCDD/F are normally expressed as International Toxicity Equivalents (I-TEQ) according to NATO/CCMS, 1988. This is also the case for the existing legislation and actual permits.

In 1998, WHO had developed new toxicity equivalents for PCDD/F (WHO-TEQ). Integrated into this evaluation are 12 dioxin-like PCBs [219].

In 2005, reevaluated toxicity equivalents (WHO 2005-TEQ) have been presented and accepted by WHO [366] [441]. Figure 8.13 shows measurement results expressed as I-TEQ in comparison to WHO-TEQ, including dioxin-like PCBs.
The total level of PCDD/F including PCB expressed as WHO 2005-TEQ varies between 11 % lower and 21 % higher than the PCDD/F expressed as I-TEQ. The average of all presented measurements is 2 % lower for the values of PCDD/F as WHO 2005-TEQ including PCB compared to PCDD/F as I-TEQ.

The total level of PCDD/F including PCB is 12 - 24 % lower when expressed as WHO 2005-TEQ compared to WHO 1998-TEQ [441] [493].

According to information provided by Eurofer, the dioxin emissions from stainless steel production is lower than in the case of carbon steel. However this affirmation has only been verified in a few plants [209].

Table 8.4 shows specific and annual emissions of PCDD/F and PCB to air from Swedish EAFs predominantly estimated from the production in 2005. The reported values are according to the toxic equivalent quantity (TEQ), using the latest weighting scheme by the WHO [441] including both PCDD/PCDF and dioxin-like PCB. The contribution from dioxin-like PCB is mostly in the range of 10 - 20 %. Most plants use iron scrap as raw material, except plant F, G and H where the production is based on iron ore. TEQ is reported as an interval when some toxic congeners are below the limit of detection.

<table>
<thead>
<tr>
<th>Plant</th>
<th>PCDD/F µg TEQ/t LS</th>
<th>PCDD/F g TEQ/yr</th>
<th>PCB µg TEQ/t LS</th>
<th>PCB g TEQ/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.67</td>
<td>0.29</td>
<td>0.22</td>
<td>0.096</td>
</tr>
<tr>
<td>B</td>
<td>0.41</td>
<td>0.025</td>
<td>0.04</td>
<td>0.002</td>
</tr>
<tr>
<td>C</td>
<td>0.091</td>
<td>0.008</td>
<td>0.015</td>
<td>0.0013</td>
</tr>
<tr>
<td>D</td>
<td>0.080</td>
<td>0.015</td>
<td>0.02</td>
<td>0.0034</td>
</tr>
<tr>
<td>E</td>
<td>3.7</td>
<td>1.8</td>
<td>0.42</td>
<td>0.21</td>
</tr>
<tr>
<td>F*</td>
<td>0.0045 - 0.0053</td>
<td>0.0005 - 0.0006</td>
<td>0.0011</td>
<td>0.0001</td>
</tr>
<tr>
<td>G*</td>
<td>0.085 - 0.091</td>
<td>0.19 - 0.20</td>
<td>0.014</td>
<td>0.032</td>
</tr>
<tr>
<td>H*</td>
<td>0.0049 - 0.020</td>
<td>0.008 - 0.032</td>
<td>8.9E-5 - 6.9E-4</td>
<td>0.0002 - 0.0011</td>
</tr>
<tr>
<td>I</td>
<td>0.056</td>
<td>0.015</td>
<td>0.012</td>
<td>0.0032</td>
</tr>
<tr>
<td>J</td>
<td>2.4</td>
<td>1.0</td>
<td>0.28</td>
<td>0.12</td>
</tr>
<tr>
<td>K</td>
<td>0.17</td>
<td>0.003</td>
<td>0.56</td>
<td>0.01</td>
</tr>
</tbody>
</table>

*Ore based plants
Legend: LS = liquid steel

Table 8.4: Specific and annual emissions of PCDD/F and PCB to air from Swedish steel plants [370]

8.2.2.1.4 Emissions from secondary metallurgy processes

Information about emissions from secondary metallurgy (mainly dust emissions) and from continuous casting is very limited. [30] reports dust emission factors before abatement from seven AOD/VOD refining installations between 6 and 15 kg dust/t LS and a single low figure of 1.35 kg dust/t LS. These seven installations have a dedusting device independent from the dedusting of EAFs. The emission factors reported in Table 8.1 include the emissions from secondary steelmaking.

The treatment of the collected off-gas flows from secondary metallurgy is performed in the same device, mostly in bag filters as primary and secondary emissions. Table 8.5 shows some emissions concentration values for different parts of the secondary metallurgy after abatement.
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### Emissions from scrap preheating

The scrap preheating may lead to an important generation of organic pollutants due to the possible presence of organic substances on the scrap which are combusted during preheating under very unfavourable conditions. This can result in increased emissions of VOC and PCDD/F emissions. In this case, the off-gases need further aftertreatment, i.e. post combustion.

### Emissions from slag processing

If the slag is collected in a slag pot at the EAF, it needs to be poured into outside slag basins for solidification. The cooling of the slag may be enhanced by water sprays resulting in fumes. These fumes can be highly alkaline if the slag contains free CaO (see Table 8.7). This is very often the case. Alkaline depositions from the fumes may cause problems in the neighbourhood.

If the slag is poured on the floor it is pre-crushed after solidification using excavators or shovel loaders and subsequently brought to an outside storage area.

After a certain period of time, the slag is processed in crushing and screening devices in order to give it the desired consistency for separating metals from the slag and for its further use in construction. Slag breaking and metal recovery can create dust emissions. The emission from crushing and screening should be extracted and subsequently cleaned [373] [417] [422] [489].

### Waste water

Water is used for the following purposes:

- cooling of the EAF
- rapid quenching of the hot off-gases
- scrubbing water if wet dedusting is applied
- vacuum generation
- direct cooling in continuous or ingot casting.

According to the water management seeking optimal treatment of all waste waters, information on the flow and treated waste water of single production steps are often not available because the mixture of different waste water streams are treated together (see Section 2.4) [363].

#### Cooling water

Water is used in the EAF unit for cooling the wall panels, the roof and for spraying the electrodes. The water used for the cooling of the EAF is about 5 - 12 m³/(m²h). For an EAF of a production capacity of 70 t/h the cooling water demand is 1000 m³/h. Since the water is led in a closed cooling cycle no waste water occurs.
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Waste water from off-gas scrubbing
In some cases in the EU, the off-gases are treated in a wet scrubber. There is no information available on applied treatment techniques and discharged quantities and its pollution.

Waste water from continuous and ingot casting
Continuous casting in the EAF process is similar to the basic oxygen furnace process. For more information, see Sections 7.2.2.2 and 7.3.7. Specific information about input/output quantities is not available. Usually this waste water is treated together with other streams from the rolling mill(s).

Waste water from vacuum generation
For vacuum treatment, the usual specific process water flow from vacuum generation ranges from 5 - 8 m³/t LS vacuum treated. In a few cases the specific process water demand is higher, in one case 42.8 m³/t LS (see Table 8.1). This water is nearly fully recycled. It should be mentioned that not all of the liquid steel has to be vacuum treated. Information on composition and treatment or recycling is not available [363] [365] [471].

Waste water from quenching
Water is used for rapid quenching. From one plant it is reported that 25 m³/h are used to quench approximately 870000 m³/h. No waste water occurs since the used water is mostly evaporated and the residual moisture leaves the process with the dust.

Drainage water from the scrapyard
The main raw material of EAF, the different kinds of scrap are often stored on unpaved scrapyards. Drainage water can be contaminated, especially in the case of scrap which contains oil/emulsions like turnings. There is no information available on quantities and pollution of drainage water. Usually it is at least treated in an oil separator prior to being discharged.

8.2.2.3 Process residues such as wastes and by-products
The various solid wastes/by-products from EAF steelmaking are compiled together with their specific quantities in Table 8.6.

<table>
<thead>
<tr>
<th>Solid waste/by-product</th>
<th>Specific quantity (range) (kg/t LS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slags from carbon steel/low alloyed steel production:</td>
<td></td>
</tr>
<tr>
<td>• Slag from EAF</td>
<td>100 - 150</td>
</tr>
<tr>
<td>• Slag from ladle</td>
<td>10 - 30</td>
</tr>
<tr>
<td>Slags from high alloyed steel production:</td>
<td></td>
</tr>
<tr>
<td>• Slag from EAF</td>
<td>100 - 135</td>
</tr>
<tr>
<td>• Slag from ladle</td>
<td>30 - 40</td>
</tr>
<tr>
<td>• AOD slag</td>
<td>approx. 160</td>
</tr>
<tr>
<td>Dстыs from carbon steel/low alloyed/high alloyed steel production</td>
<td>10 - 20</td>
</tr>
<tr>
<td>Refractory bricks</td>
<td>2 - 8</td>
</tr>
</tbody>
</table>

Table 8.6: Kind and specific quantity of solid wastes/by-products from electric arc furnace steelmaking
[46] [116]

More recent data for European EAF plants can be found in Table 8.1.
8.2.2.3.1 Slags from production of carbon steel/low alloyed steel/high alloyed steels

The chemical composition of EAF slag from the production of carbon steel and low alloyed steel can be seen in Table 8.7. This table also contains the composition of slag from the production of high alloyed steel and from secondary metallurgy (AOD and VOD).

<table>
<thead>
<tr>
<th>Component (wt-%)</th>
<th>Production of carbon/low alloyed steel</th>
<th>Production of high alloyed steel</th>
<th>Secondary metallurgy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Slag from EAF</td>
<td>Slag from ladle</td>
<td>Slag from EAF</td>
</tr>
<tr>
<td>Fe&lt;sub&gt;total&lt;/sub&gt;</td>
<td>10 - 35</td>
<td>≤ 2 - 5</td>
<td>0.40 - 4</td>
</tr>
<tr>
<td>CaO</td>
<td>25 - 45</td>
<td>30 - 50</td>
<td>2 - 49</td>
</tr>
<tr>
<td>CaO&lt;sub&gt;free&lt;/sub&gt;</td>
<td>≤ 4</td>
<td>≤ 10</td>
<td>≤ 10</td>
</tr>
<tr>
<td>SiO&lt;sub&gt;2&lt;/sub&gt;</td>
<td>10 - 18</td>
<td>10 - 20</td>
<td>28.5 - 33</td>
</tr>
<tr>
<td>Al&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt;</td>
<td>3 - 8</td>
<td>3 - 12</td>
<td>4.2 - 26</td>
</tr>
<tr>
<td>MgO</td>
<td>4 - 13</td>
<td>7 - 18</td>
<td>3.1 - 23</td>
</tr>
<tr>
<td>MnO</td>
<td>4 - 12</td>
<td>≤ 1 - 5</td>
<td>2</td>
</tr>
<tr>
<td>Cr&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt;</td>
<td>1 - 5</td>
<td>≤ 0.5</td>
<td>1 - 13</td>
</tr>
<tr>
<td>TiO&lt;sub&gt;2&lt;/sub&gt;</td>
<td>0 - 0.5</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>P&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;5&lt;/sub&gt;</td>
<td>0.01 - 0.6</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Na&lt;sub&gt;2&lt;/sub&gt;O</td>
<td>0.46&lt;sup&gt;1)&lt;/sup&gt;</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>K&lt;sub&gt;2&lt;/sub&gt;O</td>
<td>0.11&lt;sup&gt;2)&lt;/sup&gt;</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>V&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;5&lt;/sub&gt;</td>
<td>0.11 - 0.25</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>ZnO</td>
<td>0.02&lt;sup&gt;3)&lt;/sup&gt;</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>CuO</td>
<td>0.03&lt;sup&gt;3)&lt;/sup&gt;</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>NiO</td>
<td>0.01 - 0.4</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Pb</td>
<td>&lt;0.01</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>S</td>
<td>0.02&lt;sup&gt;3)&lt;/sup&gt;</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>C</td>
<td>0.33&lt;sup&gt;3)&lt;/sup&gt;</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>F</td>
<td>0.2 - 2.2</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>B&lt;sub&gt;4&lt;/sub&gt;</td>
<td>1.04 - 1.44</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

<sup>1)</sup> Data available only from one plant
<sup>2)</sup> Data from four plants; n/a = not available

In traces, other elements such as Pb, As, Sb, Hg, Cl, F and hexavalent chromium may also be present.

Table 8.7: Chemical composition of EAF slag from the production of carbon steel/low alloyed steel, high alloyed steel and from secondary metallurgy

[46] [57] [116] [200] [270] [391] [408] [442]

In the EU, a growing amount of slags from carbon and low alloyed steelmaking are used as secondary raw materials, mainly for road construction. Slags from stainless steel production are generally less suitable for such uses and need to be landfilled. The percentage of in-plant recycling of slags from the production of high alloyed steels is significantly higher than for slags from carbon and low alloyed steelmaking. But still one third is landfilled and stored (see Table 8.8) [373].
Most of the slags from ladle treatment and secondary metallurgy (also AOD and VOD slag) are landfilled; with respect to the EU, this is about 80% [30]. The rate of landfilling or recycling varies in the different Member States depending on legal requirements, availability of landfills, taxes, market situation, costs and possibilities to re-use processed slags.

Slags from four EAF plants were analysed for PCDD/F and PCB. Table 8.9 shows concentrations and annual mass flows of PCDD/F and PCB in slag for these steel plants in which scrab was used as a raw material. The concentrations found are below the limit value of 15 µg TEQ/kg specified in the regulation for persistent organic pollutants.

<table>
<thead>
<tr>
<th>Plant</th>
<th>PCDD/F</th>
<th>PCDD/F</th>
<th>PCB</th>
<th>PCB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>µg TEQ/kg</td>
<td>g TEQ/yr</td>
<td>µg TEQ/kg</td>
<td>g TEQ/yr</td>
</tr>
<tr>
<td>A</td>
<td>&lt;0.004</td>
<td>&lt;0.56</td>
<td>0.0002</td>
<td>0.029</td>
</tr>
<tr>
<td>B</td>
<td>0.014 - 0.015</td>
<td>0.053 - 0.058</td>
<td>0.0014</td>
<td>0.0069</td>
</tr>
<tr>
<td>I</td>
<td>0.002</td>
<td>0.14</td>
<td>0.0004</td>
<td>0.027</td>
</tr>
<tr>
<td>J</td>
<td>0.002</td>
<td>0.09</td>
<td>0.00005</td>
<td>0.002</td>
</tr>
</tbody>
</table>

Table 8.9: Concentrations and annual mass flows of PCDD/F and PCB in slag from steel plants using scrab as a raw material [370]

8.2.2.3.2 Refractory bricks

Refractory bricks are used for lining in the different vessels. According to the [30], spent refractory bricks were put to landfill. In recent years recovery of usable magnesia and dolomite has been introduced and landfilling has been used only for fractions that are not suitable for recovery [373]. In an EAF plant with a capacity of approximately 400000 tonnes of stainless steel per year, the spent refractory amounts up to about 9000 tonnes per year [386]. Table 8.10 shows the annual amount relating to different process steps.

<table>
<thead>
<tr>
<th>Refractory used</th>
<th>EAF</th>
<th>Steel ladle</th>
<th>Ladle furnace RH degaser</th>
<th>Strand caster</th>
<th>Ingot casting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnesite</td>
<td>1200</td>
<td>3800</td>
<td>600 (1)</td>
<td>2400</td>
<td></td>
</tr>
<tr>
<td>Dolomite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mullite (clay)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>500</td>
</tr>
</tbody>
</table>

Table 8.10: Example of annual amount of spent refractory material in one installation [386]
8.2.2.3.3 Dusts from off-gas treatment

As already mentioned the treatment of off-gases (mostly primary off-gases together with secondary off-gases) is very often performed in bag filters. The chemical composition of dusts from the production of carbon, low alloyed and high alloyed steel can be seen in Table 8.11.

<table>
<thead>
<tr>
<th>Component</th>
<th>Dust from carbon/low alloyed steel production (wt.- %)</th>
<th>Dust from alloy steel production (wt.- %)</th>
<th>Dust from stainless steel production (wt.- %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FeOtot</td>
<td>10 - 40</td>
<td>17 - 37</td>
<td>20 - 33</td>
</tr>
<tr>
<td>SiO₂</td>
<td>0.6 - 5.1</td>
<td>1.7 - 5</td>
<td>3 - 9</td>
</tr>
<tr>
<td>CaO</td>
<td>3 - 17</td>
<td>2 - 16</td>
<td>8 - 18</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>0.3 - 3</td>
<td>1 - 4</td>
<td>0.4 - 2</td>
</tr>
<tr>
<td>MgO</td>
<td>0.5 - 6</td>
<td>1.2 - 3</td>
<td>1 - 4</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.1 - 0.37</td>
<td>0.01 - 0.1</td>
<td>0.03 - 0.1</td>
</tr>
<tr>
<td>MnO</td>
<td>1.1 - 6</td>
<td>1.5 - 6.9</td>
<td>2.2 - 6.3</td>
</tr>
<tr>
<td>Cr₂O₃</td>
<td>0.13 - 2</td>
<td>0.12 - 6</td>
<td>9 - 20</td>
</tr>
<tr>
<td>Na₂O</td>
<td>0.3 - 3</td>
<td></td>
<td>0.6 - 2</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.5 - 2.3</td>
<td></td>
<td>0.7 - 3</td>
</tr>
<tr>
<td>Zn</td>
<td>21 - 43</td>
<td>2 - 15</td>
<td>2 - 25</td>
</tr>
<tr>
<td>Pb</td>
<td>0.4 - 10</td>
<td>0.05 - 3.6</td>
<td>0.2 - 4.5</td>
</tr>
<tr>
<td>Cd</td>
<td>0.02 - 0.18</td>
<td>0.01 - 0.04</td>
<td>0.01 - 0.05</td>
</tr>
<tr>
<td>Cu</td>
<td>0.08 - 0.5</td>
<td>0.01 - 0.8</td>
<td>0.015 - 0.5</td>
</tr>
<tr>
<td>Ni</td>
<td>0.01 - 0.05</td>
<td>0.01 - 0.5</td>
<td>1 - 4</td>
</tr>
<tr>
<td>V</td>
<td>0.01 - 0.035</td>
<td>0.01 - 0.2</td>
<td>0.05 - 0.12</td>
</tr>
<tr>
<td>W</td>
<td>0.5 - 1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Co</td>
<td>0.001 - 0.01</td>
<td>0.01 - 0.2</td>
<td>0.02 - 0.04</td>
</tr>
<tr>
<td>As</td>
<td>0.001 - 0.02</td>
<td>0.001 - 0.01</td>
<td>n/a</td>
</tr>
<tr>
<td>Hg</td>
<td>0.0001 - 0.005</td>
<td>0.05 - 0.7</td>
<td>0.0002 - 0.015</td>
</tr>
<tr>
<td>Cl</td>
<td>0.8 - 5</td>
<td>0.7 - 1.7</td>
<td>0.8 - 1</td>
</tr>
<tr>
<td>F</td>
<td>0.02 - 0.9</td>
<td>0.01 - 0.65</td>
<td>0.3 - 0.7</td>
</tr>
<tr>
<td>S</td>
<td>0.1 - 3</td>
<td>0.25 - 1.42</td>
<td>0.2 - 0.5</td>
</tr>
<tr>
<td>C</td>
<td>0.4 - 3.3</td>
<td>0.5 - 3.1</td>
<td>0.05 - 1.3</td>
</tr>
<tr>
<td>Basicity</td>
<td>2.0 - 6.5</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>Moisture</td>
<td>6 - 16</td>
<td>n/a</td>
<td></td>
</tr>
</tbody>
</table>

Table 8.11: Chemical composition of EAF dusts from the production of carbon steel/low alloyed steel and high alloyed steel

Dust from six plants were analysed for PCDD/F and PCB. Table 8.13 shows concentrations and annual mass flows of PCDD/F and PCB in dust for four of these plants in which iron scrub was used as a raw material.

<table>
<thead>
<tr>
<th>Plant</th>
<th>PCDD/F µg TEQ/kg</th>
<th>PCDD/F g TEQ/yr</th>
<th>PCB µg TEQ/kg</th>
<th>PCB g TEQ/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.16</td>
<td>1.0</td>
<td>0.014</td>
<td>0.089</td>
</tr>
<tr>
<td>B</td>
<td>0.21</td>
<td>0.11</td>
<td>0.015</td>
<td>0.0075</td>
</tr>
<tr>
<td>I</td>
<td>0.035</td>
<td>0.20</td>
<td>0.0020</td>
<td>0.011</td>
</tr>
<tr>
<td>J</td>
<td>0.16</td>
<td>1.0</td>
<td>0.0042</td>
<td>0.026</td>
</tr>
</tbody>
</table>

Table 8.12: Concentrations and annual mass flows of PCDD/F and PCB in dust from four steel plants using scrub as a raw material
In recent years, following regulation on waste management, the percentage of dust put into landfills has been dramatically reduced. A vast majority of dust is nowadays brought to recovery operations for non ferrous metals (Zn and Pb mainly in the case of carbon steel dusts and Cr and Ni in the case of stainless steel dusts) [373].

Different technologies exist for treating EAF dust which contains from 18 - 35 % zinc. These are well-established processes in use in the non-ferrous metals production industries. However, the zinc industry normally uses raw materials which have a higher zinc concentration. As a result, EAF dust undergoes a further process before the zinc can be recovered from it. These processes raise the zinc content to 55 - 65 % [274] [436].

According to a survey carried out in 2006 covering 36 EAF plants and 342949 tonnes of dust, EAF dust is mainly used in three different ways as shown in Figure 8.14.

![Figure 8.14: Utilisation of EAF dust](493)

8.2.2.4 Energy consumption

Electricity and natural gas are the most important energy sources in EAF operations.

During the melting process some the following types of energy concur:

- thermal energy, from the electrical arc
- thermal energy, from the combustion of natural gas or other gaseous or liquid fuels
- chemical energy, from the exothermic reactions occurring in the furnace by metal oxidation.

The energy consumption of the furnace is the balance of the three aforementioned inputs. A typical energy balance for an EAF is an input of 380 kWh/t electrical energy, 210 kWh/t through fuel combustion and 100 kWh/t through metal oxidation which corresponds to a total of 690 kWh/t of LS. From this input, 370 kWh/t are needed to melt and superheat the scrap to tap temperature, 37 kWh/t to liquefy and superheat the slag, 100 kWh/t are furnace losses and 140 kWh are as sensible heat in the off-gas.
The utilisation of the 140 kWh/t of sensible heat in the off-gas has developed over the last 40 years and is today a proven tool to reduce the total energy requirements in the EAF operations. One option is to use the sensible heat for scrap preheating. The scrap can be preheated to approx. 800 °C prior to the melting process in the furnace vessel which reduces the total energy consumption by up to 100 kWh/t LS.

8.2.2.5 Noise emissions

The following are the main noise sources in EAF steelworks:

- melting shop including EAF
- scrapyard
- primary dedusting
- roof hood dedusting
- water management equipment
- transport of slag pots
- transport of products, e.g. with wheel loaders
- slag processing in crushers, magnetic separators and screening devices.

Conventional EAFs show average sound levels (melting and treating) of $L_{WA} = 118 - 133$ dB(A) for furnaces >10 t and $L_{WA} = 108 - 115$ dB(A) for furnaces <10 t; the specific transformer power determines the level of noise emissions. In electric steelworks, sound levels of up to $L_{WA} = 127$ dB(A) can appear (measurement includes melting and treating). The main share of noise emissions are contributed by the melting shop including EAF, the scrapyard and primary dedusting.

8.2.2.6 Soil contamination

In many cases the scrapyard is unpaved and uncovered (see Section 8.1.1). Contamination of soil may arise from the storage of scrap contaminated by mineral oil/emulsions or other compounds. There is no information available about the extent and the impact of such soil contamination [417].

If the yard for slag processing is unpaved and the raw slag contains free CaO, alkaline water may enter the soil.
8.3 Techniques to consider in the determination of BAT

This section sets out techniques considered generally to have potential for achieving a high level of environmental protection in the industries within the scope of the document. Management systems, process-integrated techniques and end-of-pipe measures are included, but a certain amount of overlap exists between these three when seeking the optimum results.

Prevention, control, minimisation and recycling procedures are considered as well as the re-use of materials and energy.

Techniques may be presented singly or as combinations to achieve the objectives of the IPPC Directive. Annex IV to this Directive lists a number of general considerations to be taken into account when determining BAT and techniques within this section will address one or more of these considerations. As far as possible, a standard structure is used to outline each technique, to enable comparison of techniques and an objective assessment against the definition of BAT given in the IPPC Directive.

The content of this section is not an exhaustive list of techniques and others may exist or be developed which may be equally valid within the framework of IPPC and BAT.

The standard structure used to outline each technique is shown in Table 8.13.

