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Integrated Pollution Prevention and Control

Reference Document on Best Available Techniques in the Smitheries and Foundries Industry

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This document is one of a series of reference documents foreseen to be produced in the EIPPCB work plan as below (at the time of writing, not all the documents have been drafted):

Full title	BREF code
Reference Document on Best Available Techniques for Intensive Rearing of Poultry and Pigs	ILF
Reference Document on the General Principles of Monitoring	MON
Reference Document on Best Available Techniques for the Tanning of Hides and Skins	TAN
Reference Document on Best Available Techniques in the Glass Manufacturing Industry	GLS
Reference Document on Best Available Techniques in the Pulp and Paper Industry	PP
Reference Document on Best Available Techniques on the Production of Iron and Steel	I&S
Reference Document on Best Available Techniques in the Cement and Lime Manufacturing Industries	CL
Reference Document on the Application of Best Available Techniques to Industrial Cooling Systems	CV
Reference Document on Best Available Techniques in the Chlor – Alkali Manufacturing Industry	CAK
Reference Document on Best Available Techniques in the Ferrous Metals Processing Industry	FMP
Reference Document on Best Available Techniques in the Non Ferrous Metals Industries	NFM
Reference Document on Best Available Techniques for the Textiles Industry	TXT
Reference Document on Best Available Techniques for Mineral Oil and Gas Refineries	REF
Reference Document on Best Available Techniques in the Large Volume Organic Chemical Industry	LVOC
Reference Document on Best Available Techniques in the Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector	CWW
Reference Document on Best Available Techniques in the Food, Drink and Milk Industry	FM
Reference Document on Best Available Techniques in the Smitheries and Foundries Industry	SF
Reference Document on Best Available Techniques on Emissions from Storage	ESB
Reference Document on Best Available Techniques on Economics and Cross-Media Effects	ECM
Reference Document on Best Available Techniques for Large Combustion Plants	LCP
Reference Document on Best Available Techniques in the Slaughterhouses and Animals By-products Industries	SA
Reference Document on Best Available Techniques for Management of Tailings and Waste-Rock in Mining Activities	MTWR
Reference Document on Best Available Techniques for the Surface Treatment of Metals	STM
Reference Document on Best Available Techniques for the Waste Treatments Industries	WT
Reference Document on Best Available Techniques for the Manufacture of Large Volume Inorganic Chemicals (Ammonia, Acids and Fertilisers)	LVIC-AAF
Reference Document on Best Available Techniques for Waste Incineration	WI
Reference Document on Best Available Techniques for Manufacture of Polymers	POL
Reference Document on Energy Efficiency Techniques	ENE
Reference Document on Best Available Techniques for the Manufacture of Organic Fine Chemicals	OFC
Reference Document on Best Available Techniques for the Manufacture of Specialty Inorganic Chemicals	SIC
Reference Document on Best Available Techniques for Surface Treatment Using Solvents	STS
Reference Document on Best Available Techniques for the Manufacture of Large Volume Inorganic Chemicals (Solids and Others)	LVIC-S
Reference Document on Best Available Techniques in Ceramic Manufacturing Industry	CER

EXECUTIVE SUMMARY

The Smitheries and Foundries BREF (Best Available Techniques reference document) reflects an information exchange carried out under Article 16(2) of Council Directive 96/61/EC. This executive summary is intended to be read in conjunction with the BREF's Preface, which explains the structure of the document, its objectives, usage and legal terms. The executive summary describes the main findings, the principal BAT conclusions and the associated emission/consumption levels. It can be read and understood as a stand-alone document but, as a summary, it does not present all the complexities of the full BREF text. It is therefore not intended as a substitute for the full BREF text in BAT decision making.

Scope of this BREF

This document reflects the exchange of information on the activities covered by Annex I, categories 2.3 (b), 2.4 and 2.5 (b) of the IPPC Directive, i.e.