<table>
<thead>
<tr>
<th>Type of information considered</th>
<th>Type of information included</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Technical description of the technique (including drawings, schematics if necessary)</td>
</tr>
<tr>
<td>Achieved environmental benefits</td>
<td>Main environmental benefits (including energy, water, raw material savings, as well as production yield increases, energy efficiency, etc.) addressed by the technique</td>
</tr>
<tr>
<td>Cross-media effects</td>
<td>Main environmental side effects and disadvantages to other media caused by using the technique. Details of the environmental effects of the technique in comparison with others</td>
</tr>
<tr>
<td>Operational data</td>
<td>Data on consumption and emission levels from operational plants using the technique (including any reference conditions and monitoring methods used). Any other relevant information on how to operate, maintain and control the technique</td>
</tr>
<tr>
<td>Applicability</td>
<td>Indication of the type of plants in which the technique may be applied, considering, e.g. plant age (new or existing), plant size (large or small), techniques already installed and type or quality of product</td>
</tr>
<tr>
<td>Economics</td>
<td>Information on costs (both investment and operational) and any possible savings (e.g. reduced raw material or energy consumption, waste charges) or revenues including details on how these costs/savings or revenues have been calculated/estimated</td>
</tr>
<tr>
<td>Driving force for implementation</td>
<td>Local conditions or requirements which lead to, or may stimulate, implementation. Information on reasons other than environmental ones for implementation (e.g. increase in productivity, safety)</td>
</tr>
<tr>
<td>Example plants</td>
<td>Reference to (a) plant(s) in which the technique is applied and from which information has been collected and used in writing the section</td>
</tr>
<tr>
<td>Reference literature</td>
<td>Literature or other reference material (e.g. books, reports, studies, websites) that was used in writing the section and that contains more details on the technique</td>
</tr>
</tbody>
</table>

Table 8.13: Information breakdown for each technique described in this section
8.3.1 EAF process optimisation

Description
The EAF process has been steadily improved in order to optimise it and to increase productivity which correlates to the decrease of specific energy consumption. The most important measures/techniques which are briefly described in this section are [440]:

- (ultra) high power operation (UHP)
- water cooled side walls and roofs
- oxy-fuel burners and oxygen lancing
- bottom tapping system
- foaming slag practice
- ladle or secondary metallurgy
- scrap preheating
- automated sampling and addition of alloying elements
- increased energy efficiency
- computer-based process control and automation.

(Ultra) High power operation
Efforts to reduce tap-to-tap times have led to the installation of more powerful furnace transformers. Decisive features for (ultra) high power furnaces are the specific power supply installed, mean power efficiency ($\geq 0.7$), and timely use of the transformer ($\geq 0.7$). UHP operation may result in higher productivity, reduced specific electrode consumption, and reduced specific waste gas volume, but also in increased wear of the furnace lining [57].

Water cooled side walls and roofs
Since 1980 the last two decades, furnace walls and roofs have been lined with water cooled panels, providing the opportunity to save refractory material, to use the (ultra) high power furnace technology, and also to re-use waste heat by the application of measures for energy recovery. However, the economic viability of energy recovery should be checked on a plant by plant basis. In principle, two cooling systems can be distinguished. 'Cold or warm cooling' draws off power losses by an increase of the cooling water temperature flowing through the pipe coils. Evaporation cooling works through the evaporation of cooling water to draw off radiation heat caused by the electric arc process. To protect water cooled side panels from thermal strain, especially when foaming slag operation (see below) is not possible, a computer controlled regulation of the melt-down process helps to prevent tears in the panels caused by mechanical tension and also saves refractory material [75].

Oxy-fuel burners and oxygen lancing
Oxy-fuel burners promote a uniform melting of the scrap. It also partially offsets the effect of maximum demand control on electricity supply. Usually, additional energy input by oxy-fuel burners and oxygen lancing results in a decrease in total energy input required.

Bottom tapping system
The practice of bottom tapping is used since 1983 and widely adopted nowadays, as it makes to minimising the amount of oxidic slag (carry over) to the ladle during tapping possible. It also allows cost savings for the lowering of refractory material needed, for a more rapid tapping, and for reduced energy losses. Furthermore, it simplifies the capturing of fumes. Usually most of the new EAFs are equipped with bottom tapping systems. However some older furnaces are still equipped with spouts. The reasons for this are to ensure both, the tapping of the whole melt as well as partial tapping, the high degree of reduction of slag, that the tapping procedure is well controlled and furthermore the maintenence of the spout system is comparably easy due to its simple construction [494].
Chapter 8

Foaming slag practice
Creating a foamy slag within the furnace improves the heat transfer to the charged inputs, and also protects the refractory material inside the furnace. Because of better arc stability and fewer radiation effects, foaming slag practice leads to reductions in energy consumption, electrode consumption, noise level, and an increase in productivity. It also causes positive effects on several metallurgical reactions (e.g. between slag and melt). The density of foaming slag is less than common EAF slag which contains FeO (1.15 - 1.5 t/m³ compared to 2.3 t/m³). For this reason, the volume of slag arising during steelmaking increases and may require larger slag buckets. After tapping, the slag partly degases again. Information on adverse impacts of the foamy slag practice on the possibilities of using the slag have not been encountered. It should be noted, that the use of foaming slag practice for high-grade steelmaking is often not possible.

Ladle or secondary metallurgy
Some production steps need not be carried out in the EAF itself and can be performed more efficiently in other vessels (like desulphurisation, alloying, temperature and chemistry homogenisation). The technique of shifting specific activities to ladles, ladle furnaces, or other vessels was introduced ca. 1985 [36] [57]. The reported benefits of this development are energy savings (net savings of 10 - 30 kWh/t), a reduction of tap-to-tap times of about 5 - 20 minutes, increased the productivity, a better control of the steel temperature of the heat delivered to the continuous casting, a possible reduction of electrode consumption (up to 0.1 - 0.74 kg/t), alloy savings, and a decrease in the emissions from the EAF itself [36]. A possible drawback of using ladles or other vessels with respect to air pollution control is the increase in the numbers of emission sources, requiring higher investments for air pollution control equipment as additional fume capturing devices like hoods are needed.

Scrap preheating
The utilisation of sensible heat in the off-gas for scrap preheating has developed in the last 40 years and can be regarded as a proven tool to reduce the total energy requirements in the EAF operations. The scrap can be preheated to approx. 800°C prior to the furnace vessel which reduces the total energy consumption by up to 100 kWh/t LS. Additionally there is the option for continuous scrap charging (see Section 8.3.2).

Increased energy efficiency
The EAF power demand (electrical voltage) has been significantly increased since 1995, resulting in electric networks being more and more disturbed, which implies electric energy losses. Electric energy inputs are an important lever for action. Improving power supply by means of efficient power electronics allows for increasing productivity and a reduction in the overall energy demand. Specific electricity consumption of 360 kWh/t has been achieved with a 100 MW DC EAF at Arbed, Esch-Belval, Luxembourg. For AC EAFs, one research work has shown that improved power supply can lead to a productivity gain of approx. 7% and associated gains in energy efficiency [415].

Computer-based process control and automation
Computer-based control in EAFs has become necessary and is commonly used approx. since 1982, as the high throughputs require efficient control systems to manage the material and data flows arising in the raw material selection, EAF, ladle furnace, and continuous caster. Efficient control systems in particular enables optimization of the energy input in the furnace and permit an increase in productivity and also a decrease in dust emissions [86] [440].

Achieved environmental benefits
The achieved environmental benefits are mentioned above under the description heading.

Cross-media effects
Oxy-fuel burners increase the off-gas flow but on the other hand it decreases the overall energy demand.
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Water cooled side walls and roofs need an additional energy consumption of about 10 - 20 kWh/t but may be compensated for by advantages in the field of plant availability and maintenance. Water cooled side walls and roofs have *inter alia* provided the opportunity to apply modern technology like high power or ultra high power furnaces.

**Operational data**

No data submitted.

**Applicability**

The described techniques are applicable to both new and existing plants but have to be checked on a plant by plant basis.

**Economics**

No data submitted.

**Driving force for implementation**

The high market competition and the need to increase productivity/to reduce costs pushed the introduction of the described techniques.

**Example plants**

Many plants in the EU are equipped with the described techniques and are operated with optimised conditions.

**Reference literature**

[16] [415] [417] [422] [440]

8.3.2 Scrap preheating

**Description**

The utilisation of the sensible heat in the off-gas (approx. 140 kWh/t LS) has developed in the last 40 years and is today a proven tool in reducing the total energy requirements in the EAF operations. One option is to use the sensible heat for scrap preheating. The scrap can be preheated to approx. 800 °C prior to the EAF melting process which reduces the total energy consumption by up to 100 kWh/t LS.

Such preheating is performed either in the scrap charging baskets or in a charging shaft (shaft furnace) added to the EAF or in a specially designed scrap conveying system allowing continuous charging during the melting process. In some cases, even additional fossil energy is added in the preheating process [373].

The shaft technology has been developed in steps. In 1988 Fuchs Systemtechnik GmbH, now SIMETAL, started a development to overcome the shortfalls of the scrap bucket preheaters and opted for direct charging of the scrap into a shaft that was positioned on the roof of the EAF. With the single shaft furnace, at least 50 % of the scrap can be preheated [125].

A further modification is the double shaft furnace which consists of two identical shaft furnaces (twin shell arrangement) which are positioned next to each other and are serviced by a single set of electrode arms. The scrap is partly preheated by off-gas and partly by side wall burners.

A very efficient shaft furnace design is the finger shaft furnace. The finger shaft design uses a unique scrap retaining system with fingers which allow the preheating of 100 % of the scrap amount [162]. The first basket is preheated during the refining of the previous heat and the second during the melting down of the first one. In 1994, the first Finger Shaft Furnace started up at Hylsa in Monterrey. Through the utilisation of the furnace off-gas during the heat cycle, scrap can be preheated to a temperature of approximately 800 °C prior to the final melting in the furnace vessel. This means considerable energy and cost savings with a substantial reduction in
tap-to-tap times. All occurring emissions from the scrap preheating systems can be combusted
in a separate downstream combustion chamber.

Since 2000 continuous scrab preheating and feeding became very popular, e.g. the CONSTEEL
(see Figure 8.15) and ESC processes [490]. The scrab is charged by cranes on a special
conveyor belt. In the preheating section the the charge receives heat from the off-gases leaving
the furnace. The scrab flow is adjusted to the power input of the EAF. The charge is melted by
immersion in a molten pool, heated by the energy coming from the electric arcs and from the
chemical reactions taking place in the melt, in contrast to conventional top-charge EAF where
the melting is provided by direct heat transfer from the electric arc. The bath is always covered
by a foaming slag which is constantly promoted by controlled carbon and oxygen injection.

A recent development of the scrap preheating process is the COSS technology which combines
the benefits of the SHAFT systems (high scrap preheating) with those of the CONSTEEL
process (the continuous scrap feeding) (see Figure 8.15). [450]

![Figure 8.15: Schematic of the Consteel Process](image)

**Achieved environmental benefits**

With shaft furnaces, very high scrap preheating temperatures of up to 800 °C can be achieved.
With the described techniques for scrap preheating 70 - 100 kWh/t LS electric power can be
saved which is about 10 - 25 % of the overall electricity input. Calculated on the basis of
primary energy, the savings are about three times higher because of the low efficiency of
electricity supply. In addition, the two scrap preheating solutions reduce the tap-to-tap time
since less electric energy needs to be put into the charge and downtime for batch charging is
reduced.

In combination with an advanced off-gas treatment, scrap preheating plays a significant role in
the optimisation of EAF steelmaking, not only related to productivity but also to the
minimisation of emissions.

As a side effect, scrap preheating reduces raw dust emissions of about 20 % because the off-gas
has to pass through the scrap which acts as a filter. This reduction correlates with an increase in
the zinc content in the dust which supports its recycling.
With the continuous feeding systems, the scrap can be heated up to an average temperature of 200 - 300 °C, thus the efficiency of the furnace is increased and energy consumption is reduced. But the continuous feeding has some additional advantages like reduced electrode consumption, lower noise emissions, up to 2 % higher charge yield compared to top charged EAF, better power utilisation, less thermal stresses, reduced tap-to-tap times and 5 % less slag.

All CO and H₂ are considered to have evolved from the melting process and are burnt to CO₂ and H₂O inside the preheater. The continuity of the process allows for achieving a stable off-gas exit temperature between 800 and 1100 °C, with an oxygen excess of 8 - 10 %, which allows for the complete destruction of PCDD/F. Provided that the off-gases are rapidly cooled below 200 to 250 °C, the risk of PCDD/F formation by 'de novo' synthesis is considerably reduced. In general the continuous feeding has the advantage of avoiding uncontrolled emissions of pollutants that are typical with conventional charge by buckets.

Nevertheless, experiences from at least one continuous charging installation showed a high emissions concentrations for PCDD/F exceeding the value of 0.1 ng I-TEQ/Nm³ significantly [496]. That means that additional measures for reducing PCDD/F to ensure emissions concentrations for PCDD/F below 0.1 ng I-TEQ/Nm³ may be necessary also for continuous charging techniques from case to case. Table 8.14 shows the measurement results of a continuous charging installation for different pollutants.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>1999 - 2002</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Off-gas flow</td>
<td>Nm³/h</td>
<td>800000</td>
<td>800000</td>
</tr>
<tr>
<td>CO</td>
<td>mg/Nm³</td>
<td>250 - 400</td>
<td>142 - 177</td>
</tr>
<tr>
<td>NOₓ</td>
<td>mg/Nm³</td>
<td>20 - 50</td>
<td>5 - 10</td>
</tr>
<tr>
<td>PCDD/F</td>
<td>ng I-TEQ/Nm³</td>
<td>0.05 - 0.15</td>
<td>0.1 - 0.2</td>
</tr>
<tr>
<td>Dust (PM₁₀)</td>
<td>mg/Nm³</td>
<td>0.40 - 0.86</td>
<td></td>
</tr>
</tbody>
</table>

Table 8.14: Continuous pollution measurement from one installation for two operating periods [490]

**Cross-media effects**

Scrap preheating looks very attractive from the point of view of energy management. But the scrap preheating may lead to an important generation of organic pollutants due to the possible presence of organic substances on the scrap. Due to the process-specific low temperatures in the scrap column, the organic constituents adhering to the scrap, such as oils and greases, are only evaporated off but not thermally destroyed; one result here being the formation of volatile organic chlorinated hydrocarbon compounds and the precursor of PCDD/F [367].

Due to the aforementioned high emissions of aromatic organohalogen compounds such as polychlorinated dibenzo-p-dioxins and -furans (PCDD/F), chlorobenzenes, polychlorinated biphenyls (PCB) as well as polycyclic aromatic hydrocarbons (PAH) and other partial combustion products may occur from scrap contaminated with paints, plastics, lubricants or other organic compounds. In one EAF with conventional scrab preheating, up to 9.2 ng I-TEQ/Nm³ have been measured.

These emissions can be minimised by post-combustion of the off-gas in a specially designed post combustion chamber equipped with fossil fuel burners. Due to the high temperature to be reached in order to destroy the POPs (Persistent Organic Pollutants) that are present in the off-gas, the amount of energy required is considerable and of the order of magnitude of the energy savings provided by scrap preheating.

New scrap preheating technologies with continuous charging have solved these drawbacks to a certain extent and have optimised the process in order to minimise the energy consumption for the thermal treatment and simultaneously achieve low emission values [373] [450] 490].
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Operational data
Since its start-up, no Consteel furnace has been stopped. The following table shows some operational data for Consteel and Fuchs-Coss EAF furnaces.

<table>
<thead>
<tr>
<th>Features</th>
<th>Unit</th>
<th>Consteel Plant 1</th>
<th>Consteel Plant 2</th>
<th>Consteel Plant 3</th>
<th>Consteel Plant 4</th>
<th>Fuchs-Coss Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Furnace type</td>
<td></td>
<td>AC</td>
<td>DC</td>
<td>AC</td>
<td>AC</td>
<td></td>
</tr>
<tr>
<td>Heat size</td>
<td>t LS</td>
<td>39</td>
<td>109</td>
<td>187</td>
<td>73</td>
<td>120</td>
</tr>
<tr>
<td>Transformer power</td>
<td>MVA</td>
<td>35</td>
<td>90</td>
<td>130</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>Metallic charge mix</td>
<td></td>
<td>100 % scrap</td>
<td>100 % scrap</td>
<td>80 % scrap</td>
<td>80 % scrap</td>
<td>100 % scrap</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>15 % pig iron</td>
<td>20 % scrap</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20 % pig iron</td>
<td></td>
</tr>
<tr>
<td>Tapping temperature</td>
<td>°C</td>
<td>1635</td>
<td>1650</td>
<td>1630</td>
<td>1600</td>
<td>n/a</td>
</tr>
<tr>
<td>Average power</td>
<td>MW</td>
<td>28</td>
<td>60</td>
<td>82</td>
<td>37</td>
<td>33</td>
</tr>
<tr>
<td>Additives</td>
<td>kg/t LS</td>
<td>47</td>
<td>40</td>
<td>32</td>
<td>41</td>
<td>60</td>
</tr>
<tr>
<td>Power on time</td>
<td>min</td>
<td>32</td>
<td>41</td>
<td>50</td>
<td>43</td>
<td>35</td>
</tr>
<tr>
<td>Power off time</td>
<td>min</td>
<td>10.7</td>
<td>8</td>
<td>15</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Electrical consumption</td>
<td>kWh/t LS</td>
<td>354</td>
<td>343</td>
<td>365</td>
<td>362</td>
<td>265</td>
</tr>
<tr>
<td>Oxygen consumption</td>
<td>Nm³/t LS</td>
<td>37.4</td>
<td>35.5</td>
<td>33</td>
<td>34</td>
<td>35</td>
</tr>
<tr>
<td>Electrode consumption</td>
<td>Kg/t LS</td>
<td>1.6</td>
<td>0.8</td>
<td>0.9</td>
<td>1.4</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Table 8.15 Process data from selected Consteel and Fuchs-COSS EAF furnaces

Applicability
The Consteel process is applicable both to new and existing plants. In existing plants the local conditions related to the space availability and limitations for the conveyor installation and the scrapyard positioning have to be considered. Scrap preheating is also dependant on the available scrap types and restricts the scrap types that can be used.

Economics
With finger shaft EAFs, tap-to-tap times of about 35 minutes are achieved which is about 10 - 15 minutes shorter compared to EAF without efficient scrap preheating. This allows for a very short pay-back time which is in the order of one year.

For a new EAFs, the Consteel implementation would usually represents about 10 - 15 % of the total investment. The costs for revamping a EAF producing 1 million tonnes per year are about EUR 1 million; it varies a lot according to the size of the EAF and the necessary modifications.

The overall cost savings achievable with the Consteel process for a melt shop of one million tonnes per year productivity is around EUR 9.5 per tonne LS.

Driving force for implementation
The main driving force is to increase productivity, to reach a higher charge yield and lower conversion costs combined with lower environmental impact. In some cases, scrap preheating by means of a finger shaft furnace has been installed in combination with advanced off-gas treatment.
Another main driver is the reduction in electrical disturbances in plants where the electrical power supply network is an issue.

**Example plants**
- EAF with a finger shaft: Gerlafingen Stahl AG, Gerlafingen, Switzerland (this furnace has been retrofitted with a finger shaft)
- Twin-shell furnace with integrated preheating in a shaft: ASW, Montereau, France
- Nervacero, Spain
- Consteel at TSW, Trier, Germany
- Consteel at Celsa-Mo i Rana, Norway
- Consteel ORI Martin at Arvedi in Cremona, Italy
- Consteel Sovel Hellenic Steel Company, Greece.

In January 2009 31 shaft furnaces and 35 continuously operating Consteel systems have been installed worldwide, including those installations under construction.

Figure 8.16 shows the numbers of installed Shaft, Consteel and ESC furnaces between 1988 and 2009.

![Figure 8.16: Number of preheating installations at EAF](image)

**Reference literature**
[54] [94] [125] [162] [208] [287] [367] [373] [388] [417] [422] [450] [490]

### 8.3.3 Reducing of dust emissions from slag processing

**Description**
If the slag is collected in a slag pot at the EAF, it needs to be poured into outside slag basins for solidification. The cooling of the slag may be enhanced by water sprays resulting in fumes.

If the slag is poured onto the floor, it is pre-crushed after solidification using excavators or shovel loaders and subsequently brought to an outside storage area.
After a certain period of time the slag is processed in crushing and screening devices in order to give it the desired consistency for separating metals from the slag and for its further use in construction. Slag breaking and metal recovery can create dust emissions.

In order to minimise dust emissions, the crushing and screening devices can be enclosed and extracted. The emission from crushing and screening are subsequently cleaned by means of bag filter. The conveyor belts should be enclosed; transfer points can be wetted. If the processed slag is stored, heaps should be wetted. During loading of broken slag, water fogs can be used to minimise dust emissions [373] [417] [422] [489].

**Achieved environmental benefits**
With this technique a residual dust concentration of <20 mg/m³ can be reached.

**Cross-media effects**
No data submitted.

**Operational data**
No data submitted.

**Applicability**
The technique is applicable to both new and existing plants.

**Economics**
No data submitted.

**Driving force for implementation**
The main driving force is to reduce particulate emissions.

**Example plants**
BSW, Kehl, Germany
Georgsmarienhütte, Osnabrück, Germany
Lech-Stahlwerke (LSW), Metingen, Germany

**Reference literature**
[489]

### 8.3.4 Advanced emission collection systems

**Description**
The primary and secondary emissions to air are of high relevance (see Section 8.2.2.1). Both primary and secondary emissions should be collected as much as possible, preferably at the source of origin and then abated. The combination of 4th hole (in case of three electrodes e.g. AC) or 2nd hole (in the case of one electrode, e.g. DC), the direct extraction with canopy hood systems (or furnace enclosures) or total building evacuation are the preferred systems.

With a 4th or 2nd hole (see Figure 8.7), the primary emissions generated during the melting and refining periods can be collected almost completely. This type of direct extraction technology is state of the art in modern EAF steelmaking for the collection of primary emissions. It can also be applied to secondary metallurgy vessels.
In a canopy hood system (see Figure 8.7), one or more hoods over the furnace indirectly collect fumes escaping from the furnace during charging, melting, slag-off, and tapping steps (up to 90% of primary emissions and also secondary emissions [22]). Hood systems are commonly used within the electric EAF industry. Combined with direct extraction systems, the collection efficiency of primary emissions and also secondary emissions improves by up to 98%. Hoods are also installed to collect emissions arising at secondary metallurgy vessels, hoppers and conveyor belts.

Furnace enclosures, also called doghouses (see Figure 8.7), usually encapsulate the furnace, its swinging roof, and also leave some working space in front of the furnace door. Typically, waste gases are extracted near the top of one of the walls of the enclosure, and make-up air enters through openings in the operating floor [36]. More complex handling steps, causing time losses and possibly higher investments (e.g. need for additional door opening and closing mechanisms and procedures in order to charge and empty the furnace) are drawbacks of this type of collection technology. Collection rates of doghouses are similar or usually slightly higher than those of hood-complementary hole combinations. A positive effect of furnace enclosures is a reduction in the noise level if they are constructed in a suitable manner. Noise abatement at an EAF plant by sound protecting enclosures can reduce the average sound pressure level between 10 and 20 dB(A) [79]. Furnace enclosures may also be applied at secondary metallurgy processes [22] but a treatment of the shop walls is needed to eliminate reverberation.

Another way to collect secondary emissions from the furnace and other installations, is a complete enclosure of all plants in one sealed building. Retrofitting includes

The erection of such buildings and the additionally required large dedusting installations in order to achieve complete dedusting impose considerable costs on the operators. For this reason, the costs and benefits need to be weighed carefully for every special plant before this option is considered. A positive effect of this measure is a reduction in the noise level penetrating the outside. Usually, the pressure in the enclosing building is below atmospheric pressure to avoid the escape of fumes through occasional door openings.

For a high collection rate, a sufficient extraction volume has to be ensured. Depending on the collection system, exhausting volumes are often in the range of 600000 - 1.2 million m³/h.

Achieved environmental benefits

The combination of direct fume extraction and a hood system is often used. This combination achieves a collection of about 98% of the primary emissions. In addition, a significant share of charging and tapping (secondary) emissions can be collected, too, though this depends on the type and the number of hoods [22]. A combination of a direct extraction device and a furnace enclosure can even achieve collection rates from 97% - 100% of the total dust emissions [57]. Total building evacuation also achieves practically 100% emission collection.

In one case, the emission collection system was newly designed and optimised. This included the increase of the exhaust gas volume from 630000 to 1250000 Nm³/h, a new lining of the roofs of the steelwork and the melt shop, renewal of the primary waste gas duct from the EAF and the addition of a bag filter, 3 fans and a new stack.