"2.3. Installations for the processing of ferrous metals:
(b) smitheries with hammers the energy of which exceeds 50 kilojoule per hammer, where the calorific power used exceeds 20 MW
2.4. Ferrous metal foundries with a production capacity exceeding 20 tonnes per day
2.5. Installations
(b) for the smelting, including the alloyage, of non-ferrous metals, including recovered products, (refining, foundry casting, etc.) with a melting capacity exceeding 4 tonnes per day for lead and cadmium or 20 tonnes per day for all other metals."

After comparing the above descriptions to the actual capacitites of existing installations in Europe, the TWG outlined a working scope, which covered the following:

- the casting of ferrous materials, e.g. lamellar cast iron, malleable and nodular iron, steel
- the casting of non-ferrous materials, e.g. aluminium, magnesium, copper, zinc, lead and their alloys.

Smitheries were excluded from this document's scope since no European smitheries were reported which met the conditions stated in Annex I 2.3.(b). This document therefore only discusses foundry processes. Cadmium, titanium and precious metals foundries, as well as bell casting and art casting foundries were also excluded on capacity grounds. Continuous casting (into sheets and slabs) has already been covered in the BREF documents related to iron and steel production and non-ferrous metal industries, and therefore, it is not dealt with in this document. In covering non-ferrous metals in this document, the process is considered to start with the melting of ingots and internal scrap or with liquid metal.

From a process point of view, the following foundry process steps are covered in this document:

- pattern making
- raw materials storage and handling
- melting and metal treatment
- mould and core production, and moulding techniques
- casting or pouring and cooling
- shake-out
- finishing
- heat treatment.

The foundry industry

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

The European foundry industry is the third largest in the world for ferrous castings and second largest for non-ferrous. The annual production of castings in the enlarged European Union amounts to 11.7 million tonnes of ferrous and 2.8 million tonnes of non-ferrous castings. Germany, France and Italy are the top three production countries in Europe, with a total annual production of over two million tonnes of castings each. In recent years, Spain has taken over the fourth position from Great Britain, with both having a production of over one million tonnes of castings. Together, the top five countries produce more than 80 % of the total European production. Although the production volume has remained relatively stable over the past few years, there has been a decline in the total number of foundries (now totalling around 3000 units), which is also reflected in the employment numbers (now totalling around 260000 people). This can be explained by progressive upscaling and automation in the foundry units. However, the foundry industry is predominantly still an SME industry, with 80 % of companies employing less than 250 people.

The main markets served by the foundry industry are the automotive (50 % of market share), general engineering (30 %) and construction (10 %) sectors. A growing shift of the automotive industry towards lighter vehicles has been reflected in a growth in the market for aluminium and magnesium castings. While iron castings mostly (i.e. >60 %) go to the automotive sector, steel castings find their market in the construction, machinery and valve making industries.