A comparison of dust emissions from the steelwork stacks before and after retrofitting is shown in Table 8.16.
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<table>
<thead>
<tr>
<th>Parameter</th>
<th>Measured values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust emissions from the steelwork stacks, daily</td>
<td></td>
</tr>
<tr>
<td>average values until August 2006</td>
<td>4.5 - 5 mg/m³</td>
</tr>
<tr>
<td></td>
<td>3.25 kg/h</td>
</tr>
<tr>
<td>Dust emissions from the steelwork stacks, daily</td>
<td></td>
</tr>
<tr>
<td>average values from September 2006</td>
<td>0.35 mg/m³</td>
</tr>
<tr>
<td></td>
<td>0.44 kg/h</td>
</tr>
<tr>
<td>Achieved improvement by the retrofitting</td>
<td>- 93 %</td>
</tr>
<tr>
<td></td>
<td>- 87 %</td>
</tr>
</tbody>
</table>

| Table 8.16: Comparison of dust emissions from the steelwork stacks |

This measure has also improved the working environment significantly and reduced the diffuse dust emissions via roof fans from 6.35 mg/m³ to 2.5 mg/m³ which corresponds to a reduction of approx. 60 % [421].

**Cross-media effects**
The emission collection systems need energy, especially the fans.

**Operational data**
No data submitted.

**Applicability**
This technique is applicable both to new and existing plants.

**Economics**
No data submitted.

**Driving force for implementation**
The main driving force is to reduce particulate emissions.

**Example plants**
Many plants in Europe have a combination of direct off-gas extraction and hoods.

The following German plants are equipped with only doghouses or with a combination of doghouse and direct hole extraction: Benteler AG, Lingen, Germany; Krupp Thyssen Nirosta, Bochum, Germany; Thyssen Krupp Nirosta, Krefeld, Germany; Mannesmannrohr GmbH, Bous/Saar, Germany; TSW, Trier, Germany; Stahlwerke Thüringen GmbH, Unterwellenborn, Germany; Elbe Stahlwerke Feralpi, Riesa, Germany.

Total building evacuation: ArcelorMittal, Schifflange; Differdange and Belval, all in Luxembourg.

**Reference literature**
[16] [22] [57] [208] [366] [373]

### 8.3.5 Abatement techniques for primary and secondary emissions to air from electric arc furnaces

#### 8.3.5.1 Dust abatement by means of a bag filter and an electrostatic precipitator

**Description**
By far the most common dust abatement technique in electric arc furnace (EAF) operations is the bag filter (also called bag house) which is particularly suited to the type of dust generated in the EAF. Bag filters are very effective in capturing all particle-bound pollutants, e.g. heavy metals as well as chlororganic pollutants such as PCDD/Fs particularly if adsorption agents are used (see Section 8.3.5.3).
The off-gas flow from primary and secondary exhausting depends on the collection system. Exhausting volumes are often in the range of 600000 - 1.4 million m$^3$/h. For large bag filters as generally required in EAF steelmaking plants, a design with tubular fabric bags of around 6 m long and about 200 mm in diameter is chosen. A very important design parameter for bag filters is the air-to-cloth ratio which is, in the case of the EAF process, often between 1 and 1.3 (m$^3$/min/m$^2$).

A typical filter material for the application in EAF is a spark-resistant polyester or a PTFE-coated needle felt. However, an important issue for a sound bag filter operation is to prevent incandescent particles from reaching the filtering medium and thus burning holes into it. For this purpose, spark arresting devices, such as cyclones are often installed in the raw gas ducts.

Cleaning of the fabric, i.e. removing the dust periodically that is accumulated on the fabric surface is performed either by mechanical shaking or with a continuous, fully automated online pulse jet (compressed air) cleaning system which means that the process flow continues during cleaning. The dust cakes falling from the bags are collected in dustbins below the bags and are carried outside the filter by a conveying system.

In some rare EAF plants, ESPs are used but with a slightly less performance abatement efficiency.

**Achieved environmental benefits**

Figure 8.17 shows the dust emissions profile from one EAF plant for three years (2004 - 2006). The data show that with well designed and well operated bag filters, annual dust emission values of 1 mg/Nm$^3$ are achievable. A well designed and well maintained bag filter has a residual emission of less than 5 mg/Nm$^3$ (daily average).

![Graph showing dust emissions profile](image)

**Figure 8.17:** Daily average dust emissions from an EAF plant over three years [366]

The detailed results from the continuous dust measurements in the aforementioned three EAF plants over three years are shown in the Table 8.17.
Table 8.17: Daily average dust emissions from three EAF installations (2004 - 2006) [366]

Table 8.18 shows the results from seven dust and heavy metals measurements carried out in Germany and Austria.

Table 8.18: Residual dust and heavy metals concentrations from seven EAF installations after abatement [407] [421] [424]

Cross-media effects
In 2004 at the Böhler Edelstahl plant in Kapfenberg, Austria, about 3900 tonnes of dust were separated from the waste gas of the EAF and the AOD converter. The dust is disposed of at the internal landfill. Trials for re-using the dust in the EAF were not successful, mainly due to high costs.

About 6.9 tonnes of dust per year arise from waste gas treatment of the EAF at the Marienhütte, Graz, Austria. The dust with a zinc content of about 38 % is treated externally in order to recover the zinc.

Bag filters capture essentially particulate matter including all of the heavy metals that are present as particulates at the filtering temperature as well as the organic substances that are adsorbed to the particulate matters, among them PCDDs and PCDFs. Bag filters play an essential role in PCDD/F abatement as described in Sections 8.3.5.2 and 8.3.5.3.

Operational data
Higher emissions may occur when, for instance, parts of the bag filters are destroyed. This can be avoided by good operation which consists of continuous monitoring of dust emissions and consequent replacement of all destroyed bag filters. Good design consists of well dimensioned bag chambers thus minimising mechanical wear, spark arrestors and temperature control and the detection of excessive dust accumulations.
There are different types of fabric used for the manufacturing of filter bags. Some allow maximum temperatures of 125 – 130 °C, others may be used at temperatures up to 250 °C. The fabrics suited for low temperature filtration tend to have higher abatement efficiencies. The off-gas flow should be cooled down to the suitable temperature. This is often done by mixing the primary and secondary flows. If the resulting temperature is still too high, and in case of separate filtering of the primary and the secondary flow, additional cooling devices need to be installed in the primary off-gas flow.

Electricity consumption is approximately 20 kWh/t liquid steel for bag filters and whole building evacuation.

**Applicability**

Waste gas treatment with a bag filter is applicable for new and existing plants.

**Economics**

No data submitted.

**Driving force for implementation**

No data submitted.

**Example plants**

Most European EAF steelmaking plants use fabric filters for dust abatement.

Examples of the aforementioned technique are given in Table 8.19.

<table>
<thead>
<tr>
<th>Example plants</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luxembourg</td>
<td>Three EAFs plants</td>
</tr>
<tr>
<td>Böhlen Edelstahl,</td>
<td>The EAF plant produces high alloyed steel with a total capacity of 180000 tonnes/yr.</td>
</tr>
<tr>
<td>Kapfenberg, Austria</td>
<td>The steelwork includes an EAF (50 t/charge), ladle metallurgy with an AOD converter and a special steelwork with vacuum treatment and remelting units. For primary dedusting, main emission sources (EAF and AOD converter) are enclosed. The waste gas extracted from both emission sources is treated by a bag filter. Waste gas volume is about 900000 Nm³/h</td>
</tr>
<tr>
<td>Marienhütte, Graz, Austria</td>
<td>EAF plant producing about 365000 t/yr carbon steel, which is processed into steel bags and reinforcing steel. The EAF has a capacity of 35 t. During the melting process primary emissions are extracted from the 4th hole of the EAF. Secondary emissions are collected by a roof hood extraction. Primary and secondary emissions are conducted through a mixing chamber and treated together in a bag house filter. Total waste gas volume is about 1 million Nm³/h</td>
</tr>
<tr>
<td>Elbe Stahlwerke</td>
<td>The off-gas volume is about 1250000 Nm³/h; the filter area is 19270 m²</td>
</tr>
<tr>
<td>Feralpi, Riesa, Germany</td>
<td></td>
</tr>
<tr>
<td>BSW, Kehl, Germany</td>
<td>The off-gas volume is approx. 1800000 Nm³/h; the filter area is 38000 m²</td>
</tr>
<tr>
<td>Ovako Imatra, Finland</td>
<td>The off-gas volume is approx. 620000 Nm³/h; the filter area is 9400 m². Filter material is PTFE coated needle felt, filter cleaning with a pulse-jet system, and continuous monitoring by two systems: the tribometric measuring system by SINTROL and the optical measuring system SICK</td>
</tr>
</tbody>
</table>

Table 8.19: Example plants using dust abatement techniques
[208] [366] [360] [421] [424]

**Reference literature**

[208] [366] [367] [375] [388] [407] [421] [424] [471]
8.3.5.2 Reduction of PCDD/F by means of post-combustion in combination with bag filter

Description
Post-combustion in a combustion chamber aims primarily at the full combustion of CO and H\textsubscript{2} remaining in the off-gas in order to avoid uncontrollable reactions in the gas cleaning equipment.

Secondarily, this post-combustion, when it is well optimised (i.e. when the temperature and the residual time are adequate) reduces the emission of organic and organochlorine compounds such as PAH, PCB or PCDD/F. Post-combustion with the additional aim of minimising organic micropollutants needs an adequate retention time, turbulence and temperature (three Ts).

The heat produced by this combustion is generally not recovered unless recovery from cooling water is possible.

To avoid the 'de novo' synthesis of PCDD/F, it is essential to have a rapid cooling (quenching) of the fumes as soon as possible after post-combustion to a temperature of below 250 °C at which all risk of 'de novo' synthesis is excluded. In some cases, this might be obtained by dilution of the secondary circuit; mostly, however this cooling is obtained by water injection in a quenching tower. Figure 8.18 shows the schematic of an EAF applying post-combustion and subsequent quenching of the off-gas.

![Diagram of EAF with post-combustion and quenching](image)

Figure 8.18: Post-combustion of the primary off-gas within the given duct system from an EAF with subsequent rapid cooling

[16]

Achieved environmental benefits
With a proper post-combustion followed by a rapid cooling (by dilution with air or water quenching) emission concentration of PCDD/F of lower than <0.1 - 0.5 ng I-TEQ/Nm\textsuperscript{3} can be achieved (see Figure 8.19 and Table 8.20 and Table 8.21).
Table 8.19 shows the results from seven dust and heavy metals measurements put through in Germany and Austria.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Bag filter</th>
<th>Eletrostatic precipitator</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust</td>
<td>0.5 - 5</td>
<td>1.8</td>
<td>mg/Nm$^3$</td>
</tr>
<tr>
<td>PAH</td>
<td>&lt;0.00001</td>
<td>&lt;0.001</td>
<td>mg/Nm$^3$</td>
</tr>
<tr>
<td>PCDD/F</td>
<td>0.0015 - 0.1 $^2$</td>
<td>&lt;0.001</td>
<td>ng/Nm$^3$</td>
</tr>
</tbody>
</table>

Notes: Values are annual averages and relate to the central dedusting system. PAH contains benzo(a)pyrene and dibenzo-(a,h)-anthracene

1) ESP applied in stainless steel production

2) Upper end of the range relates to measurements carried out in 1997

Table 8.20: Emission concentrations of air emissions after abatement
[407] [421] [424]
### Table 8.21: Performance of post-combustion at four German EAF

<table>
<thead>
<tr>
<th>PLANT</th>
<th>EAF 1</th>
<th>EAF 2</th>
<th>EAF 3</th>
<th>EAF 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Features</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tapping weight (t)</td>
<td>105</td>
<td>138</td>
<td>85/85</td>
<td>140</td>
</tr>
<tr>
<td>Power supply (MVA)</td>
<td>105</td>
<td>96</td>
<td>57/68</td>
<td>105</td>
</tr>
<tr>
<td>Collection of emissions</td>
<td>4th hole, hood</td>
<td>4th hole, hood</td>
<td>4th hole, hood</td>
<td>4th hole, furnace encapsulation</td>
</tr>
<tr>
<td>Post-ombustion (PC)</td>
<td>PC chamber (air)</td>
<td>PC in duct</td>
<td>PC chamber (air)</td>
<td>PC in duct</td>
</tr>
<tr>
<td>Waste gas cooling</td>
<td>Injection of water</td>
<td>Water conditioning of waste gas</td>
<td>Spray cooling system (quenching)</td>
<td>Cooling by air-cooled heat exchanger</td>
</tr>
<tr>
<td>Off-gas cleaning system</td>
<td>Bag filter</td>
<td>Electrostatic precipitator</td>
<td>Bag filter (1 for both)</td>
<td>Two bag filters for primary and secondary dedusting</td>
</tr>
<tr>
<td><strong>Number of measurements at the plant</strong></td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td><strong>Gas concentrations:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dust in crude gas (prim.)</td>
<td>3398</td>
<td>14246</td>
<td>4200</td>
<td>12500</td>
</tr>
<tr>
<td>Dust in crude gas (sec.)</td>
<td>148</td>
<td>273</td>
<td>p and s together</td>
<td></td>
</tr>
<tr>
<td>Dust in clean gas (prim.)</td>
<td>0.76</td>
<td>1.05</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Dust in clean gas (sec.)</td>
<td>average</td>
<td>average</td>
<td>average</td>
<td>average</td>
</tr>
<tr>
<td>PCDD/F (prim.)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PCDD/F (sec.)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PCDD/F (Mix, prim. and sec.)</td>
<td>0.016</td>
<td>0.021</td>
<td>0.01</td>
<td>0.02</td>
</tr>
</tbody>
</table>

1. crude and clean gas dust concentrations in mg/Nm³, PCDD/F concentration in ng I-TEQ/Nm³
2. average of two measurement spots
- not relevant or no information available

(prim.): concentrations after dedusting device for primary off-gases
(sec.): concentrations after dedusting device for secondary off-gases
Cross-media effects
Post-combustion with additional burners consumes considerable quantities of energy (in the order of 30 kWh/t). Since the hot off-gases need to be quenched to prevent 'de novo' synthesis of PCDD/Fs, the energy cannot be recovered.

Operational data
The water consumption for quenching can be up to 40 tonnes per hour.

The thermal combustion before quenching can be obtained with natural gas burners in post-combustion chambers.

Sometimes a lack of reliability of the technique was observed. The two main reasons for this are:

- insufficient temperature level reached in the post-combustion chamber during the first few minutes of the EAF melting process, exactly the time when probably the highest load of organic pollution is carried from the furnace
- the distance between the post-combustion chamber and the quenching tower, in this specific case due to retrofitting situation, was long and thus there was a permanent potential for the 'de novo' synthesis. A quenching system right next to the post-combustion chamber would most likely have given much better results.

Applicability
The post-combustion unit at BSW, Kehl, Germany are operated without significant problems. In principle post-combustion can be applied both to new and exiting plants but in existing ones the local circumstances and possibilities (like available space, given off-gas duct system etc.) have to be checked on a plant by plant basis.

Economics
Investment costs for a quenching tower were about EUR 1.2 millions in 1997. More data about economics are not available. This represents a higher investment compared to an adsorption process (see Section 8.3.5.3)

Driving force for implementation
The main driving force for the implementation of post-combustion and subsequent rapid cooling are the environmental and health concerns for reducing PCDD/F emissions.

Example plants
BSW, Kehl, Germany; Gerlafingen Stahl AG (Swiss steel), Gerlafingen, Switzerland; ArcelorMittal, Differdange and Esch-Belval, both in Luxembourg.

Reference literature
[68] [73] [167] [366] [367] [373] [375]

8.3.5.3 Reduction of PCDD/F by means of additives in combination with bag filters

Description
In order to reduce persistant organic pollutants, especially PCDD/F, in the total off-gas (primary and secondary emissions), adsorbents (eg. activated carbon, pulverised activated lignite or mixtures of these ones with lime) can be dosed to the exhaust duct before the dust abatement device. The necessary amount depends on the type and size of the adsorbent. Usually it is between 20 and 150 mg/Nm³ off-gas. The size of pulverised activated lignite is typically between 0 and 0.4 mm, on average 0.63 μm. Being milled, the average size is about 24 μm which leads to lower dosing rates. Carbonaceous adsorbents used have an average grain size of around 25 μm.
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Adsorption takes place in three steps; first, when the stream of adsorption agent hits the raw gas flow, secondly as the adsorbent-enriched raw gas travels to the filtering device, and thirdly, (especially with the use of bag filters) as the gas phase crosses the adsorbent-enriched dust coating layer on the filter medium [497].

The carbon to which the PCDD/F molecules are adsorbed is separated from the gas phase together with the EAF dust contained in the raw gas in the subsequent bag filters.

Figure 8.20 shows a schematic of an adsorbent injection system.

![Schematic of an adsorbent injection system](image)

**Figure 8.20:** Schematic of an adsorbent injection system

[375]

**Achieved environmental benefits**

Residual PCDD/F emission concentrations of 0.01 - 0.1 ng 1-TEQ/Nm$^3$ are achievable in practice. Some calculations, using the factors given in Section 8.2.2.1.3 show these emissions values to correspond to 0.01 - 0.14 ng WHO-TEQ PCDD/F (including dioxin-like PCBs). The removal efficiency is quite stable and reliable.

Besides PCDD/F adsorption, activated carbon and pulverised activated lignite have shown a high efficiency of separation of heavy metals and certain efficiency in removing mercury from the gas phase. Table 8.22 shows the results of some measurements with and without injection of pulverised activated standard and supermilled lignite.
Table 8.22: PCDD/F reduction as a result of pulverised activated lignite (HOK) injection.

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>750</td>
<td>850</td>
<td>770</td>
<td>690</td>
<td>840</td>
<td>1250</td>
</tr>
<tr>
<td>100</td>
<td>40</td>
<td>50</td>
<td>15</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1)</td>
</tr>
<tr>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td>2)</td>
<td></td>
</tr>
</tbody>
</table>

1) Standard quality lignite; particulate size 63 μm (300 m²/g)
2) Supermilled activated lignite; particulate size 24 μm (1200 m²/g); considered to have a high pyrophoric index.

Table 8.23 shows the results of the dioxin measurements according to the progress after gradual retrofitting and optimisation of the abatement system of an EAF plant by installation of a second injection system for activated coal in the collection ducts prior to the bag filter. The volume of the exhausted waste gas is approximately 1250000 Nm³/h.

<table>
<thead>
<tr>
<th>After start-up of first injection system for activated coal.</th>
<th>PCDD/F Emission concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average concentration from three measurements in September, October and November 2006</td>
<td>0.04 ng TEQ/Nm³</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>After start-up of second injection system for activated coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement 06 - 08 March 2007</td>
</tr>
</tbody>
</table>

Table 8.23: Progress in PCDD/F abatement after installation of a second carbon injection system

Investigations show that the persistent organic pollutants, such as PCDD/F, adsorbed on activated lignite are bonded irreversibly due to the high bonding forces and are reliably destroyed or catalytically decomposed during the thermal treatment of dust.

Cross-media effects
The amount of energy for pulverised activated lignite dosage is not considerable. The filter dust contains the lignite coke powder and slightly increased PCDD/F amounts but this does not interfere with dust treatments for the recovery of non-ferrous metals.

Operational data
Attention should be paid to the final carbon content of the dust mixture abated at the bag filter. In order to avoid the risk of ignition, the carbon content of the EAF dust should stay below 4 %.

The use of activated carbon or lignite differs in grain size and in the effective adsorption surface area and consequently in the amount of injection required. Activated coal has the highest specific free surface and shows a very good adsorptive effect. Activated lignite coke is a more economic alternative than activated coke and the supermilled lignite with diameters of 0.024 mm also shows a very good adsorptive efficiency and leads to half the dosing rates necessary compared to standard lignite coke [367]. Sometime inerts have to be added to the injected carbon based materials to avoid ignition. Table 8.24 shows the characteristics of different adsorbents and absorbent materials.
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<table>
<thead>
<tr>
<th>Adsorption and absorption materials</th>
<th>Grain size (mm)</th>
<th>Surface area BET 1) (m²/g)</th>
<th>Precipitative pollutants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard powdered activated lignite coke</td>
<td>Carbon</td>
<td>0.063</td>
<td>300 - 400</td>
</tr>
<tr>
<td>Super-milled powdered activated lignite coke</td>
<td>Carbon</td>
<td>0.024</td>
<td>1200</td>
</tr>
<tr>
<td>Powdered activated (charcoal) carbon</td>
<td>Carbon</td>
<td>0.025</td>
<td>500 - 1600</td>
</tr>
<tr>
<td>Zeolite</td>
<td>Z</td>
<td>4 - 90</td>
<td></td>
</tr>
</tbody>
</table>

1) BET - abbreviation created from the initials of the family names of the people who developed this theory as a rule for the physical adsorption of gas molecules on a solid surface.

### Table 8.24: Characteristics of different adsorbent and absorption materials [498]

Comprehensive investigations have shown that only a very short contact time is required to have PCDD/F adsorbed on activated lignite coke. However, the separation efficiency depends on the probability of contact between the sorbent and the pollutant molecule. The distribution of the adsorbent in the waste gas flow plays a major role here. An important precondition for achieving optimum separation efficiency is the presence of a homogeneous and, at the same time, turbulent mixture already at the injection point where the first pollutant separation step takes place. A significant factor in selecting the adsorbents is an optimum pore radii distribution for pollutant molecule adsorption.

Provisions have to be taken to avoid sparks from reaching the bag filters in order to prevent possible glow fires, since the increased carbon content of the separated dust may increase its ignitability. The explosion risk has been assessed to be low. Fire and explosion protection is achieved through a combination of prevention measures (e.g. adsorbent inertisation, avoid entry of sparks, limit the amount of adsorbent in the filter dust). Some techniques applied are spark detectors, nitrogen flooding systems, temperature surveillance in the bag house, detection of dust accumulations in the bag house collecting bins. Spontaneous ignition reactions of the filter dust are reliably prevented through consistent avoidance of large volume deposits in the plant section subjected to hot gas flows.

The low PCDD/F emissions in the clean gas attainable with dosing rates 25 - 35 mg/Nm³ illustrate the high adsorptive effect of lignite coke adsorber.

### Applicability
This technique is applicable to both new and existing plants.

### Economics
Investment for the total off-gas flow (primary and secondary off-gases) from an EAF plant producing about 1 Mt steel/yr is about EUR 500000.

### Driving force for implementation
The main driving forces for the implementation of this technique reducing PCDD/F are environmental and health concerns and, in the case of Feralpi in Riesa, Germany, the increase in production capacity.

### Example plants
The technique has been implemented in several European EAF plants since 1997.

ArcelorMittal, Esch-Belval, Differdange and Schiffflange, all in Luxembourg; Swiss Steel, Gerlafingen, Switzerland; Stahlwerk Thüringen, Unterwellenborn, Germany; Elbe Stahlwerke Feralpi, Riesa, Germany; ArcelorMittal, Genk, Belgium.
8.3.6 Treatment of waste water from continuous casting
The techniques for the treatment of waste water from continuous casting are can be considered to be similar to those described in Section 7.3.7.

8.3.7 Closed loop water cooling system
Generally, water is only used in the EAF steelmaking processes in connection with non-contact cooling, and only if a wet scrubbing technique for off-gas cleaning is used. As wet scrubbing is only applied in few cases, this topic is not further investigated in this section. The most relevant use of water considered here is the water used for the cooling of the elements of the furnace. Additionally, some water may be used for the cooling of waste gas or in the secondary metallurgy step. The water needed for the cooling elements amounts to 5 - 12 m³/m²h [16].

Achieved environmental benefits
By application of this technique no discharge of waste water occur.

Cross-media effects
The closed loop system requires additional energy for water pumping and water recooling.

Operational data
No data submitted.

Applicability
This technique can be applied to both new and existing plants.

Economics
No data submitted.

Driving force for implementation
Legal requirements and limited availability of cooling water.

Example plants
Preussag Stahl AG, Peine, Germany; BSW, Kehl, Germany and many other plants in the EU

Almost all EU EAF plants use closed loop water cooling.

Reference literature
[16].

8.3.8 EAF dust processing for the recovery of heavy metals
Description
Depending on the type of steel produced, about 10 - 30 kg/t steel of dust are separated from the off-gas (see Table 8.1).

Separated dusts obtained by the gas cleaning facilities usually contain a significant share of heavy metals. In the case of carbon steel essentially zinc and, to a lesser extent, lead (see Table 8.11) and in the case of stainless steel substantial amounts of chromium and nickel are present apart from zinc.
Processes for zinc recovery and recovery or removal of other heavy metals are suitable options for reclaiming valuable resources, that have already been mined and treated at least once. Pyrometallurgical and hydrometallurgical options exist for the recovery of zinc, in principle. For dusts from the production of carbon/low alloyed steel, different techniques exist and are operated mostly by companies that have close links to the non-ferrous metals production sector.

The recovery processes for EAF dusts might require minimum concentration levels of heavy metals (primarily zinc between 20 and 24 %) to operate economically. In order to increase the zinc content of their dust, some EAF operators recycle part of the generated dust back into the furnace.

**Achieved environmental benefits**
These heavy metals are toxic and might be leachable, necessitating special care for further processing and possibly landfilling of the dusts.

Quantitative recovery of dust and recycling of heavy metals can be achieved. The options described are desirable to different degrees according to their potential to satisfy the aim of prevention and control of environmental pollution. The use of the iron and heavy metal content of the dust is preferred compared to landfilling.

**Cross-media effects**
Recycling of precipitated EAF dusts for zinc enrichment by returning them to the EAF results in certain impacts on the steelmaking process, such as increased energy consumption. Also the method of dust addition to the furnace might affect the performance of the furnace.

In the case of pelletisation of the dust before transport/recycling, additional energy is needed for pelletisation and additional dust emissions may occur.

**Operational data**
No data submitted.

**Applicability**
This technique is applicable to both new and existing plants.

**Economics**
No data submitted.

**Driving force for implementation**
The main driving forces for the implementation of this technique are limited space for landfilling, stringent standards for landfilling and cost aspects like taxes on landfilled wastes.

**Example plants**
There are many plants in the EU that have examples of dust recovery to external plants.

**Reference literature**
[16] [69] [116] [373] [394]
8.3.9 EAF slag processing (carbon and low alloyed steel)

Description
In an EAF operation, some 60 - 263 kg of slag per tonne of steel are generated according to a tight specification, with the aim of performing metallurgical work (see Table 8.1). Solidified EAF slag from carbon steel production can be regarded as an artificial rock, similar to natural rock, consisting of ironoxides (FeO), lime (CaO), siliciumoxide (SiO₂), and other oxides (MgO, Al₂O₃, MnO) (see Table 8.7). EAF slags are characterised by high strength, good weathering resistance, and also high resistance against polishing. They also have properties that make them suitable for use in hydraulic engineering [57]. An important criterion for the use of EAF slag in general is the consistency in volume, which depends on the presence of free lime. Most of the slags from low carbon steel grades are relatively low in free lime (see Table 8.7) and are suitable for various applications like road construction, earthfill and hydraulic engineering. EAF slags from carbon steel production typically meet the specifications of aggregates used in construction. The deciding factors with respect to these uses are environmental acceptability and structural suitability. If the required legal conditions for use in construction are met, the EAF slag has to be crushed, screened, and sized for use. Ferrous slag components are separated via magnetic separators. The treated slag is used in various construction purposes, also dependent on the grain size. Figure 8.21 shows a processing scheme for a German plant for slag preparation. In 1994, about 90 % of EAF slags generated by the production of non-alloyed and medium-alloyed steel in certain EAFs have been used [57].

Slags arising at high grade steel production are only used to a limited extent, so far. Possible uses may be also in the road construction area, after a preperation treatment. At Böhler Edelstahl, Kapfenberg, Austria about 270 kg slag arises per tonne steel produced. EAF slag is not suitable for the construction industry due to the slag composition and properties (the extension of the slag). Most of the slag arises from the EAF (approx. 70 %) and the AOD converter (approx. 30 %). Low amounts also arise from ladles, which can be recycled into the EAF. The EAF and AOD slags are disposed of at the internal landfill site. Recyclability of slag from high alloy steel should either require better assessment or some special treatment depending on the properties of such slag (e.g. expansivity) (see also Section 8.3.10).
Options for using the wide spectrum of secondary metallurgy slags are limited. Grain size and consistency of volume are decisive factors for the use of secondary metallurgy slags. They sometimes may be used in the construction area. But a significant share of the arising slags has to be landfilled, as hardly an option for prevention, reduction, or utilisation exists.

**Achieved environmental benefits**
Slag from EAF that produce carbon or low alloyed steel can be treated with subsequent recycling in road construction.

**Cross-media effects**
The treatment of slags requires energy. Attention has to be paid to alkaline fumes when the slag contains free CaO (see Section 8.2.2.1.6).

**Operational data**
No data submitted.

**Applicability**
This technique is applicable both to new and existing carbon steel plants. Further processing may procure a better suitability for use as a construction material.

**Economics**
No data submitted.
Driving force for implementation
The main driving forces are limited space for landfilling and cost aspects like taxes on landfilled wastes.

Example plants
BSW, Kehl, Germany (treatment of slag with subsequent use for construction purposes)

Georgsmarienhütte GmbH, Georgsmarienhütte, Germany (selling of slag for external preparation with subsequent use in road construction - slag from EAF and secondary metallurgy are mixed); Preussag Stahl AG, Peine, Germany (treatment and use in the construction sector)

ARES, Schifflange; ProfilARBED, Differdange; ProfilARBED, Belval, all in Luxembourg (high performance road surfacing, hydraulic engineering and other applications).

Reference literature
[16] [373] [424]

8.3.10 Treatment of high alloyed EAF slags

Description
Some techniques to consider are:

a) the treatment of liquid slag during tapping with residues which contain Al₂O₃.
b) reduction of the slag during tapping with aluminium
c) optimisation of oxygen blowing and use of some reduction agents
d) prevention of dust formation when emptying slag pots. The highly basic slag from stainless steel plants contains Ca₂S, which undergoes a phase transformation during cooling. The transformation includes a certain increase in volume. Hence, the slag will disintegrate and form dust which, with the help of wind, can be carried to places far outside of the plant area. By quenching the slag, the phase transformation can be suppressed and no dusting will occur. At Sandvik, Sandviken Sweden, the problem with dust formation has been solved by emptying slag pots filled with hot and partially liquid slag into a box surrounded by a retaining dike. 12 m³ of water is then flooded over the slag. The quick drop in temperature together with the binding of small particles with water has proven to eliminate the spreading of dust over large areas. The water itself is recirculated via a basin.
e) techniques for stainless steel slag are:
   - stabilisation of the slag by the use of a stabilising agent to prevent pulverisation
   - control of the slag composition
   - minimisation of the leaching of chromium from slag materials, achieving factor sp higher than 25 to have nearly no Cr in the eluate (Cr below detection limit value of 0.01 mg/l)
   - control of the slag cooling
   - metal separation by crushing, screening, gravity and magnetic separation.

Achieved environmental benefits
This techniques can improve the properties of EAF slags by fixing the chromium in a stable slag lattice and reduce the content of Cr in the slag.

d) The aforementioned practice caused clouds of dust rising from the pot emptying area at the Sandvik plant. The clouds were sometimes caught by the wind and were carried into the town or out over the lake where the dust fell out onto cars or boats.
According to estimations from the early implementation of the technique, the dusting was reduced by more than 90%. Since only the slag from the pot from the teeming ladle is not processed in an optimal way, the reduction in dusting is probably close to 100%.

As a measuring index of the dusting problem, the number of cars or boats around the plant that have to be cleaned can be used. In 2002 80 cars and boats had to be cleaned in total. With the new technique of 2004, no cars or boats were affected by dust from the emptying of slag pots. The results so far have been outstanding in terms of environmental and goodwill aspects.

e) Decreasing dusting at the dumping station and slag yard. Decreasing significantly the amount of wastes. Saving natural resource.

**Cross-media effects**

d) More recirculated water is used.
e) Consumption of stabiliser in the process

**Operational data**

No data submitted.

**Applicability**

d) The described technique can be used whenever the slag is hot enough to not yet have undergone the dust forming phase transformation (i.e. it is used for all slag pots, EAF and AOD, except for the one in which the remaining ladle slag from the continuous caster is emptied). All in all, 90% of the produced slag is processed using the described technique.

Pots with slag from the teeming ladle are put into a watering equipment, i.e. the pots are filled with water and are then left until they are cooled down and the slag is soaking wet.

e) The technique can be applied to both new and existing plants

**Economics**

No data submitted.

**Driving force for implementation**

e) Reduced energy consumption, Reduced environmental impact, Efficient material flow, low bloom stock level and increased productivity.

**Example plants**

d) Sandvik Materials Technology, Sandviken, Sweden

e) Outokumpu Stainless Tornio Works, Finland.

**Reference literature**

[208] [408]

### 8.3.11 Near net shape strip casting

The techniques for continuous near net shape strip casting are considered to be similar to those described in Section 7.3.15.
8.3.12 Techniques to prevent noise emissions

Description
Some constructional and operational techniques applied to prevent noise emissions include the following:

- restrict some noisy activities at night (e.g. scrapyard, scrap transport to the installations)
- to organise special noise reducing information and training for the crane operators
- to continuously monitor of the noise in the scrapyard
- to construct the EAF building in such a way to absorb noise from mechanical shocks resulting from the operation of the furnace
- to construct and install cranes destined to transport the charging baskets to prevent mechanical shocks
- to create special acoustical insulation of the inside walls and roofs to prevent the airborne noise of the EAF building
- to separate the furnace and the outside wall to reduce the structure-borne noise from the EAF building
- to construct physical barriers
- to reduce the free fall height of the scrap in order to reduce noise and dust emissions at the discharge of scrap metal
- to enclose the scrap stock piles
- to continuously scrap feed and melt.

Noise reduction measures at the dedusting system
The new dedusting system had to fulfil high noise reduction requirements. Examples of this technique includes the following:

- installation of fans with noise-insulation
- additional capture of fans in reinforced concrete chambers
- installation of noise absorbing sandwich elements at the new filter house
- exchange of the profiled sheeting of the existing filter house by sandwich elements
- definition of maximum noise levels for the individual plant units.

Additional noise-reducing measures in the context of production increase include the following:

- noise-reducing measures at the existing dust filter
- compensating measures at other plant units, e.g:
  - relocation of the stretcher leveller
  - noise-reducing measures at compressors of the wire rod mill,
  - reduction of noise levels in the rolling mill by installation of new low-noise roll stands.

Achieved environmental benefits
With the techniques described above, values between 37 and 50 dB(A) Leq(1h) can be achieved. Measurements at 150 m from the EAF building are below 34 dB(A) Leq(1h).

With continuous scrap feeding and melting systems such a Consteel, the noise level can be reduced from 110 dB (A) to 90 dB (A).

Cross-media effects
No data submitted.

Operational data
Some examples of insulation parameters used in the EAF building are materials with an $R'_w$ of 56 dB for the walls and 55 dB for the roof (values according to DIN 55210 Part 3).
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**Applicability**
This techniques are applicable to all EAF types of plants.

**Economics**
No data submitted.

**Driving force for implementation**
The driving force for implementation is the prevention of noise emissions in the neighbouring area of the plant. Plants located close to residential homes tend to have implemented techniques to prevent noise.

**Example plants**
Arbed Esch-Belval, Luxembourg
Feralpi, Riesa, Germany.

**Reference literature**
[366] [426] [417] [421] [450] [491]
Chapter 8

8.4 Best available techniques for electric arc furnaces steelmaking and casting

In understanding this section and its contents, the attention of the reader is drawn back to the Preface of this document and in particular the fifth section of the Preface: ‘How to understand and use this document’. The techniques and associated emission and/or consumption levels, or ranges of levels, presented in this section have been assessed through an iterative process involving the following steps:

- identification of the key environmental issues for electric arc furnaces and casting in the iron and steel industry
- examination of the techniques most relevant to address those key issues
- identification of the best environmental performance levels, on the basis of the available data in the European Union and worldwide
- examination of the conditions under which these performance levels were achieved; such as costs, cross-media effects, main driving forces involved in implementation of these techniques
- selection of the best available techniques (BAT) and the associated emission and/or consumption levels for this sector in a general sense all according to Article 2(12) and Annex IV to the Directive.

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

On the basis of this assessment, best available techniques, and as far as possible emission and consumption levels associated with their use, are presented in this section that are considered appropriate to electric arc furnaces and in many cases reflect current performance of some installations within the sector. Where emission or consumption levels ‘associated with best available techniques’ are presented, this is to be understood as meaning that those levels represent the environmental performance that could be anticipated as a result of the application, for electric arc furnaces, of the techniques described, bearing in mind the balance of costs and advantages inherent within the definition of BAT. However, they are neither emission nor consumption limit values and should not be understood as such. In some cases it may be technically possible to achieve better emission or consumption levels but due to the costs involved or cross-media considerations, they are not considered to be appropriate as BAT for electric arc furnaces. However, such levels may be considered to be justified in more specific cases where there are special driving forces.

The emission and consumption levels associated with the use of BAT have to be seen together with any specified reference conditions (e.g. averaging periods).

The concept of ‘levels associated with BAT’ described above is to be distinguished from the term ‘achievable level’ used elsewhere in this document. Where a level is described as ‘achievable’ using a particular technique or combination of techniques, this should be understood to mean that the level may be expected to be achieved over a substantial period of time in a well maintained and operated installation or process using those techniques.

Where available, data concerning costs have been given together with the description of the techniques presented in the previous Section 8.3. These give a rough indication about the magnitude of costs involved. However, the actual cost of applying a technique will depend strongly on the specific situation regarding, for example, taxes, fees, subsidies and the technical characteristics of the installation concerned. It is not possible to evaluate such site-specific factors fully in this document. In the absence of data concerning costs, conclusions on economic viability of techniques are drawn from observations on existing installations.
In this section for **electric arc furnaces**, specific techniques are considered as BAT (including the associated emission and consumption levels). ‘Best Available Techniques’ for a specific installation will usually be the use of one individual technique or a combination of the techniques listed in this section. Additionally, general BAT elements which can apply for the whole sector, mentioned in Section 2.8, have to be considered.

Where techniques identified individually as BAT can be used in combination, the effects of such combinations should be considered when drawing conclusions on BAT based permit conditions for individual cases.

If not otherwise mentioned, the BAT associated emission levels (BAT-AELs) given in this section are expressed on an annual average basis under standard conditions.

The BAT (including the associated emission and consumption levels) given in this chapter are ‘BAT in a general sense’ (i.e. considered to be appropriate to the sector as a whole). It is intended that they are a reference point against which to judge the current performance of an existing installation or to judge a proposal for a new installation. In this way, they will assist in the determination of appropriate ‘BAT-based’ conditions for the installation or in the establishment of general binding rules under Article 9(8) of the IPPC Directive. It is foreseen that new installations can be designed to perform at or even better than the BAT levels presented in this section. It is also considered that existing installations could move towards the BAT levels presented in this section or do better, subject to the technical and economic applicability of the techniques in each case.

While the BAT reference documents do not set legally binding standards, they are meant to give information for the guidance of industry, Member States and the public on achievable emission and consumption levels when using specified techniques. The appropriate permit conditions for any specific case will need to be determined taking into account the objectives of the IPPC Directive and the local considerations.

### Air

1. **BAT for the materials storage, handling and transport (see Sections 2.6.3 and 2.6.5)**

   *Electric arc furnace processes - primary and secondary dedusting (including charging, melting, tapping, ladle furnace, secondary metallurgy, casting)*

2. **BAT for the EAF process** is to achieve an efficient extraction of dust emissions and subsequent off-gas cleaning from all emission sources by applying the following techniques individually or in combination (see Sections 8.3.4 and 8.3.5.1):
   - I. a combination of direct off-gas extraction (4th or 2nd hole) and hood systems
   - II. direct gas extraction and doghouse or elephant house systems
   - III. total building evacuation
   - IV. to use well designed bag filter or any other technique with the same removal efficiency

   The **BAT-AEL** is an extraction efficiency of >98%.

   The **BAT-AEL** is <5 mg dust/Nm³, determined as a daily mean value.

   *Separate secondary dedusting (i.e. in case of high alloy steels, stainless steels including secondary metallurgy and continuous casting)*

3. **BAT for the collection of secondary dust emissions for these processes** is an efficient extraction of emissions with subsequent off-gas cleaning by means of bag filter or any other technique with the same removal efficiency (see Sections 8.3.4 and 8.3.5.1).

   The **BAT-AEL** for these operations is 10 mg/Nm³, determined as a daily mean value.
4. BAT for the EAF process is to prevent mercury emissions by avoidance of raw materials and auxiliaries which contains mercury as far as possible (see Section 2.6.3).

5. BAT is to monitor Hg (has to be further defined concerning frequency)

6. BAT for the EAF process is to prevent and reduce PCDD/F and PCB by applying the following techniques individually or in combination (see Sections 8.3.5.2 and 8.3.5.3) in conjunction with an appropriate dust removal (see Section 8.3.5.1):
   I. avoidance raw materials which contain PCDD/F and PCB or precursors as far as possible
   II. appropriate post combustion
   III. appropriate rapid quenching
   IV. injection of adequate adsorption agents into the duct before dedusting

The BAT-AEL for PCDD/F is 0.1 ng I-TEQ/Nm³. This range is based on a 6 - 8 hours random sample with steady state conditions.

7. BAT for on-site slag processing is to reduce dust emissions by applying the following techniques individually or in combination (see Section 8.3.3):
   I. Efficient extraction of dust emissions from the slag crusher and use of screening devices with subsequent off-gas cleaning

The BAT-AEL is <20 mg/m³, determined as the average over the sampling period (spot measurement, for at least half an hour).
   II transport of untreated slag by shovel loaders
   III. extraction or wetting of conveyor transfer points for broken material
   IV. wetting of slag storage heaps
   V. use of water fogs when broken slag is loaded.

**Water**

*Water consumption, treatment and discharge*

8. BAT is to minimise the water consumption from the EAF process by the use of closed loop water cooling systems for the cooling of furnace devices (see Section 8.3.6).

9. BAT is to minimise the waste water discharge from continuous casting by applying the following techniques in combination (see Sections 7.2.2.2, 7.3.6 and 7.3.7):
   I. removal of solids by sedimentation and/or filtration
   II. removal of oil in skimming tanks or any other effective device
   III. recirculation of cooling water and water from vacuum generation as much as possible.

The BAT-AELs are for waste water from continuous casting machines (see Section 7.3.7):

- TOC <10 mg/l
- Iron <5 mg/l
- Zinc <1 mg/l
- Nickel <0.5 mg/l
- Total chromium <0.5 mg/l
- Total Hydrocarbons <5 mg/l
- Toxicity to fish eggs as dilution factor TF <2

The BAT-AELs are based on a qualified random sample or a 24-hour composite sample.
10. BAT for waste water from EAF is to use sedimentation and flocculation (coagulation) (see Sections 7.3.6 and 7.3.7).

The BAT-AEL for waste water in general is:

- Suspended solids <20 mg/l

The BAT-AELs are based on a qualified random sample or a 24-hour composite sample.

Production residues like wastes and by-products

11. BAT is to prevent waste generation by applying the following techniques in descending order and priority (see Sections 8.3.8, 8.3.9 and 8.3.10):

   I. appropriate collection and storage to facilitate a specific treatment
   II. recovery and on-site recycling of refractory materials and slag (EAF, ladle, ladle furnace, strand caster, ingot caster) from the EAF process and use internally i.e. for substitution of dolomite, magnesite and lime
   III. use of filter dusts for external recovery of non-ferrous metals such as zinc in the non ferrous metals industry, if necessary, after enrichment of filter dusts by recirculation to the EAF
   IV. separation of scale from continuous casting in the water treatment process and recovery with subsequent recycling, i.e. in the sinter/blast furnace or cement industry
   V. external use of refractory materials and slag from the EAF process as a secondary raw material
   VI. controlled disposal of unavoidable wastes from the EAF process.

12. For the handling, storage and transport of solid wastes see general BAT, Section 2.6.4

Energy

13. BAT is to reduce the electrical energy consumption by applying integrated continuous scrap preheating for recovering sensible heat from the EAF waste gas (see Section 8.3.2).

14. BAT is to reduce the energy consumption by applying continuous near net shape strip casting (see Section 7.3.15).

Noise

15. BAT is - additionally to the techniques in Section 2.6.9 - to reduce noise emissions from all EAF installations and processes generating high sound energies by applying a combination of the following constructional and operational techniques depending on and according to local conditions (see Section 8.3.12):

   I. construct the EAF building in such a way as to absorb noise from mechanical shocks resulting from the operation of the furnace
   II. construct and install cranes destined to transport the charging baskets to prevent mechanical shocks
   III. special use of acoustical insulation of the inside walls and roofs to prevent the airborne noise of the EAF building
   IV. separation of the furnace and the outside wall to reduce the structure-borne noise from the EAF building
   V. housing of processes generating high sound energies (i.e. EAF and decarburisation units) within the main building
16. BAT is to minimise the noise emissions from the EAF by applying a constant feed of the EAF and melting immersion under foaming slag where conditions allow for it (see Sections 8.3.2 and 8.3.12).

The BAT AEL is <90 dB (A)
9 ALTERNATIVE IRONMAKING TECHNIQUES

This chapter is not as detailed as previous chapters as there is only one installation in the EU of this type (DRI plant in Germany)

Although the blast furnace (BF) route is the main process for iron production, several other production routes for hot metal are being developed and applied commercially. These 'smelting reduction' techniques invariably use coal instead of coke as the main fuel. Some of the new techniques also replace pellets and sinter by pulverised iron ore. These alternative technologies are described in more detail below.

Iron has been made in blast furnaces for more than 500 years. During that time, the blast furnaces have evolved into highly efficient reactors. However, other techniques are now available which present a challenge to the blast furnace route for hot metal production.

Blast furnaces require coke, and coke plants are expensive and have many environmental problems associated with their operation. Thus, it would be beneficial from an economic and environmental point of view to produce iron ore without the use of coke. Nowadays, nearly all blast furnaces reduce their coke consumption significantly by means of reductant injection at tuyères. However, coke can never be fully replaced in a blast furnace because of its burden supporting function. The minimum blast furnace coke rate is approximately 200 kg/t hot metal.

There is an increasing production of steel from scrap in electric arc furnaces (EAFs). Production of steel from scrap consumes considerably less energy compared to the production of steel from iron ores. The problems with the quality of scrap-based steel introduce restraints and the use of direct reduced iron (DRI) as feedstock enlarges the possibilities of the EAF steelmaking route.

In summary, the following aspects put pressure on the blast furnace production route of steel:

- the environmental aspects of sinter plants
- the environmental and economic aspects of the coke oven plant
- the relative inflexibility and scale of the hot metal production
- the increasing competition by the scrap based and DRI EAF steelmaking route.

But the advantages of the BF route as regards recycling capability and economical investment should be recognised.

This has triggered the improved environmental and economic operations of the blast furnace route and the development of alternative routes for ironmaking.

Two main types of alternative ironmaking which can be considered as proven types of alternative ironmaking are the following: direct reduction (DR) and smelting reduction (SR).

In an overview of past, present and future routes for iron and steelmaking are given.
9.1 Direct reduction (DR)

Direct reduction involves the production of solid primary iron from iron ores and a reducing agent (e.g., natural gas). The solid product is called direct reduced iron (DRI) and is mainly applied as feedstock in electric arc furnaces (EAF). The direct reduction process has been commercialised since the 1970s and a variety of processes have been developed.

Because there is no separation of iron from gangue in the reduction facility, high-grade ores or concentrates (>90 % Fe) must be used for the reduction to metallic iron in the solid state. The process temperatures are less than 1000 °C. DRI has a metallisation rate of >92 % and a carbon content of <2 %. The direct reduced iron is normally used as feedstock for EAFs.
DRI may have a high gangue content, and this reduces its value in EAF steelmaking, particularly in areas with high electrical power costs. In an additional melting stage, the gangue minerals contained in the DRI combine with added lime to form a fluid slag by which the gangue can be easily removed and the resultant hot metal can then be fed directly into the EAF. This is the route the commercial and semi-commercial rotary hearth furnace-based processes are following at the time of writing (2009).

A drawback of DRI is that it can pose a fire hazard. Therefore, DRI can be melted into briquettes, as hot briquetted iron (HBI), when the product has to be stored or transported over some distance.

The first commercial plants were built in the late 1960s. Because the leading direct reduction processes require a cheap source of natural gas, most of the plants are situated in the oil and gas rich belt around the equator.

Table 9.1 shows the percentage of DRI production related to the world hot metal production for 1996 and 2006.

<table>
<thead>
<tr>
<th>Year</th>
<th>World annual production (Mt)</th>
<th>Percentage related to the world hot metal production (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996/97</td>
<td>36.5</td>
<td>4.4%</td>
</tr>
<tr>
<td>2006</td>
<td>59.8</td>
<td>6.8%</td>
</tr>
</tbody>
</table>

Table 9.1: World production of DRI

Two thirds of the world production of DRI in 2006 was concentrated in five countries: India (15.0 Mt - 4 Mt more than in 2005), Venezuela (8.6 Mt), Iran (6.9 Mt), Mexico (6.2 Mt) and Saudi Arabia (3.6 Mt). New plants were commissioned in India, Nigeria, Trinidad, Saudi Arabia, Qatar and Russia [417]. The DR method has been successful, especially in producing powders.

Available processes

DRI processes can be divided up by the type of reactor employed, namely:

- shaft furnaces (Midrex, HyL)
- rotary kilns (SL/RN Process)
- rotary hearth furnaces (Fastmet®, Fastmelt®, Inmetco™/RedIron, and ITmk3®)
- fluidised bed reactors (Circofer®).

Many of these solid-state processes use natural gas as the fuel and as the reducing agent (carbon monoxide and hydrogen). Approximately 92% of the DRI is produced by using (reformed) natural gas as a fuel. In a limited number of sites, coal is used as a fuel.