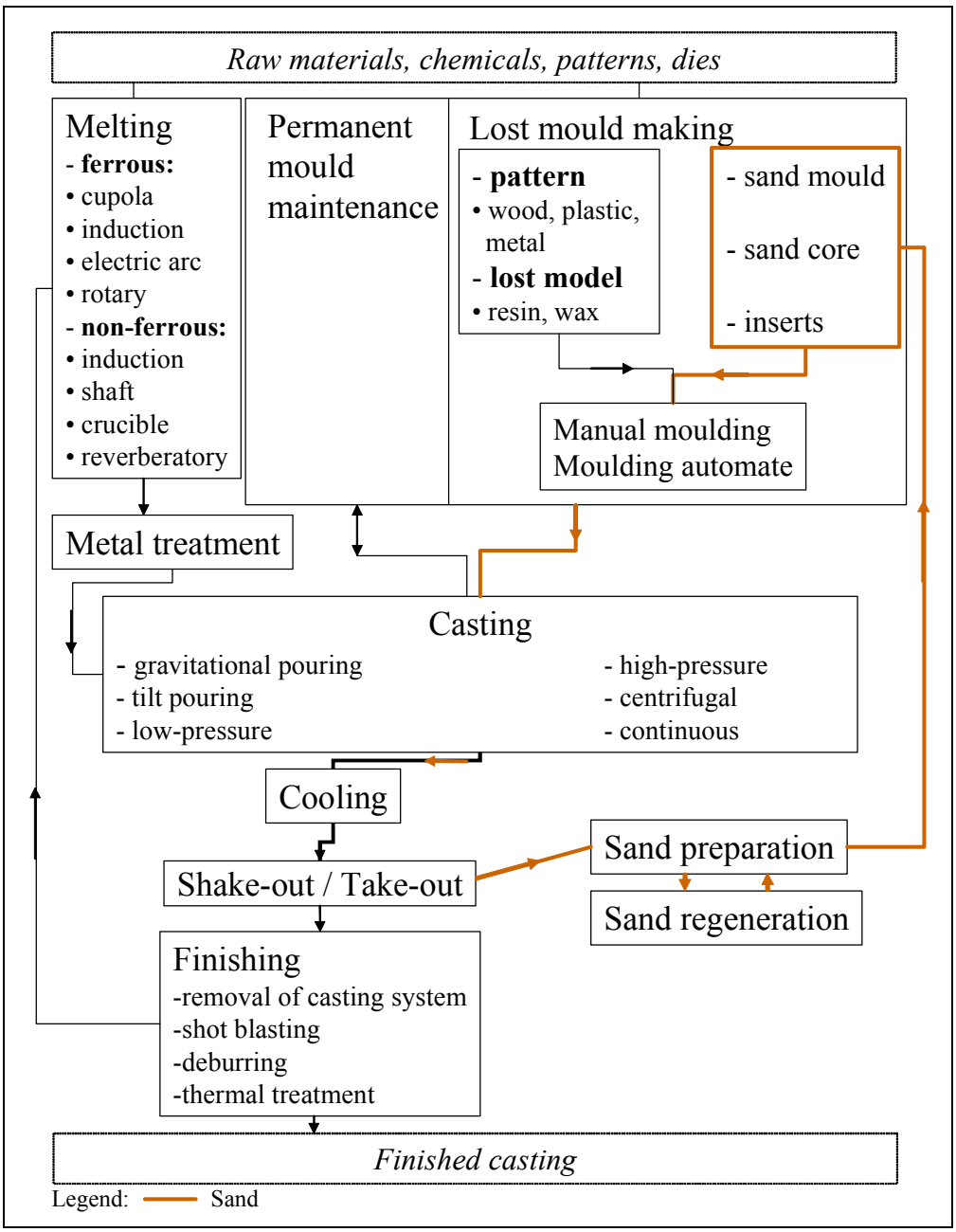
The foundry process

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

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

Various process options can be taken, depending on the type of metal, size of series and type of product. Generally, the main division within the sector is based on the type of metal (ferrous or non-ferrous) and the type of moulding used (lost moulds or permanent moulds). While any combination is possible, typically ferrous foundries largely use lost moulds (i.e. sand moulding) and non-ferrous foundries mainly use permanent moulds (i.e. die-casting). Within each of these basic process options a variety of techniques exist according to the type of furnace used, the moulding and core-making system (green sand or various chemical binders) applied, and the casting system and finishing techniques applied. Each of those have their own technical, economic and environmental properties, advantages and disadvantages.

Chapters 2, 3 and 4 of this document follow a process-flow approach to describe the various operations, from pattern making to finishing and heat treatment. Applied techniques are described, emission and consumption levels given and techniques to minimise the environmental impact are discussed. The structure of Chapter 5 is based on a distinction between the type of metal and the type of moulding.



The foundry process

Key environmental issues

The foundry industry is a major player in the recycling of metals. Steel, cast iron and aluminium scrap is remelted into new products. Most possible negative environmental effects of foundries are related to the presence of a thermal process and the use of mineral additives. Environmental effects therefore are mainly related to the exhaust and off-gases and to the re-use or disposal of mineral residues.