As feedstock, iron ore pellets and lump ore are used in processes with a shaft furnace (Midrex, HyL) and fines and concentrates are used in processes with a fluidised bed (Circored, Finmet, Iron carbide) or a rotary hearth furnace (Fastmet, Inmetco).

An alternative to DRI is iron carbide (Fe₃C). Iron carbide is produced by means of direct reduction also, but the product contains approximately 90 wt-% Fe₃C. The carbon content is relatively high: 6 wt-%, which provides enough energy to reduce electricity consumption in the EAF. Iron carbide can be used in the same applications as DRI. The first commercial iron carbide plant, of a capacity of 300000 metric tonnes per year was commissioned in 1995 in Trinidad (actual production in 1998 was 150000 t/yr).

In Table 9.2, the characteristics of the commercially available types of DRI making are summarised.
During the steelmaking process, DRI is superior to scrap in purity and uniformity of composition, but these benefits come at a higher cost.

DRI utilisation is reasonable in following situations:

- when good quality scrap runs short, thus causing the quality of the steel products to deteriorate, and making it necessary to add reduced iron to raise the quality of the raw material
- in mini-mills built in regions where the delivery of iron sources such as scrap is difficult, or where the construction of an integrated steel plant with a blast furnace is not necessary from the viewpoint of the size of the demand, in which case reduced iron can be used as the main raw material [98]
- in blast furnaces where increased capacity of hot metal output is required.

Environmental aspects of DRI

The main benefit of a direct reduction unit compared to a blast furnace is that the direct reduction unit uses natural gas or coal as a fuel. Therefore, a coke oven plant is no longer needed, significantly reducing emissions. The impact on the environment of a direct reduction unit itself is very limited. There is little dust emission, which is easy to collect. The water need is low and water can be recycled to a large extent. Furthermore, a methane based direct reduction unit produces much less CO₂ than a coal based unit. ITmk3 technology providers claim that because part of the sensible heat of the off-gas is recovered and recycled to the heat input as preheated air, the estimated CO₂ emissions of this route + EAF is 20 - 25 % smaller than BF + BOF route [208].

However, DRI contains some gangue (3 - 6 %) and this leads to an increased power consumption of the EAF with increasing DRI input.

---

### Table 9.2: Characteristics of commercially available direct reduction processes

<table>
<thead>
<tr>
<th>Process</th>
<th>Midrex</th>
<th>HyL III</th>
<th>Iron carbide</th>
<th>Fastmet/Inmetco</th>
<th>Finmet</th>
<th>Circored</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Status</strong></td>
<td>Industrial</td>
<td>Industrial</td>
<td>Industrial</td>
<td>Industrial¹¹</td>
<td>Industrial²</td>
<td>Industrial²</td>
</tr>
<tr>
<td><strong>Type of reactor</strong></td>
<td>Shaft</td>
<td>Shaft</td>
<td>Fluid bed</td>
<td>Rotary hearth</td>
<td>Fluid bed</td>
<td>Fluid bed</td>
</tr>
<tr>
<td><strong>Iron source</strong></td>
<td>Pellet/Lump ore</td>
<td>Pellet/Lump ore</td>
<td>Fines: 0.1 - 1 mm</td>
<td>Fines/Concentrates</td>
<td>Fines 0.1 - 12 mm</td>
<td>Fines 0.1 - 1.0 mm</td>
</tr>
<tr>
<td><strong>Type of fuel</strong></td>
<td>Natural gas</td>
<td>Natural gas</td>
<td>Natural gas</td>
<td>Coal/Natural gas</td>
<td>Natural gas</td>
<td>Natural gas</td>
</tr>
<tr>
<td><strong>Utilities - Steam</strong></td>
<td>-</td>
<td>Steam</td>
<td>Steam</td>
<td>Steam</td>
<td>Reformer</td>
<td>Reformer</td>
</tr>
<tr>
<td><strong>Peripheral facilities</strong></td>
<td>Reformer</td>
<td>Reformer CO₂ removal</td>
<td>Reformer</td>
<td>Reformer CO₂ removal</td>
<td>Reformer CO₂ removal</td>
<td></td>
</tr>
<tr>
<td><strong>Typical plant capacity (kt/yr)</strong></td>
<td>1000</td>
<td>1000</td>
<td>320</td>
<td>450</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td><strong>Energy Input (GJ/t product)</strong></td>
<td>10.5</td>
<td>11.3</td>
<td>12.6</td>
<td>12.6</td>
<td>12.5</td>
<td>14</td>
</tr>
<tr>
<td><strong>Product</strong></td>
<td>DRI/HBI</td>
<td>DRI</td>
<td>Fe₃C-powder</td>
<td>DRI/HBI</td>
<td>HBl</td>
<td>HBl</td>
</tr>
<tr>
<td><strong>Product metallisation (%)</strong></td>
<td>&gt;92</td>
<td>&gt;92</td>
<td>Fe₃C &gt;90 %</td>
<td>&gt;92</td>
<td>&gt;92</td>
<td>&gt;92</td>
</tr>
<tr>
<td><strong>Product Carbon content (%)</strong></td>
<td>1 - 2</td>
<td>1 - 2</td>
<td>&lt;6.0</td>
<td>&lt;0.2</td>
<td>0.5 - 1.5</td>
<td>0</td>
</tr>
</tbody>
</table>

¹¹ Under construction (status: end of 1998)
9.2 Smelting reduction (SR)

Smelting reduction (SR) is associated with the production of hot metal from iron ore without coke. SR employs two units: in the first, iron ore is heated and reduced by gases generated in from the second unit, which is a smelter-gasifier supplied with coal and oxygen. The partially reduced ore is then smelted in the second unit, and liquid hot metal or (in some cases) liquid steel is produced. Smelting-reduction technology enables a wide range of coals to be used for ironmaking.

Examples of this technology include the Corex and Finex processes which are operating on a commercial basis.

9.2.1 Corex and Finex process

Description
The Corex process is a two-stage process: in the first step, iron ore is reduced to sponge iron in a shaft furnace by means of reducing gas; in the second step, the reduced iron is melted in the melter-gasifier vessel. Reducing gas (CO and H₂) which is used in the reduction shaft is supplied by gasification of coal by means of oxygen, forming a fixed/fluidised bed in the melter-gasifier. The partial combustion of the coal in the melter-gasifier generates the heat to melt the reduced iron. Liquid iron and slag are discharged at the bottom, by a conventional tapping procedure similar to that used in blast furnace operations.

Because of the separation of iron reduction and iron melting/coal gasifying in two steps, a high degree of flexibility is achieved and a wide variety of coals can be used. The process is designed to perform at an elevated pressure, up to 5 bar. The charging of coal and iron ore is performed through a lock hopper system.

The reducing gas contains some 65 - 70 % CO, 20 - 25 % H₂ and 2 - 4 % CO₂. After leaving the melter-gasifier, the hot gas is mixed with cooling gas to adjust the temperature to approx. 850 °C. The gas is then cleaned in hot cyclones and fed into the shaft furnace as a reducing gas. When the gas leaves the shaft furnace, it still has a relatively high calorific value and may be used as an export gas where the opportunity exists. The calorific value of the gas is estimated at 7.5 MJ/Nm³ in the case of the use of a typical steam coal (28.5 % volatile matter), but other coal types may result in other heating values of the export gas.

A further development of Corex is the Finex process, jointly developed by Siemens VAI and the Korean steel producer Posco. The main difference between Corex and Finex is that Finex can directly use fine ore, as well as non-coking coal [417]. In the Finex process a fourstage fluidised bed system is located upstream of a melter gasifier. After the reduction of the fine ores in the fluidised beds the outcome gets hot-compacted prior to charging into the melter gasifier.

Main achieved emission levels
The Corex process uses coal as an energy source. Therefore, emissions from the coke oven are avoided. All the higher hydrocarbons that are liberated from the coal are cracked into CO and H₂ in the melter-gasifier. Therefore, no by-products like tar, phenol, BTX, PAH, etc. are generated.
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The sulphur charged with the coal into the process is, to a large extent, picked up in the shaft furnace by DRI and calcined additives and is subsequently fed to the melter-gasifier. Here, most of the sulphur is transferred to the liquid slag as in the BF route and becomes harmless to the environment. The amount of sulphur discharged from the Corex process by gas and water (2 - 3 % of the total sulphur input) is much lower than from the traditional coke oven/sinter plant/blast furnace route (20 - 30 %). The export gas contains 10 - 70 ppmv H2S, depending on the type of coal used and the operational conditions. As oxygen (O2) instead of air is used for the gasification of char, no significant NOX and cyanide (CN) formation occurs. The required use of oxygen results in significant additional overall energy demands.

Dust emissions from the Corex plant are significantly lower than in the traditional production route. All dust emissions at the coke oven are avoided. The dust content of the export gas is less than 5 mg/Nm3. Most of the dust which is captured in the gas cleaning system is recycled to the process.

Some performance data of the Iscor, South Africa plant are given in Table 9.3.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Using lump ore</th>
<th>Using pellets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melting capacity</td>
<td>t HM/hour</td>
<td>45</td>
</tr>
<tr>
<td>Specific melting capacity</td>
<td>t HM/m3 per day</td>
<td>3.0</td>
</tr>
<tr>
<td>Coal consumption</td>
<td>kg/t HM</td>
<td>1080</td>
</tr>
<tr>
<td>C/fix consumption</td>
<td>kg/t HM</td>
<td>615</td>
</tr>
<tr>
<td>O2 consumption</td>
<td>Nm3/t HM</td>
<td>540</td>
</tr>
<tr>
<td>Slag quantity</td>
<td>kg/t HM</td>
<td>450</td>
</tr>
<tr>
<td>Carbon</td>
<td>%</td>
<td>4.5</td>
</tr>
<tr>
<td>Silicon</td>
<td>%</td>
<td>0.3</td>
</tr>
<tr>
<td>Sulphur</td>
<td>%</td>
<td>0.05</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>%</td>
<td>0.15</td>
</tr>
<tr>
<td>Export gas</td>
<td>Nm3/t HM</td>
<td>1750</td>
</tr>
<tr>
<td>Net calorific value</td>
<td>MJ/t HM</td>
<td>7.5</td>
</tr>
<tr>
<td>CO</td>
<td>%</td>
<td>45</td>
</tr>
<tr>
<td>CO2</td>
<td>%</td>
<td>32</td>
</tr>
<tr>
<td>H2</td>
<td>%</td>
<td>16</td>
</tr>
<tr>
<td>Dust</td>
<td>mg/Nm3</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Emission</td>
<td>g/t HM</td>
<td>39 - 139</td>
</tr>
<tr>
<td>SO2</td>
<td>g/t HM</td>
<td>26 - 333</td>
</tr>
<tr>
<td>NOX</td>
<td>g/t HM</td>
<td>21 - 33</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>GJ/t HM</td>
<td>17</td>
</tr>
</tbody>
</table>

Table 9.3: Relevant performance data of the Corex plant at Iscor's Pretoria Works, South Africa

[78] [82]

Cross-media effects

The reduction gas from the melter-gasifier is cleaned in cyclones. The dust from these cyclones can be recycled to the melter-gasifier. The topgas from the shaft furnace and the cooling gas (to cool the reduction gas) are cleaned in scrubbers and thus a sludge is generated. The sludge can largely be recycled into the melter-gasifier after granulation or supplied to the cement industry. A small (not quantified) part may be disposed of.

The Corex process has a high specific coal consumption and a relatively large off-gas flow, with a medium-high calorific value. The use of this off-gas as an energy source largely determines the energetic efficiency of the process. Cooling water is supplied in a closed circuit.
Operational data
No data submitted.

Applicability
No data submitted.

Economics
Reported capital costs were EUR 195 per tonne hot metal. For the example the currency was converted into Ecu in 1996 and for the review into EUR.

Driving force for implementation
No data submitted.

Example plants
After a Corex plant was successfully commissioned in 1995 by Posco, Pohang, South Korea, the plant was converted to the Finex configuration with a production capacity of 600 000 tonnes per year in 2003. In this, a four stage fluidised bed system is located upstream of a melter gasifier. After the reduction of the fine ores in the fluidised beds the outcome gets hot-compacted prior to charging into the melter gasifier. A second plant with an annual capacity of 1.5 million tonnes went into operation at the Pohang site in April 2007.

By the end of 2007, a total of six Corex plants and two Finex plants have been in operation, representing an aggregate capacity of 7.45 million tonnes hot metal.

<table>
<thead>
<tr>
<th>Corex/Finex plant</th>
<th>Number</th>
<th>Commissioned</th>
<th>Charge/burden</th>
<th>Capacity in million t/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posco, Pohang Works, South Korea</td>
<td>1</td>
<td>1995/2003</td>
<td>Lump ores/fines</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2007 (Finex)</td>
<td>fines</td>
<td></td>
</tr>
<tr>
<td>Jindal South West Steel, Torangallu, India</td>
<td>2</td>
<td>1997/2001</td>
<td>Lump ores, pellets</td>
<td>1.60 (2 x 0.8)</td>
</tr>
<tr>
<td>Mittal Steel, Saldanha Southafrika</td>
<td>1</td>
<td>1999</td>
<td>Lump ores, pellets</td>
<td>0.65</td>
</tr>
<tr>
<td>Baosteel, Shanghai, China</td>
<td>1</td>
<td>2007 start up in 2010</td>
<td>Lump ores, pellets</td>
<td>1.50</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td>1.5</td>
</tr>
<tr>
<td>Essar Steel, Hazira, India</td>
<td>2</td>
<td>2007</td>
<td>pellets</td>
<td>1.60 (2 x 0.8)</td>
</tr>
</tbody>
</table>

Another example for smelting reduction is the PRIMUS technique using a two-step process, consists of the combination of a multiple hearth furnace (MHF) aiming to dry, heat up and initiate reduction followed by an electric arc furnace (EAF) leading to complete iron reduction and providing hot metal, form the slag and finalise the zinc reduction. This technique permits the treatment of all typical iron and steelmaking residues which cannot normally be recycled withing the existing plant, such as EAF dust, BF sludge, steelworks sludge and oily mill sludge scale (see 2.5.4.4.3).

Reference literature
[44] [78] [82] [440]
9.2.2 Processes under development

The following smelting reduction processes are in an advanced stage of development and are briefly described in this paragraph:

- HIsmelts
- Direct Iron Ore Smelting (DIOS)
- AISI-DOE/CCF
- ROMELT

In Table 9.5, the characteristics of these processes are summarised. Short descriptions of the individual processes will be given in the following pages.

<table>
<thead>
<tr>
<th>Process</th>
<th>HIsmelts (Australia)</th>
<th>DIOS (Japan)</th>
<th>AISI-DOE/CCF (US/Netherlands)</th>
<th>ROMELT (Russia)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main components</td>
<td>Vertical smelt • Reduction</td>
<td>Prereduction in fluidised bed • Gas reforming furnace • Smelting reduction furnace • Oxygen plant</td>
<td>Cyclone converter furnace • In-bath melting vessel • Oxygen plant</td>
<td>Bath smelter</td>
</tr>
<tr>
<td>Feedstock</td>
<td>Fines</td>
<td>Fines</td>
<td>Fines</td>
<td>Fines/waste oxides</td>
</tr>
<tr>
<td>Fuel</td>
<td>Pulverised coal</td>
<td>Coal Fines/granular coal</td>
<td>Coal fines</td>
<td>Coal fines</td>
</tr>
<tr>
<td>Metal product</td>
<td>Liquid iron</td>
<td>Liquid iron</td>
<td>Liquid iron</td>
<td>Liquid iron</td>
</tr>
<tr>
<td>Oxygen consumption (Nm³/t HM)</td>
<td>Uses hot blast 500</td>
<td>430 - 680</td>
<td>750 - 850</td>
<td></td>
</tr>
<tr>
<td>Coal consumption (kg/t HM)</td>
<td>630 - 700</td>
<td>950</td>
<td>700 - 750</td>
<td>900 - 1200</td>
</tr>
<tr>
<td>Off-gas quantity (Nm³/t HM)</td>
<td>1850</td>
<td>2080</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Cal. Value (MJ/Nm³)</td>
<td>1.44</td>
<td>3.74</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Net energy consumption (GJ/t HM)</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Energy output (GJ/t HM)</td>
<td>2.7</td>
<td>7.8</td>
<td>4.0</td>
<td>n/a</td>
</tr>
<tr>
<td>Status</td>
<td>Pilot</td>
<td>Pilot</td>
<td>Pilot</td>
<td>Pilot</td>
</tr>
</tbody>
</table>

Legend: HM = hot metal

Table 9.5: Characteristics of the smelting reduction processes under development [44] [98]
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HIsmelt

Description
In this process ores, coal and fluxes are injected into an iron bath by a total of eight lances of which four tend to be used for the cold coal and lime and four serve to inject ore and dolomite (5%) in their hot condition 600 - 700 °C. The ores are quickly reduced and melt directly in the bath. Hot blast (1200 - 1250 °C) with a 35% O₂ content is injected via a central lance through the slag causing the CO and H₂ fractions to be postcombusted in the off-gas. A hot metal sump is usually required in order to start up the plant. Hot metal tapping is performed continuously via a forehearth, while slag tapping is performed by batch tapping every two to three hours via the slag taphole [440].

Operational data
SR in the HIsmelt process leads to lower silicone contents amounting to less than 0.01% and also lower phosphorus contents of less than 0.02% in the hot metal [440].

Status
A HIsmelt plant was commissioned at Kwinana, Western Australia by the HIsmelt Corporation. This plant is designed for an annual production of 800000 tonnes hot metal [440].

Environmental implications
Compared to blast furnace ironmaking, a fuel saving of 10% is predicted. Furthermore, operation of an iron ore pretreatment plant (pellet plant, sinter plant) and a coke oven plant is no longer necessary. In contrast to the other smelting reduction processes, a hot blast is needed. This will probably influence the NOₓ emissions of this process in a negative way.

DIOS

Description
The Direct Iron Ore Smelting (DIOS) process consists of three sub-processes: a fluidised bed pre-reduction furnace (PRF) to pre-reduce the iron ore, a gas reforming furnace (GRF) to mix coal powder into the gas, and a smelting reduction furnace (SRF) to further reduce and smelt the iron ore.

Combustion oxygen is injected from the top of the SRF. The generated carbon monoxide (CO) is used to pre-reduce the iron ore in the PRF. Nitrogen is injected in the bottom of the SRF to agitate the slag in the furnace.

Status
At NKK's Keihin Works, Japan, a pilot plant has operated since 1994, producing approximately 500 tonnes of iron per day.

Environmental implications
It is expected that the energy consumption of DIOS will be 5 - 10% lower compared to the blast furnace route. Furthermore, the iron pretreatment plant (pellet plant, sinter plant) and the coke oven plant are no longer needed.

Reference literature
[78]
**AISI-DOE/CCF**

**Description**
The AISI-DOE project and the Cyclone Converter Furnace (CCF) project have started out as two separate development projects.

The AISI-DOE project was a co-operative R&D project for direct ironmaking (smelting reduction) by a number of universities and American and Canadian steelmaking companies. The project was co-ordinated by the American Iron and Steel Institute and sponsored by the US Department of Energy. The aim of the project is to produce steel from pre-reduced iron ore and coal in a vertical bath smelter. The development of the vertical bath smelter has formed the most important part of the project.

The CCF project is a joint initiative of Corus, Ijmuiden, the Netherlands and Ilva, Italy. The most important part of the project is the development of the cyclone reactor. In the cyclone, the iron ore is pre-reduced and melted. The molten mixture falls into the lower part of the vessel where reduction is completed. The fuel consists of granular coal which is injected together with oxygen in the lower part of the vessel.

The high operating temperature of the cyclone reactor and the fact that it can handle a high level of entrained materials from the iron bath make a direct connection of the pre-reduction and the final reduction stages possible. Combining the two stages means that the heat transfer efficiency is not critical since there is no inter-stage cooling. The fact that both pre-reduction and final reduction take place in one vessel marks an important difference between the CCF and the other existing units for bath smelting reduction.

The CCF project had focused mainly on the development of the cyclone reactor.

In 1995, both parties recognised the possibility of combining their technology. With the combined techniques, a smelting reduction pilot plant can be realised.

**Status**
The AISI-DOE project has been operated in a number of trials, but no pilot plant has been commissioned. The CCF project has been operated on pilot plant scale, with a capacity of 20 tonnes per hour. With the combined technique, a 700000 tonnes per year pilot plant is planned at Ijmuiden.

**Environmental aspects**
Since no coke oven plant, sinter plant or pellet plant is required, a marked reduction of emissions can be achieved. Energy consumption per tonne steel will also be lower. Furthermore, power can be generated from the flue-gases which exit the cyclone at about 1800 °C.

**Reference literature**
[43] [65] [78]

**ROMELT**

**Description**
The ROMELT process has been under development in Russia for over 10 years. It is similar to other bath smelting processes, but does not use a pre-reducer. The process uses ore or waste oxides. Its coal consumption has been reported to be 900 - 1200 kg/metric tonne.

**Status**
A 500 - 1000 metric tonnes/day pilot plant at Novolipetsk, Russia has produced over 300000 metric tonnes hot metal. Detailed plans for a 350000 metric tonnes/yr have been made.
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Environmental aspects
Since no coke oven plant, sinter plant or pellet plant is required, a significant reduction of emissions compared to conventional primary ironmaking can be expected. Energy consumption per tonne steel will be lower as well.

Reference literature
[44] [65]

Plasmasmelt
In plasma-based smelting reduction processes, the reactions take place in a coke-filled shaft furnace with tuyères spaced symmetrically around the lower part of the furnace. The shaft is completely filled with coke. Plasma generators and equipment for injection of metal oxides mixed with slag forming material and possibly reductants are attached to the tuyères. In front of each tuyère, a cavity is formed inside the coke column where reduction and smelting take place. At regular intervals, the produced slag and metal are tapped from the bottom of the shaft furnace. In the case of iron ore smelting, the off-gas from the furnace, consisting mainly of carbon monoxide and hydrogen, can be used for pre-reduction of the ore. In other applications of the process, such as the reclaiming of alloying metals from the bag house dust, the produced gas is utilised as a fuel gas. If the raw material contains metals with high vapour pressures, for example zinc and lead, these metals leave the furnace with the off-gas which is then passed through a condenser where the metals are recovered from the gas [383].

Ausmelt
The Ausmelt process was developed by Ausmelt Ltd. Australia. Lump ore or ore fines are fed continuously into a converter along with lump coal and flux. Fine coal, oxygen and air are injected to allow submerged combustion. The degree of oxidation and reduction is controlled by adjusting fuel to air and coal ratios as well as the proportion of fine coal injected down the lance. All reactions are completed in a single reactor.

9.3 Comparison of the conventional blast furnace route with the direct reduction and smelting reduction route

The primary environmental benefit claimed for direct reduction (DR) and smelting reduction (SR) processes is that they can operate without coke or sinter. This prospect might prevent the necessity for coking plants and sinter machines that potentially have a significant environmental impact.

Emissions from reduction plants are generally low, with particulate releases to air after abatement of the order of 10 mg/Nm$^3$. Abatement tends to be based on wet technology leading to an aqueous waste stream, although this may be capable of being addressed by recycling the water or by dry cleaning. If DR or SR processes use iron pellets or sinter, then the emissions associated with the processing of these materials must be considered when comparing environmental performances of the various ironmaking routes.

In Table 9.6 a comparison of the conventional blast furnace route with the DR and SR route for ironmaking is given.
### Chapter 9

<table>
<thead>
<tr>
<th>Features</th>
<th>Traditional BF Route(^{1})</th>
<th>Direct Reduction (DR)</th>
<th>Smelting Reduction (SR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scale of production</td>
<td>Long established and energy and resource efficient with unit plant throughputs of 2 Mt/yr and greater. Still the principal route for ironmaking, accounting for 95 % of world production</td>
<td>Gas based processes account for the vast majority of installed DR capacity worldwide, with 63 % of that capacity being via the MIDREX route. Such processes currently have a maximum unit plant capacity of 1.3 Mt/yr. DRI as produced is normally used as a replacement for scrap in the EAF steelmaking route. DRI processes have relatively low throughputs compared to the blast furnace and have generally been installed to take advantage of local factors such as very low cost energy and/or iron ore feed.</td>
<td>SR is less diffused. Only the Corex/Finex process is commercialised. Currently, there is about 7.45 Mt/yr of installed operating capacity (8 sites)</td>
</tr>
<tr>
<td>Feedstocks</td>
<td>Coal&lt;br&gt;Coking coals required for coke making&lt;br&gt;Coke breeze &amp; anthracite required (where used) for sinter plants&lt;br&gt;Coal for BF injection (can be non-coking coal specification)&lt;br&gt;&lt;strong&gt;BF Injectants&lt;/strong&gt;&lt;br&gt;Besides coal, oil (inc. waste oil), natural gas and plastics are being injected into BF&lt;br&gt;&lt;strong&gt;Metallics&lt;/strong&gt;&lt;br&gt;A wide range of feedstock of variable quality and specification can be used</td>
<td>Coal (where used - minority of processes)&lt;br&gt;Wide range of solid fuels from anthracite to lignite including charcoal (rotary kilns)&lt;br&gt;&lt;strong&gt;Gas&lt;/strong&gt;&lt;br&gt;Sulphur content of gas must be low to avoid poisoning of the reformer catalyst and effecting product quality.&lt;br&gt;&lt;strong&gt;Metallics&lt;/strong&gt;&lt;br&gt;As no physical change of state takes place in the process, high quality pellets and lump ore are required</td>
<td>Coal&lt;br&gt;Non-coking coals, specification requirements more flexible than for BF route&lt;br&gt;&lt;strong&gt;Metallics&lt;/strong&gt;&lt;br&gt;Lump and fine ore, sinter or pellets&lt;br&gt;&lt;strong&gt;Oxygen&lt;/strong&gt;&lt;br&gt;Large quantities of oxygen are required for the Corex process (with associated energy implications)</td>
</tr>
<tr>
<td>Energy Requirements</td>
<td>Typically around 17 - 18 GJ/t of liquid iron (less gas, steam and heating credits from carbon in iron)</td>
<td>Typically 10.5 - 14.5 GJ/t solid DRI (gas-based) assuming 100 % lump ore operation. (Extra energy required for melting and pellets, if used)</td>
<td>Difficult to quantify as process efficiency is dependent on the credit given for exported power or production of more DRI by gas-based DR process.</td>
</tr>
<tr>
<td>Product Quality</td>
<td>Stable and of dependable quality</td>
<td>Product prone to re-oxidation unless passivated or briquetted. Quality highly dependent on feed quality</td>
<td>Identical to BF iron</td>
</tr>
</tbody>
</table>

\(^{1}\) \text{Note:} This table compares the characteristics of the Traditional BF Route, Direct Reduction (DR), and Smelting Reduction (SR) processes. The Traditional BF Route is the most common method for ironmaking, while DR and SR are alternative methods that have their own unique characteristics and applications.
### Features

<table>
<thead>
<tr>
<th>Environmental Performance</th>
<th>Traditional BF Route&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Direct Reduction (DR)</th>
<th>Smelting Reduction (SR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Releases to the environment include dusts, VOC, PAH and a variety of organic chemicals from the coke ovens. Sinter plants release SO(_2), NO(_X), dust, VOC, PCB, PCDD/F and PAH (see Table 4.1) while BF discharge dust and SO(_2) from cast houses (see Table 6.4 to Table 6.6). The process route also uses large quantities of water. However, the route provides for the recycling of various solid wastes/by-products which would not be available in many DRI processes. The desulphurising capability of the blast furnace also allows for higher sulphur containing fuels and reductants to be used in an environmentally friendly manner. BF slag can be used for road construction or pelletised to make slag cement. Both by-products have the environmental advantage that they reduce the demand for primary aggregates. It is important to remember that the traditional ironmaking route provides for many recycling and disposal opportunities for ferruginous arisings, filter cakes and oils from downstream steel production that may not be available in many reduction processes. The traditional route also has the ability to use a wide range of feedstocks and reductants of varying quality.</td>
<td>As most DR processes make use of iron pellets the environmental impact of releases from the pelletisation process should be taken into account. The DRI product typically contains 2 - 4 % gangue requiring further energy for processing and additional environmental releases to be considered. Dust releases are similar to the BF route as raw material fines are screened before processing. There is a need to provide an environmentally satisfactory route for utilisation of fines if DR is to replace traditional ironmaking. NO(_X) is released at the gas reforming stage. The most successful DR processes use natural gas although coal remains the largest energy source available to man. In terms of sustainable development, it may be considered that gas should be reserved for the production of high value products. Dispensing with coking plants prevents emissions to air of dust and VOCs from the ovens and a variety of organic chemicals to air and water from by-products plants. Emissions from refiners processing the residual coke making oils and tars from the coke ovens will also be eliminated. In addition, the large quantities of water used in the process will be saved. Removing sinter plants reduces releases to atmosphere of metallic/non-metallic dust and gaseous pollutants such as sulphur dioxide. The majority of blast furnaces now have casthouse fume arrestment and bell-less charging systems installed and their environmental performance will therefore be comparable to releases from reduction plants with equivalent systems.</td>
<td>In some SR processes large quantities of waste gas are required to be utilised. In addition the SR energy requirements and CO(_2) emissions are higher than at the BF route. There is a need to provide an environmentally satisfactory route for utilisation of fines if SR is to replace traditional ironmaking.</td>
<td></td>
</tr>
</tbody>
</table>
### Chapter 9

#### Features

<table>
<thead>
<tr>
<th></th>
<th>Traditional BF Route(^1)</th>
<th>Direct Reduction (DR)</th>
<th>Smelting Reduction (SR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross-media</td>
<td>As DR produces no physical change of state or separation of chemical impurities, product quality is wholly dependent on the quality of feedstocks. The DRI produced may not be of equivalent quality to that of iron from blast furnaces if low quality feedstocks are used. For environmental accounting purposes, DRI needs to be in molten form to be directly comparable to blast furnace iron. The additional energy requirements and emissions connected with this physical change of state need to be considered.</td>
<td>Considering smelting reduction processes, large volumes of top gases are produced by Corex and energy efficiency will be poor unless the gases are utilised for power generation or used to produce more sponge iron. Coal consumption and oxygen requirements are higher than the BF route and carbon dioxide emissions are significantly greater. Oxides of nitrogen from gas reforming have to be taken into consideration in both SR and DR operations.</td>
<td></td>
</tr>
<tr>
<td>Installation costs (indicative)</td>
<td>EUR 1150 million for 3.5 Mt/yr (including cost of sinter plant and coke ovens)</td>
<td>EUR 210 million for 1.36 Mt/yr (assuming availability of suitable pellets or lump ore)</td>
<td>EUR 240 million for 0.60 Mt/yr (including the cost for the oxygen plant and assuming lump ore operation)</td>
</tr>
</tbody>
</table>

\(^1\) coke oven, sinter plant and blast furnace.

---

**Table 9.6:** Comparison of the conventional blast furnace route with the direct reduction and smelting routes for ironmaking [200] [417] [440]
Chapter 10

10 EMERGING TECHNIQUES

The term 'Emerging technique' is understood in this document as a innovative technique that has not yet been applied in any industrial sector on a commercial basis. This chapter contains those techniques that may appear in the near future and that may be applicable to the iron and steel production sector. For example, this chapter:

- identifies any novel pollution prevention and control techniques that are reported to be under development and may provide future economic or environmental benefits
- includes techniques to address environmental issues that have only recently gained interest in relation to the sector at hand
- does not include established techniques in other sectors that may be emerging in practice within this sector.

Applied to this particular sector, the European Union has had (for more than 50 years) and continues to have a strong R & D programme to develop the steel sector. Some of the projects in this chapter have been financed by these programmes.

10.1 General emerging techniques

10.1.1 Carbon dioxide mitigation strategies (ULCOS project) [378], [250]

Specifically, because the CO₂ which is generated when energy is consumed is a greenhouse gas (GHG), energy savings has undergone a major change in purpose, and is now considered part of the solution to the problem of global warming, which is a global scale environmental issue.

As mentioned in the IPCC report, there is no unique option for mitigating climate change. The solution is rather a portfolio of mitigating actions for the stabilisation of atmospheric greenhouse gas concentrations.

Indeed, progress in the past has been large and simply extrapolating current technologies leaves little leeway for drastic new reductions in emissions.

To overcome this true difficulty, one should examine breakthrough technologies, which have received little attention in the past, because they did not belong to the economic technological episteme of the time. When considering changes the goal should be to reduce GHG (greenhouse gases) emissions and not simply to save energy; when most energy savings have been collected, as is the case in the most advanced steel companies, carbon and energy have to be decoupled to continue mitigating emissions.

ULCOS stands for Ultra–low carbon dioxide (CO₂) steelmaking. It is a consortium of 48 European companies and organisations from 15 European countries that have launched a co-operative R & D initiative to enable drastic reduction in carbon dioxide (CO₂) emissions from steel production. The consortium consists of all major EU steel companies, energy and engineering partners, research institutes and universities and is supported by the European Commission. The aim of the ULCOS project is to reduce carbon dioxide(CO₂) emissions by the most advanced techniques by at least 50 percent. The total budget of the project is EUR 47 million (2004 - 2009). The project is targeted to run beyond 2015 with some full size implementation in industrial production lines.
There are three areas to be explored under this rationale:

- capturing and sequestering CO₂ with optional transportation and storage
- use of energy and reducing agents not based on carbon, which means hydrogen and electricity and to a lesser extent natural gas
- use of sustainable biomass as grown in eucalyptus plantations, for example.

All of these issues are being extensively explored in the European ULCOS project and more generally in other programmes in the World.

### 10.1.1.1 Top gas recycling blast furnace (TGR-BF)

The concept of the Top Gas Recycling Blast Furnace is based on the separation of the off-gases so that the useful components can be recycled back into the furnace and used as a reducing agent. This would reduce the amount of coke needed in the furnace (see the concept of Blast Furnace with top-gas recycling, under optimisation within the ULCOS project, in Figure 10.1). In addition, the concept of injecting oxygen (O₂) into the furnace instead of preheated air, is based on the removal of unwanted nitrogen (N₂) from the gas, facilitating carbon dioxide (CO₂) capture and storage (CCS, see Section 10.1.2).

![Schematic of the Top-Gas Recycling blast furnace to minimise GHG emissions with capture and the optional storage of CO₂](image)

Capture technologies are mainly based on three physical principles: physisorption, chemisorption and physical separation with membranes or molecular sieves. All of these operate either in a batch, by capturing CO₂ in a first phase and then releasing it in a second phase, or continuously in a filtration process using membranes.

To experimentally test this concept, a gas separation plant was constructed next to the experimental blast furnace at the MEFOS research institute in Sweden. On the experimental blast furnace, equipment was installed to operate with pure oxygen (O₂) and with the reinjection of carbon monoxide (CO) gas. The combination of the modified blast furnace and the gas separation plant was successfully tested in 2007.
Even without CCS, the TGR-BF concept leads to a substantial mitigation of CO₂ emissions, mostly related to the lowered coke consumption (approx. 25% lowered per tonne of hot metal). As the topgas recycling reduces the surplus of top gas that is available for energy production, and thus this amount of energy has to be produced from other sources, the total CO₂ savings lower than 25%, but it is still in the range of 10% - 20% (depending on the fuel mix used).

Plans are currently being developed to test this technique on a commercial scale blast furnace. This will take place in the next phase of the ULCOS project requiring an initial R & D investment of several hundred million Euros.

In a second stage the captured CO₂ will be compressed and transported for storage in geological formations (such as oil and gas fields, unminable coal beds and deep saline formations), in mineral carbonates, or for use in industrial processes.

**10.1.1.2 Carbon-lean fuels and reducing agents**

Replacing carbon by hydrogen or electricity is a challenge of a greater scale, as both hydrogen and electricity are energy carriers that need to be produced from other fuels.

Until today, this is the reason why electricity has been more expensive than coal, gas or oil. This is also why little work has been carried out on a subject like the production of iron by electrolysis of iron ore in mainstream steel R & D.

The picture may change completely in the future. Indeed, the carbon constraint brought about by Kyoto and post-Kyoto policies would change the price structure of fuels. For example, carbon will have an extra price tag due to the need for capturing and sequestering CO₂, which for a kWh produced by generating 1000 g/kWh would add EUR 20 to 80 to the cost of one MWh, a figure to be compared to the price of industrial electricity today, which varies between EUR 5 and 80/MWh throughout the world. Non-carbon-based electricity would not have to carry this extra burden and would thus, *mutatis mutandis*, the direct utilisation of carbon. This would probably change the price structure of energy in a drastic way. Similar orders of magnitude calculations would show that the steel industry could use large amounts of hydrogen, if it were available in large quantities at the right price, on par with what the transportation industry would use if it were to change over to fuel cell cars.

Under such novel economic conditions, hydrogen pre-reduction of iron ore would become a reasonable proposition, especially since the change from natural gas to hydrogen is a rather simple one from a process engineering point of view. Similarly, electrolysis of iron ore is a distinct possibility from the standpoint of physics. It has even been argued than it would be an "easier" technology, from a thermodynamic standpoint, than the electrolysis of alumina.

Electrolysis of iron ore would conservatively call for 4.5 MWh/t of iron or 16.2 GJ/t, a figure that is of the same order of magnitude as the energy intensity of a modern, hot phase steel mill today. To produce 1 million tonnes per year, 0.514 GW of electrical power would be necessary so that a production equivalent to an integrated mill (4 Mt/yr) would probably call for a dedicated power plant. If a standard coal-fired power plant (1000 g of CO₂ per kWh) were used, this would generate 4.5 t of CO₂ per tonne of steel, about 3 times the figure of the baseline blast furnace of today, or the ratio of efficiency between a power plant and a blast furnace. However, if electricity were CO₂ free it would only generate 27 kg CO₂ per tonne of steel. Since the technology of power plants will change in the post-Kyoto future, these figures, at least those related to coal-fired plants will decrease with the implementation of co-generation and carbon C & S concepts, such as the integrated gasification combined cycle technology. From a long-term perspective, electricity is potentially a powerful player, provided that low CO₂ intensity can be guaranteed and that prices stay commensurable with steel prices.
Electrolysis of water is a state-of-the-art technology where the electrolysis is carried out in the liquid state. Units typically produce 200 Nm$^3$/h of hydrogen, and, therefore, 600 such units would be needed to feed a 1 Mt/yr DRI plant (at the level of 1050 Nm$^3$ of H$_2$/t of DRI). The electricity requirement would be 4.85 MWh/t steel (including melting in an EAF) and 4.8 TWh/yr for 1 Mt of steel.

### 10.1.1.3 Biomass

Finally, sustainable biomass needs to also be seriously considered as an alternative for CO$_2$ mitigation. This would be an interesting historical twist, as steel was produced for millennia from biomass but this was not sustainable after the onset of industrialisation and coal became a formidable competitor to wood and charcoal. Sustainable forestry has, however, become a reality today, attested by international certification bodies, such as the Forest Stewardship Council (FSC). Moreover, forest biologists and ecologists have started to demonstrate that, under sustainable growing conditions, carbon plantations can indeed be neutral to the accumulation of GHG in the atmosphere.

Last but not least, inventories of land that could be made available for growing energy crops seem to show that there are distinct possibilities of setting up more plantations that could have a clear contribution to the production of steel in the world. The matter needs very careful attention and is clearly not settled, but the necessary work will be carried out within the ULCOS project.

### 10.1.2 CO$_2$ capture and storage

**Description**

One option to control CO$_2$ emissions is CO$_2$ capture and storage. Capture technologies are mainly based on three physical principles: physisorption, chemisorption and physical separation with membranes or molecular sieves. All of these operate either in batch, by capturing CO$_2$ in a first phase and then releasing it in a second phase, or continuously in the filtration process used with membranes. In a second phase, it consists of the separation of CO$_2$, transport to a storage location and long-term isolation from the atmosphere. First, CO$_2$ is separated from the process gas in a capture plant using similar technology to the post-combustion capture implemented in power plants and then it is compressed. Finally, it is transported for storage in geological formations (such as oil and gas fields, unminable coal beds and deep saline formations), in the ocean (direct release into the ocean water column or onto the deep seafloor), in mineral carbonates, or for use in industrial processes.

**Achieved environmental benefits**

The emissions of CO$_2$ decrease to a large extent.

**Cross-media effects**

CO$_2$ capture and storage increase energy demands (especially for capture and compression), which normally increases CO$_2$ emissions. The amount of avoided or net captured CO$_2$ represents the difference between emissions without and emissions with implementing the technique.

**Operational data**

No data submitted.

**Applicability**

No data submitted.
Chapter 10

Economics
The IPCC gives a range of capture costs between 25 and 115 $2002/t CO₂ net captured for the industrial sector. This wide range reflects on the one hand the variety of technologies used and on the other hand it reflects the missing experience with that technology. These published figures should therefore only be considered as a rough estimate and presenting one scenario among many other possible ones. Because of R & D efforts, those current costs could be reduced by at least 20 - 30 % over the next ten years. However many uncertainties remain for costs in an industrial sector such as iron and steel due to its lack of capture experience. Additional costs for capture are transportation costs (1 - 8 $2002/t CO₂ transported over 250 km) and storage costs (1 - 30 $2002/t CO₂).

Driving force for implementation
No data submitted.

Example plants
No data submitted.

Reference literature
[415]

10.1.3 Ceramic filters for the abatement of both particles and nitrogen oxides from gas streams

Description
This dry flue-gas cleaning uses ceramic filters. They are designed to combine filtration and SCR reaction in one unit using a catalytic filter. These filters allow for the use of the high energy content of the gas as well as preventing the plugging of the catalyst (oxides of Ti, V and W). Furthermore, the combination of two units into one unit reduces processing costs as well as investment and maintenance costs.

Ceramic hot gas filter elements with a fine filtering outer membrane and a catalyst integrated into the support structure of the filter elements can be used to achieve an efficient particle removal as well as an efficient NOX removal. The use of these filter elements enables to realise the combination of a filter and a SCR reactor into one unit. Moreover, the function of the integrated catalytic layer can be tailored in such a way as to allow not only catalytic NOX removal but also catalytic oxidation of volatile organic compounds (VOC).

The pollutants SO₂ and HCl are removed by using, for example, sodium bicarbonate (NaHCO₃) or calcium hydroxide (Ca(OH)₂) as sorbents, whereas NOX is catalytically converted with NH₃ and O₂ to N₂ and H₂O by passing through the catalytic filter elements.

Achieved environmental benefits
Preliminary results reduced NO content by 83 - 98 % (NO inlet at levels of 500 - 1720 ppmv and temperatures between 140 - 360 °C). By injecting sodium bicarbonate, the removal of SOX can be up to 99 %. Filtration efficiencies are typically higher than 99.99 %

Cross-media effects
N₂O formation was not detected.

Operational data
This system has a simpler plant set-up compared to a wet cleaning process and tends to be smaller. This system can work at high temperatures (up to 500 °C).

Applicability
Especially applicable for small and medium scale plants.
Chapter 10

Economics
The capital investment, maintenance and running costs are lower than for a conventional multi-step wet flue-gas cleaning system. Moreover, the dry cleaning system prevents waste water generation in the gas cleaning process.

Driving force for implementation
No data submitted.

Example plants
The technique has been tested in Spain at a biomass power plant of 3.5 MWth.

Reference literature
[377] [381]

10.1.4 Burning and recycling of dry waste dust

Description
This technique aims at treating dry dusts from integrated steelworks, e.g. BOF and BF dusts pyrometallurgical in a special reactor. By doing so, volatile and hazardous metals and compounds can be eliminated and a iron-rich fraction can be produced.

In this case, the reactor is of circular oval shape with 4.5 m length, 2.8 m width and 3.1 m height. The dusts are carried into the reactor by nitrogen. Upon entering the reactor, the carbon in the dust (up to 30 %) and additional propane are used as fuels for the oxy-fuel burner which creates an adiabatic flame temperature of 2200 - 2350 °C. At this temperature, the dust gets melted and forms slag droplets of liquid slag which are tapped every 2 - 3 hours. This ironoxide slag amounts for approx. 80 % of the input which can be recycled back to the BF process to utilise the iron value. The off-gas is led into an afterburner in order to further oxidise the metals and organics. The dust is separated in cassette filter and amounts for approx. 20 % of the input.

The main parts of the equipment are:

- the transport system for the dusts
- the stock station for the dusts
- the weighing device for the dusts
- the pneumatic transporting system for the dusts to the reactor
- the reactor equipped with an oxy-fuel burner (AGA) and with a tapping hole
- the post combustion and cooling system for the exhaust gas
- the cassette filter
- an additional device for instrumentation and for process control.

The capacity of the pilot plant is 20000 tonnes of handled dusts as a maximum. In the case of Ovako Koverhar, the main dusts are BF dust and BOF dust. The total yearly dust amount is 20000, which corresponds to the maximum capacity of the plant.

The product coming out of the reactor consists of approximately 50 % Fe in the form FeO/Fe3O4. The zinc content is typically 0.1 - 0.2 % and the K2O content is 0.5 - 1.0 %. The product is suitable for recycling in the blast furnace.

The amount of cassette filter dust is 15 - 20 % of the dust input. The zinc content in this dust is approximately 10 % and alkali (K2O+Na2O) content is 20 - 30 %. An external company handles this dust.

Achieved environmental benefits
The BF dust is classified as problematic dust. BOF dust is a serious environmental hazard, but which is possible to put into the corresponding stocking yard.
After scale up, the whole of the dusts of the integrated steelwork can be treated in this plant. The amount of dusts to be landfilled is reduced by approx. 80 %. By the pyrometallurgical treatment and by afterburning the dusts to be landfilled can be regarded as less hazardous.

The emissions after the cassette filter are less than 5 mg/Nm³.

The energy efficiency of the process is high, because the need for external energy is minimal. (C-content in the BF dust is 20 - 30 %).

Cross-media effects
No data submitted.

Operational data
The metallurgy of the process is working well in principle, but the equipment needs some further developmental work.

Applicability
The applicability of the process for the handling of dry dusts is expected to be good. The main purpose for developing this technique was to treat BF and BOF dusts from steelworks, but it can be assumed that it is suitable for the treatment of a wide range of metallurgical production residues.

Economics
The handling of the dusts by an external company is more expensive compared to handling the dusts on-site, especially when the whole capacity of the plant is in use.

Driving forces for implementation
The driving forces for implementation include:

- a significant improvement in environmental performance
- savings in the total costs
- potential for engineering activities.

Example plants
Ovako, Koverhar, Finland.

Reference literature
[208]

10.2 Emerging techniques for sinter plants

10.2.1 Waste gas cleaning with a high temperature metallic filter

Description
The high temperature metallic filter operates on similar principles to conventional pulse jet bag filters, except that it uses cylinders of fine stainless steel mesh as the filter modules rather than bag bags. The basis of the filter is that a filter cake is developed on the metallic mesh and this acts as the actual filtration medium. The filter is cleaned by use of a reverse pulse of air and, after cleaning, the filter compartment is kept offline and the filter cake is re-established by internally recirculating dust laden gas through the filter.

State of development: The feasibility of using high temperature metallic filters on sinter plants was demonstrated with financial support from the ECSC using a pilot scale filter. A larger scale demonstration project, again supported financially by the ECSC, is currently being carried out to evaluate the performance of the filter when operated continuously. The demonstration plant is around one-twentieth of the full scale.
One advantage is that this technique overcomes limitations associated with economically priced bag materials, e.g., temperature limits, sensitivity to moisture, bag blinding from hydrocarbons, release of sticky dusts, corrosive effects of acid gases. There is the potential to operate the metallic filter at a higher filtration velocity which can be used in conjunction with carbon or alkaline injectants for the removal of PCDD/F and waste gas desulphurisation. Used filter modules can be recycled by charging to an electric arc furnace.

Some trials have been also carried out injecting activated carbon and lignite coke powders to reduce PCDD/F, PAH and PCB emissions.

**Achieved environmental benefits**

Depending on the configuration, dust emission concentrations of 3 - 20 mg/Nm$^3$ have been achieved. When the filter was used in parallel with an existing ESP, i.e. with the same inlet dust burden and particle size range as the ESP, dust emission concentrations of <5 mg/Nm$^3$ were achieved. When the filter was located downstream of the ESP, with dust inlet loadings of 20 - 40 mg/Nm$^3$ and particle size range mainly <PM$_{10}$, dust emission concentrations were generally 10 - 20 mg/Nm$^3$.

Efficiencies achieved have been about 99.9 % with an inlet dust loading of 8 g/Nm$^3$.

Trials injecting 50 - 250 mg/Nm$^3$ of activated carbon and lignite coke powders have reduced PCDD/F concentration to 0.1 - 0.2 ng I-TEQ/Nm$^3$ (compared to 1 ng without injection of powders). Emissions of PAH were reduced by about 75 % and PCB by about half.

**Cross-media effects**

Energy consumption is similar to that of a bag filter of similar size. The location of the filter downstream of an ESP affords the possibility of segregating dust that is rich in alkali metals and chlorides from other materials that are more amenable to recycling via the sinter plant.

**Operational data**

Future developments will be dependent on the outcome of the existing demonstration plant trials. A pressure drop of 16 - 22 mbar is not dissimilar to values encountered on bag filters.

**Applicability**

This technique can be regarded as an end-of-pipe technology that is applicable to existing or new sinter plants. It provides an alternative to bag filter for use in high temperature applications in aggressive environments.

**Economics**

Investment costs and operating costs would be similar to those of a bag filter. However, filter modules in the high temperature metallic filter are expected to have a much longer life than bag bags, leading to lower replacement costs.