Emissions to air are the key environmental concern. The foundry process generates (metal-laden) mineral dusts, acidifying compounds, products of incomplete combustion and volatile organic carbons. Dust is a major issue, since it is generated in all process steps, in varying types and compositions. Dust is emitted from metal melting, sand moulding, casting and finishing. Any dust generated may contain metal and metal oxides.

The use of cokes as fuels, or the heating of crucibles and furnaces with gas or oil-fired burners can cause emissions of combustion products, such as NO_x and SO_2. Additionally, the use of cokes and the presence of impurities (e.g. oil, paint, …) in scrap can cause the production of some products of incomplete combustion or recombination (such as PCDD/F) and dust.
In the making of moulds and cores, various additives are used to bind the sand. In binding the sand and pouring the metal, reaction and decomposition products are generated. These include inorganic and organic (e.g. amines, VOCs) compounds. The generation of decomposition products (mainly VOCs) further continues during the casting cooling and de-moulding operations. These products can also cause an odour nuisance.

In the foundry process, emissions to air will typically not be limited to one (or several) fixed point(s). The process involves various emission sources (e.g. from hot castings, sand, hot metal). A key issue in emission reduction is not only to treat the exhaust and off-gas flow, but also to capture it.

Sand moulding involves the use of large sand volumes, with sand-to-liquid-metal weight ratios generally ranging from 1:1 up to 20:1. The used sand can be regenerated, re-used or disposed of. Additional mineral residues such as slag and dross are generated in the melting stage when removing impurities from the melt. These can be either re-used or disposed of.

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

Foundries may have a high water consumption e.g. for cooling and quenching operations. In most foundries, water management involves an internal circulation of water, with a major part of the water evaporating. The water is generally used in the cooling systems of electric furnaces (induction or arc) or cupola furnaces. In general, the final volume of waste water is very small. Nevertheless, when wet dedusting techniques are used, the generated waste water requires special attention. In (high) pressure die-casting, a waste water stream is formed, which needs treatment to remove organic (phenol, oil) compounds before its disposal.

Consumption and emission levels

A general overview of the inputs and outputs of the foundry process is given in the figure below. The ‘Casting’ step mentioned in the centre of the picture covers also all necessary moulding operations. The major input streams are metal, energy, binders and water. The key emissions are dust, amines and VOCs, and for specific furnace types also SO_2, dioxins and NO_x.

The melting stage uses 40 – 60 % of the energy input. For a certain metal type, the energy use is dependent on the type of furnace used. The melting energy input ranges from 500 to 1200 kWh/t metal charge for ferrous metals and from 400 to 1200 kWh/t metal charge for aluminium.

The amounts and types of binders, chemicals and sand used are very dependent on the type of casting made, especially regarding its size and shape, as well as whether serial or batch wise production is used.