**Driving force for implementation**

No data submitted.

**Example plants**

No full scale reference plants are in operation yet.

**Reference literature**

[316] [389]
10.2.2 Use of carbon impregnated plastics for PCDD/F adsorption

**Description**
Plastics are widely used in the construction of flue-gas cleaning equipment due to their excellent corrosion resistance. PCDD/F are adsorbed on to plastics (polymers which contains carbon particulates) and they are typically implemented after other waste treatments (e.g. wet scrubbers).

**Achieved environmental benefits**
For the waste incineration sector, the following results are reported: with inlet concentrations of 6 - 10 ng TEQ/Nm³, gas phase removal efficiencies in the range of 60 - 75 % are reported across a wet scrubber. This compares with 0 - 4 % without the impregnated packing material. Absorption efficiency is reported not to have declined over the test period (one year). Using a dry system instead of a wet scrubber, the removal efficiency is higher (over 97 % in one test of nine months of operation) since the water film in a wet scrubber poses a mass transfer limitation for the PCDD/F.

**Cross-media effects**
The adsorption material becomes saturated after a certain period of time. Therefore the charged material can periodically be removed for disposal or, if permitted, burned in the furnace.

**Operational data**
No data submitted.

**Applicability**
The use of carbon impregnated plastics is applied in the waste incineration sector but not yet applied in the iron and steel sector. The technique can also be used in a more extensive tower packing installation and/or in combination with subsequent upstream or downstream dioxin flue-gas treatment. Working temperatures are between 60 - 80 °C.

**Economics**
No data submitted.

**Driving force for implementation**
Driving force is the abatement of PCDD/F emissions to met permit requirements.

**Example plants**
No data submitted.

**Reference literature**
[239] [437]

10.2.3 Quenching
Another method to suppress PCDD/F formation in the windboxes may be rapid quenching of the hot off-gas by injecting cold water mist into the windboxes. The injection should again take place as close as possible to the bottom of the sinter bed in order to suppress the PCDD/F formation (T<260 °C) [265].
10.3 Emerging techniques for coke ovens

10.3.1 Super coke oven

An example of a super coke oven is the project SCOPE 21 in Japan from which a description of a pilot unit in Nagoya is given here. SCOPE 21 stands for super coke oven for productivity and environment enhancement toward the 21st century.

A national Japanese project was launched by the Japan iron and steel federation (JISF) in the nineties to develop a next-generation coke oven. The target of this project was to develop an innovative coke production process that features environmental friendliness, energy efficiency, and high productivity.

SCOPE 21 was finished in 2003. Studies were supported by all of the major Japanese steelmakers (NSC, KSC, NKK, Sumitomo Metals etc.) in co-operation with universities. At the moment several activities are under way with a view toward applying this process with actual equipment.

Description

The idea of the project SCOPE 21 is to combine and associate well known coke plant techniques such as:

1. preheating of the coal blend to 350 - 400 °C in a fluidised bed with the possibility of partial briquetting
2. transporting and charging the blend by gravity without emissions by means of feeders
3. carbonising the charge in a classical oven built with super dense silica bricks showing a very high thermal conductivity and equipped with tightly sealed doors. The total coking time is between 6 - 8 hours and the final temperature of the coke is 850 °C
4. discharging the coke in a dry quenching facility where the temperature of the coke is first increased to 1000 °C in the prechamber, then dry cooled for transportation.

All material movements are executed in a closed transport system. The dimensions of the pilot oven are at half the industrial scale (height: 7.5 m; length: 8 m; width: 450 mm). Figure 10.2 below gives the flow sheet of the process.
Results

Studies on the economic optimisation of the overall system have found that a coking plant with the SCOPE 21 coking plant could lead to the following reported advantages:

- higher productivity, increased by 2.4 times comparing to a conventional coke oven
- better coke quality
- increase in the rate of non or slightly caking coal to 50 %
- savings of 20 % in the energy consumed in the coke making process
- reduction in NOX emissions by 30 %
- prevention of smoke and dust.

10.3.2 Single oven pressure control (SOPRECO) technique

At the time of writing this document in conventional coke plants, the distillation gas flow from a single oven to the collecting main is controlled by an on/off valve. This system is based on a modification of this valve, optimised by experience and CFD simulations.

The system is based on a special valve driven by a hydraulic or pneumatic actuator and controlled by the pressure in the ascension pipe. The valve is properly shaped to operate in the full range of flowrate conditions over the whole coking cycle.

A continuous control of the oven pressure during the distillation time can prevent overpressure during the first phase of the process, by maintaining a negative pressure in the collecting main; this permits a full reduction of the emissions from doors, charging holes, etc.

Moreover, a continuous oven pressure control prevents negative relative pressure at the oven bottom during the last phase of distillation when the coke gas flowrate is low. Due to the possible air infiltration with consequent coke combustion and material damage at the hearth level, it is necessary to prevent a pressure lower than atmospheric. Therefore, the advantages of a coke oven pressure control concerns both emission reduction (during the first part of distillation) and prevention of oven air infiltration (during the last part of distillation).
This system was originally designed to be installed in existing operating batteries without significant modifications, and without affecting the plant operation. In case of failure, the system can be easily and immediately converted to the conventional operational mode. These are the main advantages compared with other existing systems. However, for new plants, a new valve design, suggested by CFD simulations, has been designed in order to obtain an even better pressure control.

The system has been installed in oven number 45 in Lucchini, Piombino, Italy coke plant, showing full reliability and good operation. In March 2006 Sollac Mediterranée decided to install a this system in the new coke oven battery at ArcelorMittal, Fos sur Mér, France. This plant is now in the commisioning phase.

The following Figure 10.3 shows the simple geometry of SOPRECO valve to be installed in existing operating coke ovens.

Figure 10.3: Sopreco valve

[320] [343]
In Figure 10.4, the general Sopreco system scheme is shown.

10.3.3 Alternatives in coke oven gas (COG) utilisation

For some coke oven plants for different reasons it is reasonable to deviate from the conventional utilisation of coke oven gas. Alternative utilisation possibilities require different methods and processing steps of coke oven gas pretreatment. The options investigated for coke oven gas utilisation focus on hydrogen recovery, methanol synthesis, steam generation for electric power generation and the use as a reducing agent in the blast furnace (BF) or direct reduction (DR) plant operation. These alternative potentials for the utilisation of coke oven gas are subject to an overall assessment giving consideration to the relevant steelworks infrastructure. The benefits from direct and indirect coke oven products are dependent on the specific local and operational works requirements.

For the energetic utilisation of COG, an alternative option to the classical heat recovery is to discharge the approx. 800 °C hot raw gas from the coke oven uncooled and lead it directly to a combustion or partial oxidation system. This technique has not reached industrial application because a promising technical solution for pressure control of the individual oven chambers under high temperature conditions does not yet exist.
Other options for alternative COG utilisation include:

- the injection of COG and tar as auxiliary reducing agents into the BF. This technique has already been put into practice.
- Use of COG as a reducing agent for the production of direct reduced iron (DRI) or hot briquetted iron (HBI). For the DRI production, when utilising coke oven gas as reducing agent, an additional production process is needed. In this case, the coke oven gas is partially cleaned.

10.4 Emerging techniques for blast furnaces

[233] [356]

10.4.1 Reduction of CO emissions from hot stoves with an internal combustion chamber

**Description**
In Section 6.1.4, the two basic designs of hot stoves (with internal or with external combustion chambers) are described. In the case of internal combustion chambers, high emissions of CO occur as a result of leaks from cracks in the refractory mass. This leakage seems to be inevitable and leads to emissions of unburned gas. It is, however, possible to reduce leakage by inserting steel sheets of an appropriate grade into the refractory wall during relining.

**Achieved environmental benefits**
The impact of cracks (high CO emissions) can be significantly reduced. Results from measurement before and after inserting steel sheets are yet not available.

**Status**
This measure has already been introduced at one integrated steelworks in the EU-27.

10.4.2 Slag heat recovery

**Description**
Liquid slag from the blast furnace contains a large amount of sensible heat. Its temperature is approximately 1450 °C and around 250 - 300 kg/t hot metal is produced in modern blast furnaces. None of the commercially applied systems in the world utilise this potential energy source. This is mainly caused by the technical difficulties in developing a safe, reliable, and energy efficient system, which in addition does not influence the slag quality.

**Achieved environmental benefits**
The estimated energy savings are approximately 0.35 GJ/t hot metal.

**Status**
Tests were carried out at the end of last decade. No commercial application is known yet.

**Reference literature**
[65]

10.4.3 Injection of waste in blast furnaces

Investigations have been carried out for the use of oil-contaminated mill scale together with fly ash. Injection rates up to 100 kg/t hot metal were tested [238].
10.5 Emerging techniques for BOF and casting

10.5.1 Improvement of BOF slag stability for extended use

Description
The use of BOF slag in civil engineering is limited due to its content of free lime that influences the volume stability. Recently, a treatment process for liquid slag has been developed to overcome this problem. After tapping the slag into the slag pot, the liquid slag is treated by injection oxygen and sand (SiO$_2$). By doing this, the free lime is bound into stable phases and the resulting slag aggregates are volume stable. Furthermore the environmental behaviour of the slag can be improved.

Status
This processing step was developed in a research project finished in 1998. At the time of writing this document it is used in two European basic oxygen steelmaking plants. Realisation strongly depends on the market demand of civil engineering and the political conditions on the broader use of this by-product.

The process is much more difficult to control than expected; the viscosity can create problems for the reactivity and the homogeneity. The technical problems are solved globally. The predictability of batch suitability to be treated to obtain the desired quality has improved. The current trial steps are the process optimisation and the cost reduction. Reference plants are ThyssenKrupp Steel Beeckerwerth, Duisburg, Germany and ArcelorMittal, Gent, Belgium.

Main achievements
With stability improvement, the requirements of slag use in civil engineering can be fulfilled. In road construction, slag replaces natural resources and prevents emissions in the production process of the natural material. The saving by the use of slag can be twice the volume of slag because of better load bearing and thermal insulation properties. This is the base for better resource efficiency of the input raw material in steelmaking and a reduction in necessary landfill.

Reference literature
[363]

10.5.2 Improving clean gas dust content in wet scrubber based BOF plants by upgrading to Hydro-Hybrid-Filters

Description
Most BOF plants worldwide are equipped with a wet scrubber based gas cleaning plant. These plants can usually achieve residual dust contents of between 30 and 50 mg/Nm$^3$.

Upgrading the existing plant by a downstream installation of a small wet electrostatic precipitator (wet ESP) can further reduce the clean gas dust emissions. The combined system is a so called 'Hydro-Hybrid-Filter'.

The idea is that the cleaning of the BOF gas is no longer based on only the existing scrubber. The scrubber acts as a prededusting devise to precipitate coarse dust and as a cooling and conditioning tower for the downstream ESP. The pressure loss of the wet scrubber can be reduced significantly and hence, power consumption of the fan can be reduced.

The downstream wet ESP is a small unit consisting of one or more fields only as the dust content of the gas is already significantly reduced by the scrubber. Furthermore, the gas volume decreases due to low temperature.
Already existing equipment such as the fan or water treatment devices etc. can be further used with few or no modifications. Existing BOF gas recovery is not affected by this modification.

**Status**
The technique is under development.

**Achieved environmental benefits**
Hydro-Hybrid-Filter systems can achieve clean gas dust emissions of $\leq 10 \text{ mg/Nm}^3$. Additional energy consumption of the ESP will be over-compensated for by reduced energy consumption of the fan.

**Cross-media effects**
No data submitted

**Applicability**
The technique is under development.
Installation is possible in all existing BOF plants with a wet scrubber gas cleaning plant. New plants would preferably be equipped with dry ESP techniques.

**Economics**
Due to the small size of the additional ESP and further use of existing equipment investment costs are low.

Operating costs can be reduced due to a decreased differential pressure of the scrubber which consequently reduces electric power consumption of the fan.

**Driving force for implementation**
The relatively low investment costs for upgrading existing wet scrubber based gas cleaning systems to meet local emission standards may lead to the implementation of the Hydro-Hybrid-Filter where a complete replacement of wet scrubbers is not feasible.

**Example plants**
The technique is currently under development.

**Reference literature**
Patent application
[489]

### 10.5.3 Whirl hood for secondary dedusting

**Description**
Dust sources as caused by tapping the converter or by charging scrap into the converter are difficult to capture because the converter is tilted out of its upright position and the fume is escape diffuse to the production hall. The production steps need some free space above the lids of the converter for the crane and the scrap basket. Therefore, the suction hood should have some distance to the dust source. To get a good capture ratio in the secondary dedusting system in spite of the construction conditions, there are different suction hood designs. A new development is the “whirl hood” or “hurricane hood”. There is an air roll produced in the hood by evacuating the air at both sides on the axes of the roll. These flow conditions move the particles in the axial area of the air roll by the pressure distribution in the roll and they are evacuated through the opening of the two opposite suction pipes to the dedusting system. It is important that the evacuation pressure in the roll suction hood be strong enough to ensure stability.
Status
The engineering of this type of suction hood has been developed some years ago by a consultant. There are some first experiences with charging in some steelworks and a new system will be built in the near future.

Achieved environmental benefits
If the system is well designed, it should be able to reach a better capture rate of fugitive sources which cannot be evacuated directly at the source itself. It is not possible to quantify this effect because the capture cannot be measured and must be estimated by judgement of visible dust emissions. There are no results in operation facilities to compare this design with because any change in the suction system is also accompanied by an improvement of the compliance of the whole suction system.

Reference literature
[363]

10.5.4 Recycling of BOF and EAF slags as a flux agent in electric steelmaking

Description
Several possibilities have been tested:

a) recycling of liquid ladle slag into the EAF. A recycling rate of 80 % has been achieved
b) recycling of solid ladle slag into the EAF. Around 15 % of lime has been substituted by ladle slag in a ratio of 1:2. About 50 % of the generated ladle slag can be recycled
c) recycling of spent refractory materials from EAF, BOF and secondary metallurgy. Careful processing and quality controls are a prerequisite in recycling.

Achieved environmental benefits
a) no processing of the slag is necessary.
b) no processing of the slag is necessary.
c) spent magnesite is a suitable substitute for olivine and of soft-burnt dolomite.

Cross-media effects
a) some increases in the total energy consumption can be seen due to the additional opening of the furnace.

Operational data
a) no detrimental impact has been observed on the quality of steel in the EAF
b) handling of solid materials has the advantage that a selection of favoured slag composition is possible. Some minor effects with respect to metallurgy and steel quality are induced.

Applicability
c) a recycling test have been carried out at sinter plant, blast furnace burden and the BOF converter.

Economics
b) the operational costs are counterbalanced by savings in lime. Economic benefits are due to the reduced amount of dumped ladle slag.

Driving force for implementation
A step towards steelmaking without residues is the driving force for implementation.

Example plants
RIVA Acciaio, Verona Works, Italy; Krupp Edelstahlprofile (KEP), Siegen, Germany; EKO Stahl, Eisenhüttenstadt, Germany.
10.6 Emerging techniques for EAF

10.6.1 Contiarc furnace

Description

The Contiarc furnace is a direct current arc furnace with an annular shaft formed by an outer and inner vessel. The furnace operates continuously with raw material being charged into the top of the annular shaft. The submerged, continuous nature of the furnace makes it more energy-efficient than the cupola. In addition, it is now possible to both melt and smelt iron in the same furnace system producing 80 tonnes/hr while melting and smelting. The furnace can take low-grade scrap (automobile shreddings), direct reduced iron (DRI) and/or hot briquetted iron (HBI) and combine it with coal and silica rock to produce quality ductile base iron with 3.5 % carbon (C) and 2.5 % silicon (Si).

The furnace is charged automatically through a hopper system that feeds a conveyor to the top of the furnace. Once the charge reaches the top of the furnace, it is deposited into one of eight hoppers that are positioned in a rotating carousel around the top of the furnace. The computerised charging system works in unison with the computerised furnace control system to determine where within the annular shaft a charge is required.

By maintaining a full stack of charge material, the heat content of the furnace gases acts as a preheater for the charge material. Due to the volume of gas, stack permeability is not an issue; however, the charge material must be sized properly to prevent bridging in the stack.

The continuous arc melting concept is driven by the central cathode (graphite electrode) inside the inner vessel and the corresponding conductive bottom anode. In a traditional arc furnace, when a charge is added, the electrode rises to the top of the charge. In the continuous arc furnace, the inner vessel keeps the electrode submerged. The central graphite electrode is protected against damage from falling scrap by the inner vessel. Its tip operates at a distance below the bottom of this vessel so that the long direct current arc burns between the electrode and the molten metal bath. The shell is shielded from the radiation of the direct current arc by charge materials.

The completely encapsulated melter ensures a reducing atmosphere in the lower part of the furnace and a slightly oxidising condition in the shaft to achieve the desired process metallurgy and a utilisation of gases. In addition, this design results in low losses of oxidised iron or silicon. A bag house system captures emissions.
Main achievements
The Contiarc furnace is designed to perform both melting and smelting operations. This provides the following advantages:

- the ability to melt low cost and abundant shredded scrap, borings, HBI and/or DRI (thus maintaining tramp element control)
- quartz (SiO), through gravel used in the construction industry, can be substituted for high cost ferrosilicon as a means of developing the necessary silicon level in the melt
- coal can be used instead of coke during melting to carburise the base metal and reduce the quartz because the carbon product is not required for heat generation
- without the use of coke, the sulphur level of the molten metal is reduced
- there is less slag with the Contiarc than that associated with the cupola since it is a reduction furnace which means that many oxides that normally act as slag are reduced back into the metal
- during melting, temperature control in the Contiarc furnace is flexible meaning it can be adjusted by a simple variation of the current/voltage ratio. This allows the iron to be superheated before tapping.

Example plants
In July 2001, the first continuous submerged direct current electric arc (Contiarc) furnace went into operation at ACIPCO, Birmingham, US.

10.6.2 Recycling of stainless steel dust by injection into the EAF

Description
Dust recycling plant tests by co-injection with carbon and/or FeSi as reducing agents were carried out.

Achieved environmental benefits
FeSi use as a further reducing agent has allowed for reaching recovery of Cr, Mn, Ni and Fe respectively of 81, 38, 97 and 93 %. In addition, this practice leads to a decrease of the chrome oxidation in the slag at least by 20 % but nevertheless with chromium oxide content still relatively high.

These trials also allowed for verifying that the slag foaming increases the electric power efficiency by at least 20 % in spite of a higher arc voltage.

Cross-media effects
The zinc content in the new dust increases significantly depending of the zinc content in the recycled dust.

Operational data
No data submitted.

Applicability
No data submitted.

Economics
Calculations showed that annual operating costs can be reduced by 9 % with the use of this technique.

Driving force for implementation
No data submitted.

Example plants
Pilot projects in Krupp Edelstahlprofile (KEP), Siegen, Germany.
Chapter 10

Reference literature
[391]

10.6.3 Intermetallic bag filter to minimise emissions of dust, PCDD/F and heavy metals

Description
An intermetallic bag filter with high temperature resistance combines filtering and catalytic operations and allows for a drastic decrease in dust and associated pollutant emissions.

Achieved environmental benefits
In pilot tests at LME Trith-Saint-Léger, France, dust reduction efficiency of 99.9%, PCDD/F reduction efficiency of more than 95% and heavy metal reduction efficiency of 95 - 100% (except for heavy metals present in the gas phase like mercury) were achieved. Moreover, energy can be saved as a consequence of moderate waste gas cooling. This technique should be operated at 350 - 550 °C whereas traditional cleaning is operated at 150 - 200 °C.

Cross-media effects
No data submitted.

Operational data
No data submitted.

Applicability
No data submitted.

Economics
No data submitted.

Driving force for implementation
No data submitted.

Example plants
No data submitted.

Reference literature
[415]

10.6.4 Recovery of old tyres in EAF

Description
As has been applied in cement plants, old tyres (which represent 2.2 Mt/yr in Europe, 1999) can be recovered and can replace coal (anthracite) in electric steelmaking. An optimised recovery process in EAF requires an adapted addition of tyres, charged at the right place, neither on top nor at the bath bottom, and oxygen lances have to be operated in such a way as to prevent post-combustion anywhere else than in the arc furnace.

Achieved environmental benefits
This technique allows for both recovery of old tyres and decrease in the demand of coal mining.

Cross-media effects
Recovery of old tyres does not give extra emissions in terms of PCDD/F, heavy metals, PAH, SO₂, and VOC) and does not demand extra energy.
Operational data
No data submitted.

Applicability
No data submitted.

Economics
No data submitted.

Driving force for implementation
No data submitted.

Example plants
In pilot tests at Ascometal Hagondange, France; SAM Neuves-Maisons, France and LME Trith-Saint-Léger, France, a substitution rate of 1.7 kg old tyres for 1 kg anthracite was achieved. An addition of 5 - 12 kg old tyres/t LS is achievable if tyres are cut into small pieces a length of no more than 10 - 15 cm. In 2006, LME Trith-Saint-Léger, France had a treatment capacity of 7000 t old tyres/yr.

Also ArcelorMittal, Belval and Differdange, both in Luxembourg have carried out some trials.

Reference literature
[415]

10.6.5 Recycling of (BOF and EAF) slags as a flux agent in electric steelmaking

For details of this technique, see Section 10.5.4.
11  CONCLUDING REMARKS

To be written after completion of the BREF
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<td>Internet publication</td>
</tr>
<tr>
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<td>Prof. Dr. Ameling, VDEh</td>
<td>Presentation</td>
</tr>
<tr>
<td>[480, 2006]</td>
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<td>IEA Clean coal centre, Anne carpenter</td>
<td>Internet publication</td>
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<tr>
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<td>Infomil contribution according to a specific request related to the I&amp;S BREF draft sent in February 2008</td>
<td>Infomil</td>
<td>e-mail</td>
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<td>[483, 2009]</td>
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<td>LKAB</td>
<td>e-mail</td>
</tr>
<tr>
<td>[488, 2009]</td>
<td>Introduction to PW Bell less top charging technology</td>
<td>Paul Wurth</td>
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<tr>
<td>[490, 2008]</td>
<td>Consteel EAF Technology- Instructive Document</td>
<td>Tenova, C. Giavani</td>
<td>e-mail</td>
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<tr>
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<tr>
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<td>Norwegian comments on the first draft</td>
<td>Norwegian TWG member</td>
<td>e-mail</td>
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<td>[493, 2008]</td>
<td>Comments from Luxembourg on the Iron and Steel BREF draft</td>
<td>Pierre Dornseiffer</td>
<td>e-mail</td>
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<td>[494, 2008]</td>
<td>Austrian comments on the first draft</td>
<td>Austrian TWG member</td>
<td>e-mail</td>
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<td>[496, 2006]</td>
<td>Stadtverwaltung Trier, Auskunft über die Trierer Stahlwerke GmbH</td>
<td>Bernhard Schmitt</td>
<td>Personal Communication</td>
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## References

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<th>Citation</th>
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<tr>
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<td>Der Einsatz von Sorbentien im gesamten System von Abgasreinigungsanlagen; LPN Consulting, Potsdam</td>
<td>Lutz-Peter Nethe</td>
<td>Publication</td>
</tr>
<tr>
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<td>Peter Kästli</td>
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<tr>
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<td>Recommendations on monitoring and response procedures for radioactive scrap metal</td>
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<tr>
<td>[508, 2007]</td>
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<td>Manfred Bergmann; Andreas Schmitz, Mark Hayden, Katri Kosonen</td>
<td>Publication</td>
</tr>
<tr>
<td>[512]</td>
<td>Proposal for Techniques for Solids Handling in Steelworks; 31 March 2009</td>
<td>Roy Caughlin</td>
<td>e-mail</td>
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<td>Citation</td>
<td>Title</td>
<td>Author(s)</td>
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<td>Steel Institute VDEh</td>
<td>Technical background paper</td>
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<td>Description of the DK-Process</td>
<td>Steel Institute VDEh e-mail</td>
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<tr>
<td>[523, 2008]</td>
<td>Description of the Oxyacup-Process</td>
<td>Wolfgang Volkenhausen e-mail</td>
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<td>[524, 2009]</td>
<td>Eurofer contribution according to a specific request from EIPPCB related to the waste water in general</td>
<td>Eurofer e-mail</td>
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<tr>
<td>[526, 1998]</td>
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<td>Rainer Remus Minutes</td>
<td></td>
</tr>
<tr>
<td>[527]</td>
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<td>C. Mensink et al.; VITO Flemish Institute for Technological Research</td>
<td>Publication</td>
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<tr>
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<td>David Mark Perryman Broom, Environment Agency</td>
<td>Publication</td>
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<tr>
<td>[531]</td>
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<td>SGS Belgium S.A.</td>
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<tr>
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<td>Steel Institute VDEh; R. Fandrich, H-B. Lüngen, C-D. Wuppermann</td>
<td>Publication</td>
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References
Glossary

Conversions

<table>
<thead>
<tr>
<th>Unit 1</th>
<th>Unit 2</th>
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<tr>
<td>2.05 mg NO₂/Nm³</td>
<td>= 1 ppmv NO₂</td>
</tr>
<tr>
<td>2.85 mg SO₂/Nm³</td>
<td>= 1 ppmv SO₂</td>
</tr>
<tr>
<td>1 W</td>
<td>= 1 J/s</td>
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Indications of emissions:

1. Emissions to air

- mass of emitted substances related to the volume of waste gas under standard conditions (273 K, 1013 mbar), after deduction of water vapour content, expressed in the units (g/Nm³), (mg/Nm³), (µg/Nm³) or (ng/Nm³)
- mass of emitted substances related to time, expressed in the units (kg/h), (g/h) or (mg/h)
- ratio of mass of emitted substances to the mass of products generated or processed (consumption or emission factors), expressed in the units (kg/t), (g/t), (mg/t) or (µg/t).