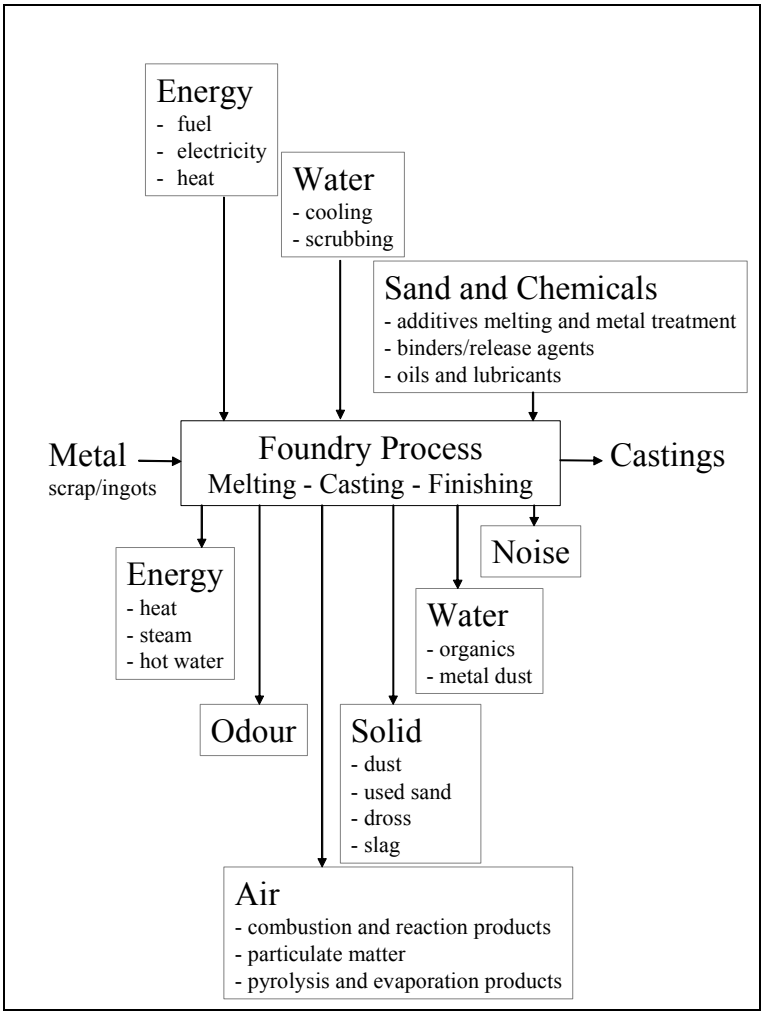
Water consumption is largely dependent on the type of furnace used, the type of flue-gas cleaning applied and the casting method applied.

Dust is generated in each of the process steps, albeit with different levels of mineral oxides, metals and metal oxides. Dust levels for metal melting range from below detection limit, for certain non-ferrous metals, to above 10 kg/tonne, for the cupola melting of cast iron. The high

amount of sand used in lost mould casting results in dust emissions during the various moulding stages.

Amines are used as a catalyst in the most commonly used core-making system. This results in guided emissions from the core-shooting machines and diffuse emissions from core-handling.

Volatile organic compounds emissions (mainly solvents, BTEX and to a lesser extent phenol, formaldehyde, etc.) result from the use of e.g. resins, organic solvents, or organic-based coatings in moulding and core-making. Organic compounds are thermally decomposed during metal pouring and are emitted further during shake-out and cooling. Emission levels between 0.1 – 1.5 kg/tonne of casting are presented in this document.



Mass stream overview of the foundry process

Techniques to consider in the determination of BAT

The minimisation of emissions, efficient raw material and energy usage, optimum process chemical utilisation, the recovering and recycling of waste and the substitution of harmful substances are all important principles of the IPPC Directive. For foundries the focal points are air emissions, the efficient use of raw materials and energy, and waste reduction, in conjunction with any recycling and re-use options.

The environmental issues as mentioned above are addressed by using a variety of process-integrated and end-of-pipe techniques. Over 100 techniques for pollution prevention and control are presented in this document, ordered under the following 12 thematic headings, which are largely based on the process flow:

1. *Raw material storage and handling*: Materials storage and handling techniques aim at the prevention of soil and water pollution and optimisation of the internal recycling of scrap metal.
2. *Metal melting and molten metal treatment*: For each furnace type, different techniques may be considered for optimisation of the furnace efficiency and minimisation of any residue production. These mainly involve in-process measures. Environmental considerations can also be taken into account in the selection of the furnace type. Special attention is paid to cleaning of the aluminium melt and the melting of magnesium, due to the high pollution potential of the products used until recently (HCE and SF_6).
3. *Mould- and core-making, including sand preparation*: Best practice measures and techniques for minimising the consumption may be applied for each type of binder system and for die-casting release agents. For the reduction of VOCs and odour emissions from lost mould systems, water-based coatings and inorganic solvents may be considered. While water-based coatings are commonly used, the applicability of inorganic solvents in core-making is still limited. Another approach is the use of different moulding methods. However, those techniques are used only in specific fields of application.
4. *Metal casting*: In order to improve the efficiency of the casting process, measures aimed at increasing the metal yield (i.e. the mass ratio of molten metal over finished casting) may be considered.
5. *Fume, flue-gas and exhaust air capture and treatment*: Dealing with the emissions to air in all the different foundry stages requires an adequate capture and treatment system to be in place. According to the unit operation, various techniques may be considered, depending on the type of compounds emitted, the off-gas volume and the ease of capture. Techniques applied for off-gas capture play an important role in the reduction of fugitive emissions. Additionally, for fugitive emissions, good practice measures may be considered.
6. *Waste water prevention and treatment*: In many cases, waste water can be prevented or minimised by taking in-process measures. Waste water that cannot be prevented, will contain mineral or metal dust, amines, suphates, oil or lubricants, depending on its source within the process. The applicable treatment techniques differ for each of these compounds.
7. *Energy efficiency:* Metal melting consumes 40 – 60 % of the energy input of a foundry. Energy efficiency measures should therefore take both the melting and the other processes (e.g. air compression, plant actuation, hydraulics) into account. The need for furnace and off-gas cooling generates a hot water or hot air stream, which may allow an internal or external utilisation of the heat.
8. *Sand: regeneration, recycling, re-use and disposal:* Since foundries make intensive use of sand as an inert primary material, the regeneration or re-use of this sand is an important point of consideration as part of its environmental performance. Various techniques are applied for regeneration of the sand (i.e. treatment and internal re-use as moulding sand), the selection of which depends on the binder type and the sand flow compostion. If sand is not regenerated, then external re-use may be considered in order to prevent the need for its disposal. Its application in various areas has been demonstrated.
9. *Dust and solid residues: treatment and re-use:* In-process techniques and operational measures may be considered for the minimisation of dust and residues. The collected dusts, slags and other solid residues may find an internal or external re-use.
10. *Noise reduction:* Various foundry activities are point sources of noise. For foundries near housing, this may cause a nuisance to the neighbours. The setting up and implementation of a noise reduction plan, covering both general and source-specific measures, may therefore be considered.
11. *Decommissioning*: The IPPC Directive requests attention be paid to consideration of the possible pollution upon decommissioning of the plant. Foundries present a specific risk for soil pollution at this stage. There are a number of general measures, which apply more widely than just to foundries, which may be considered to prevent pollution at the decommissioning stage.
12. *Environmental management tools*: Environmental management systems are a useful tool to aid the prevention of pollution from industrial activities in general. Their presentation is therefore a standard part of each BREF document.

BAT for foundries

The BAT chapter (Chapter 5) identifies those techniques that the TWG considered to be BAT in a general sense for the foundry industry, based upon the information in Chapter 4 and taking account of the Article 2(11) definition of "best available techniques" and the considerations listed in Annex IV to the Directive. The BAT chapter does not set or propose emission limit values but suggests emission levels that are associated with the use of BAT.

During the information exchange by the TWG, many issues were raised and discussed. A selection of these are highlighted in this summary.The following paragraphs summarise the key BAT conclusions relating to the most relevant environmental issues.

The BAT elements will need to be adapted to the foundry type. A foundry basically consists of a melting shop and a casting shop, both with their own supply chain. For lost mould casting this supply chain includes all activities related to moulding and core-making. In the BAT chapter, a distinction is made between the melting of either ferrous or non-ferrous metal, and for casting in either lost or permanent moulds. Each foundry may be classified as a combination of a particular melting with an associated moulding class. BAT is presented for each class. Generic BAT, which are common to all foundries, are also presented.

Generic BAT

Some BAT elements are generic and apply for all foundries, regardless of the processes they utilise and the type of products they produce. These concern material flows, finishing of castings, noise, waste water, environmental management and decommissioning.