2. Emissions to water

- mass of emitted substances related to the volume of waste water, expressed in the units (g/m³), (g/l), (mg/l) or (µg/l).

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Ω</td>
<td>ohm</td>
</tr>
<tr>
<td>°C</td>
<td>degree Celsius</td>
</tr>
<tr>
<td>AC</td>
<td>Alternating current</td>
</tr>
<tr>
<td>AISI</td>
<td>American Iron and Steel Institute</td>
</tr>
<tr>
<td>AOD</td>
<td>Argon-oxygen-decarburization</td>
</tr>
<tr>
<td>AOX</td>
<td>Absorbable organically bound halogens</td>
</tr>
<tr>
<td>AS</td>
<td>Activated sludge</td>
</tr>
<tr>
<td>BF</td>
<td>Blast furnace</td>
</tr>
<tr>
<td>BOD</td>
<td>Biochemical oxygen demand</td>
</tr>
<tr>
<td>BOF</td>
<td>Basic oxygen furnace</td>
</tr>
<tr>
<td>Borneff 6</td>
<td>Sum of six PAH (Fluoranthene, Benzo[b]fluoranthene, Benzo[k]fluoranthene, Benzo[a]pyrene, Indeno[1,2,3-cd]pyrene and Benzo[g,h,i]perylene)</td>
</tr>
<tr>
<td>Bq</td>
<td>Bequerel</td>
</tr>
<tr>
<td>BTX</td>
<td>Benzene, Toluene, Xylene</td>
</tr>
<tr>
<td>ca.</td>
<td>circa</td>
</tr>
<tr>
<td>CAS-OB</td>
<td>Composition adjustment by sealed argon bubbling</td>
</tr>
<tr>
<td>CCF</td>
<td>Cyclone converter furnace</td>
</tr>
<tr>
<td>CCM</td>
<td>Continuous casting machine</td>
</tr>
<tr>
<td>CDQ</td>
<td>Coke dry quenching</td>
</tr>
<tr>
<td>CEN</td>
<td>European committee for standardization</td>
</tr>
<tr>
<td>CFD</td>
<td>Computational fluid dynamics</td>
</tr>
<tr>
<td>CHP</td>
<td>Combined heat and power</td>
</tr>
<tr>
<td>CNS</td>
<td>Thiocyanate</td>
</tr>
<tr>
<td>COD</td>
<td>Chemical oxygen demand</td>
</tr>
<tr>
<td>COG</td>
<td>Coke oven gas</td>
</tr>
<tr>
<td>COS</td>
<td>Carbon oxisulphide</td>
</tr>
<tr>
<td>CRI</td>
<td>Coke reactivity index</td>
</tr>
<tr>
<td>CSQ</td>
<td>Coke stabilisation quenching</td>
</tr>
<tr>
<td>CSR</td>
<td>Coke strength after reaction</td>
</tr>
<tr>
<td>CV</td>
<td>Calorific value</td>
</tr>
<tr>
<td>DAV</td>
<td>Daily average</td>
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<tr>
<td>DC</td>
<td>Direct current</td>
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### Glossary

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<td>DCI</td>
<td>Direct carbon injection</td>
</tr>
<tr>
<td>DH</td>
<td>Dortmund-Hörder</td>
</tr>
<tr>
<td>Diffuse emission:</td>
<td>Diffuse emissions occur during regular operation such as coal and coke handling, transport of coal and coke, coal blending beds, ascension pipes, coke pushing, coke quenching; if not captured they can be released by the roof, roof-hatch, window or from stored material. Minimisation is possible only by prevention and/or further treatment after transferring them into ducted emissions (i.e. by capturing them) (see Section 5.2.2.1)</td>
</tr>
<tr>
<td>DIOS</td>
<td>Direct iron ore smelting reduction</td>
</tr>
<tr>
<td>DOC</td>
<td>Dissolved organic carbon</td>
</tr>
<tr>
<td>DR</td>
<td>Direct reduction</td>
</tr>
<tr>
<td>DRI</td>
<td>Direct reduced iron</td>
</tr>
<tr>
<td>DSI</td>
<td>Direct sample induction</td>
</tr>
<tr>
<td>EAF</td>
<td>Electric arc furnace</td>
</tr>
<tr>
<td>ECSC</td>
<td>European Union for Coal and Steel</td>
</tr>
<tr>
<td>ELPI</td>
<td>Electrical low pressure impactor</td>
</tr>
<tr>
<td>ELV</td>
<td>Emission limit value</td>
</tr>
<tr>
<td>EMS</td>
<td>Environmental management system</td>
</tr>
<tr>
<td>EMAS</td>
<td>Eco-Management and Audit Scheme</td>
</tr>
<tr>
<td>EN ISO 14001</td>
<td>European norm (EN) published by the International Organisation for Standardisation (ISO) concerning environmental management standards.</td>
</tr>
<tr>
<td>EOS</td>
<td>Emission optimised sintering</td>
</tr>
<tr>
<td>EPA</td>
<td>Environmental Protection Agency (US)</td>
</tr>
<tr>
<td>ESP</td>
<td>Electrostatic precipitator</td>
</tr>
<tr>
<td>ESCS</td>
<td>Electrostatic space cleaner super</td>
</tr>
<tr>
<td>ETP</td>
<td>Electrostatic tar precipitator</td>
</tr>
<tr>
<td>EU-10</td>
<td>Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia and Slovenia</td>
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<tr>
<td>EU-15</td>
<td>Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden and the United Kingdom</td>
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<td>EU-25</td>
<td>EU-10 + EU-15: Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden and the United Kingdom</td>
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<td>EU-27</td>
<td>Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and the United Kingdom</td>
</tr>
<tr>
<td>EUR</td>
<td>Euros (European currency)</td>
</tr>
<tr>
<td>FF</td>
<td>Fabric filter</td>
</tr>
<tr>
<td>Fugitive emissions</td>
<td>Fugitive emissions happen during irregular operation from leakages at the battery, e.g. because of leakage of vessels, oven doors, flanges etc. or at the by-product plant. For minimisation the first option is prevention by good maintenance. PAH compounds, like benzo(a)pyrene (BaP), and benzene play an important role with regard to fugitive emissions (see Section 5.2.2.1)</td>
</tr>
<tr>
<td>g</td>
<td>gram</td>
</tr>
<tr>
<td>GSA</td>
<td>Gas suspension absorber</td>
</tr>
<tr>
<td>HBI</td>
<td>Hot briquetted Iron</td>
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<tr>
<td>HCB</td>
<td>Hexachlorobenzene</td>
</tr>
<tr>
<td>HHAV</td>
<td>Half-hourly average</td>
</tr>
<tr>
<td>HM</td>
<td>Hot metal</td>
</tr>
<tr>
<td>h</td>
<td>hour</td>
</tr>
<tr>
<td>IISI</td>
<td>International Iron and Steel Institute</td>
</tr>
<tr>
<td>I-TEQ</td>
<td>PCDD/F toxicity equivalent</td>
</tr>
<tr>
<td>IUPAC</td>
<td>International Union of Pure and Applied Chemistry</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
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<tr>
<td>--------------</td>
<td>-------------</td>
</tr>
<tr>
<td>J</td>
<td>joule</td>
</tr>
<tr>
<td>K</td>
<td>kelvin</td>
</tr>
<tr>
<td>kWh</td>
<td>Kilowatt-hour (1 kWh = 3.6 MJ)</td>
</tr>
<tr>
<td>l</td>
<td>litre</td>
</tr>
<tr>
<td>LD</td>
<td>Linz-Donawitz</td>
</tr>
<tr>
<td>LEEP</td>
<td>Low emission and energy optimised sintering process</td>
</tr>
<tr>
<td>LPG</td>
<td>Liquified petroleum gas</td>
</tr>
<tr>
<td>LS</td>
<td>Liquid steel</td>
</tr>
<tr>
<td>LWS</td>
<td>Loire-Wendel-Sprunch process</td>
</tr>
<tr>
<td>m</td>
<td>metre</td>
</tr>
<tr>
<td>m²</td>
<td>square metre</td>
</tr>
<tr>
<td>m³</td>
<td>cubic metre (water)</td>
</tr>
<tr>
<td>MEA</td>
<td>Monoethanolamine</td>
</tr>
<tr>
<td>MEERP</td>
<td>Moving electrodes Electrostatic Precipitator</td>
</tr>
<tr>
<td>MEROS</td>
<td>Maximised emission reduction of sintering</td>
</tr>
<tr>
<td>MHF</td>
<td>Multiple hearth furnace</td>
</tr>
<tr>
<td>MLSS</td>
<td>Mixed liquor suspended solids</td>
</tr>
<tr>
<td>MWₚ</td>
<td>Megawatt electric (power)</td>
</tr>
<tr>
<td>NG</td>
<td>Natural gas</td>
</tr>
<tr>
<td>Nm³</td>
<td>Normal cubic metre (273 K, 1013 mbar)</td>
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<tr>
<td>NMVOCs</td>
<td>Non-methane volatile organic compounds</td>
</tr>
<tr>
<td>OBM</td>
<td>Oxygen-bottom-blowing Maxhuette process</td>
</tr>
<tr>
<td>OCP</td>
<td>Open circuit process</td>
</tr>
<tr>
<td>PAH</td>
<td>Polycyclic Hydrocarbons</td>
</tr>
<tr>
<td>PCB</td>
<td>Polychlorinated biphenyls</td>
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<tr>
<td>PCDD/F</td>
<td>Polychlorinated dibenzo-p-dioxins/dibenyo-furans</td>
</tr>
<tr>
<td>PCI</td>
<td>Pulverised coal injection</td>
</tr>
<tr>
<td>PM</td>
<td>Particulate matter (dust)</td>
</tr>
<tr>
<td>PM₁₀</td>
<td>Fine liquid or solid particles such as dust, smoke, mist, fumes, or smog, found in air or emissions. Particles are smaller than 10 microns.</td>
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<tr>
<td>POM</td>
<td>Polycyclic organic matter</td>
</tr>
<tr>
<td>POPs</td>
<td>Persistent organic pollutants</td>
</tr>
<tr>
<td>ppm</td>
<td>parts per million (by weight)</td>
</tr>
<tr>
<td>ppmv</td>
<td>parts per million, (by volume)</td>
</tr>
<tr>
<td>pre-DN/N</td>
<td>Pre-denitrification/nitrification</td>
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<tr>
<td>RAC</td>
<td>Regenerative activated carbon</td>
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<tr>
<td>RAFT</td>
<td>Raceway adiabatic flame temperature</td>
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<tr>
<td>RH</td>
<td>Ruhrstahl-Heraeus</td>
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<tr>
<td>s</td>
<td>Second</td>
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<tr>
<td>SCOPE 21</td>
<td>Super coke oven for productivity and environment enhancement in the 21st century</td>
</tr>
<tr>
<td>SCR</td>
<td>Selective catalytic reduction</td>
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<tr>
<td>SS</td>
<td>Suspended solids</td>
</tr>
<tr>
<td>SR</td>
<td>Smelting reduction</td>
</tr>
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<td>SRF</td>
<td>Smelting reduction furnace</td>
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<tr>
<td>STP</td>
<td>Standard temperature and pressure</td>
</tr>
<tr>
<td>t</td>
<td>metric tonne (1000 kg or 10⁶ gram)</td>
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<tr>
<td>TEQ</td>
<td>Toxic equivalent quantity</td>
</tr>
<tr>
<td>TEF</td>
<td>Toxic equivalent factor</td>
</tr>
<tr>
<td>TBM</td>
<td>Thyssen-blowing-metallurgy process</td>
</tr>
<tr>
<td>TOC</td>
<td>Total organic carbon</td>
</tr>
<tr>
<td>TWG</td>
<td>Technical working group</td>
</tr>
<tr>
<td>UHP</td>
<td>Ultra high power operation</td>
</tr>
<tr>
<td>ULCOS</td>
<td>Ultra Low CO₂ Steelmaking. EC funding research programme to reduce CO₂ emissions from steelmaking.</td>
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### Glossary

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>VDI</td>
<td>Verein Deutscher Ingenieure</td>
</tr>
<tr>
<td>VOC</td>
<td>Volatile organic compounds</td>
</tr>
<tr>
<td>VOD</td>
<td>Vacuum-oxygen-decarburisation</td>
</tr>
<tr>
<td>vol-%</td>
<td>Percentage by volume</td>
</tr>
<tr>
<td>wt-%</td>
<td>Percentage by weight</td>
</tr>
<tr>
<td>W</td>
<td>Watt</td>
</tr>
<tr>
<td>Wobbe index</td>
<td>The Wobbe Index (WI) is an indicator of the interchangeability of fuel gases such as natural gas, liquified petroleum gas (LPG), and Town Gas and is frequently defined in the specifications of gas supply and transport utilities. If $V_c$ is the higher heating value, or calorific value, and $G_s$ is the specific gravity, the Wobbe Index, $I_W$, is defined as: $I_W = V_c / (G_s)^{1/2}$</td>
</tr>
<tr>
<td>WWTP</td>
<td>Waste water Treatment Plant</td>
</tr>
<tr>
<td>WHO TEFs</td>
<td>World Health Organisation toxic equivalent factors. This toxic equivalency factor (TEF) value is the only one for currently taking into account not only PCDD and PCDF values but 'dioxin-like' PCBs [219]</td>
</tr>
<tr>
<td>yr</td>
<td>Year</td>
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</table>
12 ANNEXES

12.1 Annex I. Determination of some environmental sensitive elements in waste water

[208]

**Description**
The waste water sample is preserved with nitric acid and digested in a microwave oven to dissolve residues. As internal standard Sc and Te are used. The solution is preconcentrated in an ultrasonic nebuliser and nebulised into an Inductively coupled plasma optical emission spectrometry (ICP-OES) where the intensities of the emitted light of the elements are measured. The calibration is performed on a matrix containing Milli-Q water with the addition of reference solutions. The following elements are determined simultaneously:

Al, Cd, Co, Cr, Cu, Fe, Mn, Mo, Ni, P, Pb, V, Zn.

**Achieved environmental benefits**
The procedure is capable of determining levels below legislation requirements of today. The detection limits are shown below (mg/l):

- Al 0.002
- Cd 0.00003
- Co 0.0002
- Cr 0.001
- Cu 0.0006
- Fe 0.0001
- Mn 0.00003
- Mo 0.00003
- Ni 0.0002
- P 0.0018
- Pb 0.0006
- V 0.0006
- Zn 0.00006.

This technique can be considered to be a quick and efficient technique using standard equipment. The time from observation of increased levels to corrective actions is relatively short.

**Cross-media effects**
No data submitted.

**Operational data**
No data submitted.

**Applicability**
Water from different sources can be monitored, e.g. waste water, drinking water.

**Driving force**
The driving force for implementation is to comply with national and European legislation.

**Economics**
No data submitted.

**Reference plant**
12.2 Annex II. Dioxin emissions

Major factors influencing dioxin formation are:

- the process feed (raw materials)
- the type of metallurgical process
- the process operating conditions, in particular combustion quality
- the off-gas cooling conditions, in particular the presence of a boiler or other heat exchangers
- the type of off-gas treatment systems
- memory effects. Pipes and heat exchanges may store extensive deposits, enhancing emissions and also the evolution of dioxin with time.

PCDD/F and other POPs
It is important to take into consideration that both PCDD/F are always accompanied by a host of other compounds surviving combustion, e.g. benzene, alkylbenzenes, naphthalene, phenanthrene, anthracene, furan, benzofuran, dibenzofuran, and many other aliphatic and cyclic compounds. Their sheer number is a complicating factor in analytical procedures. In this study, only limited attention is devoted to these compounds, but their potential role as surrogates and precursors is highlighted. It has adequately been shown that the dibenzo-p-dioxin (DD) structure is easily synthesised from two molecules of phenol. The same holds for their chlorinated congeners. Similarly, the polychlorinated dibenzofuran (DF) structure is easily created by a mild oxidation of PCB. Thus, both chlorophenols and PCB are potential precursors for PCDD/F formation. Some of these compounds are relevant as POPs in their own right, such as:

- hexachlorobenzene
- PCB
- polychlorinated naphthalenes.

Pathways of emissions of PCDD/F
PCDD/F, or indeed almost any pollutant, may either occur as emissions to air, water, and soil, or arise as waste streams to be eliminated or recycled.

Emissions of PCDD/F from the metallurgical industry may assume different forms, such as:

- off-gases, occurring in guided stack emissions
- off-gases, occurring as diffuse emissions
- waste water and sludge
- residues
- commercial products.

Monitoring
Modes of PCDD/F monitoring found in the EU are given in Table 12.1:

<table>
<thead>
<tr>
<th>Type</th>
<th>Monitoring frequencies</th>
<th>Period for measurement</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular</td>
<td>1 per month</td>
<td>1 day</td>
<td>TEQ values</td>
</tr>
<tr>
<td>Occasional (monitoring only at some installations of the sector)</td>
<td>6 per year</td>
<td>3 days</td>
<td>1-TEQ values (17 congeners)</td>
</tr>
<tr>
<td>Voluntary (e.g. sector agreement)</td>
<td>2 per year</td>
<td>1 week</td>
<td>5 PCDD + 5 PCDF</td>
</tr>
<tr>
<td></td>
<td>1 per year</td>
<td></td>
<td>Fingerprint</td>
</tr>
<tr>
<td></td>
<td>1 every 3 - 6 years</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 12.1: Monitoring modes of PCDD/F

[209]
Measurement methods
Some measurement method examples can be found in the report [209].

### 12.3 Annex III. WHO-12 PCBs

Polychlorinated biphenyls (PCBs) are a class of chlorinated semi-volatile organic compounds composed of 209 congeners. Numbering of congeners in the EUROFER data request follows the convention adopted by the International Union of Pure and Applied Chemists (IUPAC). Figure 12.1 illustrates the IUPAC numbering system as well as the nomenclature of positional chlorinated substitution. A group of 12 PCBs, which exhibit 'dioxin-like' behaviour, has been identified by the World Health Organisation (WHO) and the individual members of the group have been assigned toxic equivalency factors (TEFs) relative to that of 2,3,7,8-tetrachlorodibenzo-p-dioxin. The TEFs allow these 'WHO-12 PCBs' to be included as part of the overall dioxin WHO-TEQ concentration in process emissions and other environmental samples. In the data collected by EUROFER, the PCDD/F data were requested in the more usual I-TEQ unit so do not include PCB data and a clear distinction can be made between the two groups of compounds and comparisons made with past PCDD/F data. It is anticipated that the use of the WHO-TEQ will increase in the future.

A list of the TEFs for the WHO-12 PCBs is provided in Table 12.2.

#### Figure 12.1: IUPAC numbering system and positional nomenclature of PCBs [299]

![IUPAC numbering system and positional nomenclature of PCBs](image)

<table>
<thead>
<tr>
<th>IUPAC no.</th>
<th>Type</th>
<th>Structure</th>
<th>WHO-TEF</th>
</tr>
</thead>
<tbody>
<tr>
<td>77</td>
<td>non-ortho</td>
<td>3,3',4,4'TeCB</td>
<td>0.0001</td>
</tr>
<tr>
<td>81</td>
<td></td>
<td>3,4,4',5TeCB</td>
<td>0.0001</td>
</tr>
<tr>
<td>126</td>
<td></td>
<td>3,3',4,4',5PeB</td>
<td>0.1</td>
</tr>
<tr>
<td>169</td>
<td></td>
<td>3,3',4,4',5',5'HxCB</td>
<td>0.01</td>
</tr>
<tr>
<td>105</td>
<td></td>
<td>2,3,4,4',5PeCB</td>
<td>0.0005</td>
</tr>
<tr>
<td>114</td>
<td></td>
<td>2,3,3',4,4',5PeCB</td>
<td>0.0005</td>
</tr>
<tr>
<td>118</td>
<td></td>
<td>2,3,4,4',5PeCB</td>
<td>0.0001</td>
</tr>
<tr>
<td>123</td>
<td></td>
<td>2,3,4,4',5PeCB</td>
<td>0.0001</td>
</tr>
<tr>
<td>156</td>
<td></td>
<td>2,3,3',4,4',5'HxCB</td>
<td>0.0005</td>
</tr>
<tr>
<td>157</td>
<td></td>
<td>2,3,3',4,4',5'HxCB</td>
<td>0.0005</td>
</tr>
<tr>
<td>167</td>
<td></td>
<td>2,3,4,4',5,5'HxCB</td>
<td>0.00001</td>
</tr>
<tr>
<td>189</td>
<td></td>
<td>2,3,3',4,4',5,5'HxCB</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

Table 12.2: Table of toxic equivalency factors for WHO-12 PCB congeners [299]
### Annex IV. Example of template for compiling environmental data in the I&S sector

#### Table 12.3: Example of template for compiling environmental data in the I&S sector

<table>
<thead>
<tr>
<th>Resources/Energy</th>
<th>Products/By-products</th>
<th>Emission/Wastes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Name</strong></td>
<td><strong>Units</strong></td>
<td><strong>Usage</strong></td>
</tr>
<tr>
<td><strong>Raw materials</strong></td>
<td><strong>Products</strong></td>
<td><strong>Emission</strong></td>
</tr>
<tr>
<td>Coal/Anthracite</td>
<td>Coke</td>
<td>Dust (total)</td>
</tr>
<tr>
<td>Coke</td>
<td>Sinter</td>
<td>SO₂</td>
</tr>
<tr>
<td>Iron ore</td>
<td>Hot metal</td>
<td>NOₓ</td>
</tr>
<tr>
<td>Pellets</td>
<td>Liquid steel</td>
<td>CO</td>
</tr>
<tr>
<td>Lime</td>
<td>Ingots</td>
<td>CO₂</td>
</tr>
<tr>
<td><strong>Dolomite</strong></td>
<td><strong>Production residues</strong></td>
<td><strong>By-products</strong></td>
</tr>
<tr>
<td>Sinter</td>
<td>Benzene</td>
<td>Benzen(a)pyrene</td>
</tr>
<tr>
<td>Pig iron</td>
<td>Tar</td>
<td>Pyridine</td>
</tr>
<tr>
<td>Crap</td>
<td>Sodium phenolate</td>
<td>Toluene</td>
</tr>
<tr>
<td>Liquid steel</td>
<td>Ammonium sulphate</td>
<td>Xylene</td>
</tr>
<tr>
<td>Metallic charge</td>
<td>Granulated slag</td>
<td>Tar</td>
</tr>
<tr>
<td>Alloys</td>
<td>Iron sulphate</td>
<td>F (HF)</td>
</tr>
<tr>
<td>Non-metallic compounds</td>
<td>Iron oxide</td>
<td>Cl (HCl)</td>
</tr>
<tr>
<td>Others</td>
<td></td>
<td>Phenol</td>
</tr>
<tr>
<td><strong>Energy</strong></td>
<td><strong>Solid wastes</strong></td>
<td></td>
</tr>
<tr>
<td>Natural gas</td>
<td>BF slag</td>
<td>HCN</td>
</tr>
<tr>
<td>Electricity</td>
<td>BOF slag</td>
<td>H₂S</td>
</tr>
<tr>
<td>Water</td>
<td>Energetic ash &amp; slag</td>
<td>Ammonium</td>
</tr>
<tr>
<td>Technological steam</td>
<td>Ferrous sludge</td>
<td>CS₂</td>
</tr>
<tr>
<td>Coke gas</td>
<td>Refractories</td>
<td>NaOH</td>
</tr>
<tr>
<td>BF gas</td>
<td>Sulphur</td>
<td>H₂SO₄</td>
</tr>
<tr>
<td>Oxygen</td>
<td>Dust</td>
<td>PCDD/F</td>
</tr>
<tr>
<td>Oxygen (liquid)</td>
<td></td>
<td>Non-channeled emission</td>
</tr>
<tr>
<td>Argon</td>
<td></td>
<td>Basicity</td>
</tr>
<tr>
<td>Nitrogen</td>
<td></td>
<td>Moisture</td>
</tr>
<tr>
<td>Nitrogen (in bottles)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compressed air</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BF blast</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acetylene</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other technical gases</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>