BAT is to optimise the management and control of internal flows, in order to prevent pollution, prevent deterioration, provide adequate input quality, allow recycling and re-use and to improve the process efficiency. The BREF refers to storage and handling techniques covered in the Storage BREF, but also adds some foundry specific BAT related to storage and handling, such as the storage of scrap on an impermeable surface with a drainage and collection system (although applying a roof can reduce the need for such a system), the separate storage of incoming materials and residues, the use of recyclable containers, optimisation of the metal yield, and good practice measures for molten metal transfer and ladle handling.

BAT are given for finishing techniques that generate dust and for heat treatment techniques. For abrasive cutting, shot blasting and fettling, BAT is to collect and treat the finishing off-gas using a wet or dry system. For heat treatment, BAT is to use clean fuels (i.e. natural gas or low-level sulphur content fuel), automated furnace operation and burner/heater control and also to capture and evacuate the exhaust gas from heat treatment furnaces.

Concerning noise reduction, BAT is to develop and implement a noise reduction strategy, with general and source-specific measures, being applicable, such as using enclosure systems for high-noise unit operations such as shake-out and using additional measures depending on and according to local conditions.

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 utilising e.g. oil interceptors, filtration or sedimentation.

Fugitive emissions arise from uncontained sources (transfers, storage, spills) and the incomplete evacuation of contained sources. BAT is to apply a combination of measures concerning material handling and transport and to optimise exhaust gas capture and cleaning through one or more capture techniques. Preference is given to collection of the fume nearest to the source.

BAT is to implement and adhere to an Environmental Management System (EMS) that incorporates, as appropriate to individual circumstances, features concerning e.g. the

commitment of top management, planning, establishing and implementing procedures, performance checking with corrective actions and reviews.

BAT is to apply all necessary measures 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. In these measures, at least the following process parts are considered: tanks, vessels, pipework, insulation, lagoons and landfills.

Ferrous metal melting

For the operation of cupola furnaces, BAT includes techniques which can give increased efficiency, such as divided blast operation, oxygen enrichment, continuous blowing or long campaign operation, good melting practice measures, and control of the coke quality. BAT is to collect, cool and dedust the off-gas, and to apply post combustion and heat recovery under specific conditions. Several dedusting systems are BAT but wet dedusting is preferable when melting with basic slag and in some cases as one of the measures to prevent and minimise dioxin and furan emissions. Industry has expressed doubts on the implementation of secondary measures for dioxin and furan abatement that have only been proven in other sectors and in particular questions their applicability for smaller foundries. For cupolas, BAT for residue management includes minimising slag forming, pretreating the slags in order to allow their external re-use and collecting and recycling coke breeze.

For the operation of electric arc furnaces, BAT includes applying reliable and efficient process controls to shorten the melting and treatment time, using the foamy slag practice, efficiently capturing the furnace off-gas, cooling the furnace off-gas and dedusting using a bag filter. BAT is to recycle the filter dust into the EAF furnace.

For the operation of induction furnaces, BAT is to melt clean scrap; use good practice measures for the charging and operation; use medium frequency power and, when installing a new furnace, to change any mains frequency furnace to medium frequency; to evaluate the possibility of waste heat recuperation and under specific conditions to implement a heat recovery system. For exhaust capture and treatment from induction furnaces, BAT is to use a hood, lip extraction or cover extraction on each induction furnace to capture the furnace off-gas and maximise the off-gas collection during the full working cycle; to use dry flue-gas cleaning; and to keep dust emissions below 0.2 kg/tonne molten iron.

For the operation of rotary furnaces, BAT is to implement a combination of measures to optimise furnace yield and to use an oxyburner. BAT is to collect the off-gas close to the furnace exit, apply post combustion, cool it using a heat-exchanger and then to apply dry dedusting. For the prevention and minimisation of dioxin and furan emissions, BAT is to use a combination of specified measures. Similarly to the situation with cupola furnaces, industry has expressed doubts on the implementation of secondary measures for dioxin and for an abatement that have only been proven in other sectors and in particular questions their applicability for smaller foundries.

The actual metal treatment applied depends on the type of product made. BAT is to collect the exhaust gas from AOD converters using a roof canopy and to collect and treat the off-gas from nodularisation, using a bag filter. BAT is also to make the MgO-dust available for recycling.

Non-ferrous metal melting

For the operation of induction furnaces for melting aluminium, copper, lead and zinc, BAT is to use good practice measures for the charging and operation; to use medium frequency power and, when installing a new furnace, change any mains frequency furnace to medium frequency; to evaluate the possibility of waste heat recuperation and under specific conditions to implement a heat recovery system. For exhaust capture from these furnaces, BAT is to minimise emissions and if needed to collect the off-gas, maximising the off-gas collection during the full working cycle and applying dry flue-gas cleaning.

For the other furnace types, BAT mainly focuses on the efficient collection of furnace off-gas and/or the reduction of fugitive emissions.

For non-ferrous metal treatment, BAT is to use an impeller station for the degassing and cleaning of aluminium. BAT is to use SO_2 as a covering gas for magnesium melting in installations with an annual output of 500 tonnes and more. For small plants (<500 tonnes Mg parts output/year) BAT is to use SO_2 or to minimise the use of SF_6. In the case where SF_6 is used, the BAT associated consumption level is <0.9 kg/tonne casting for sand casting and <1.5 kg/tonne casting for pressure die-casting.

Lost mould casting

Lost mould casting involves moulding, core-making, pouring, cooling and shake-out. This includes the production of green sand or chemically-bonded sand moulds and chemically-bonded sand cores. BAT elements are presented in three categories: green sand moulding, chemical sand moulding and pouring/cooling/shake-out.

For green sand preparation, BAT items deal with exhaust capture and cleaning and the internal or external recycling of the captured dust. In line with the goal of minimising waste for disposal, BAT is to apply a primary regeneration of green sand. Regeneration ratios of 98 % (monosand) or 90 – 94 % (green sand with incompatible cores) are associated with the use of BAT.

For chemically-bonded sand, the proposed BAT cover a variety of techniques, and deal with a broad range of environmental issues. BAT is to minimise the binder and resin consumption and sand losses, to minimise fugitive VOC emissions by capturing the exhaust gas from core-making and core handling, and to use water-based coatings. The use of alcohol-based coatings is BAT in a limited number of applications, where water-based coatings cannot be applied. In this case, the exhaust should be captured at the coating stand, whenever this is feasible. A specific BAT is given for amine-hardened urethane-bonded (i.e. cold-box) core preparation, to minimise amine emissions and optimise amine recovery. For these systems both aromatic and non-aromatic solvents are BAT. BAT is to minimise the amount of sand going to disposal, primarily by adopting a strategy of regeneration and/or re-use of chemically-bonded sand (as mixed or monosand). In the case of regeneration, the BAT conditions are given in the table below. Regenerated sand is re-used only in compatible sand systems.

Sand type	**Technique**	**Regeneration ratio[1] (%)**
Cold setting monosand	Simple mechanical regeneration	75 – 80
Silicate monosand	Heating and pneumatic treatment	45 – 85
Monosands of cold-box, SO_2, hot-box, croning Mixed organic sands	Cold mechanical or thermal regeneration	in cores: 40 – 100 in moulds: 90 – 100
Mixed green and organic sand	Mechanical-thermal-mechanical treatment, grinding or pneumatic chafing	in cores: 40 – 100 in moulds: 90 – 100
(1) mass of regenerated sand/total mass of sand used		

BAT for chemically-bonded sand regeneration (mixed and monosand)

Alternative moulding methods and inorganic binders are considered to have a promising potential for minimisation of the environmental impacts of moulding and casting processes.

Pouring, cooling and shake-out generate emissions of dust, VOCs and other organic products. BAT is to enclose pouring and cooling lines and provide exhaust extraction, for serial pouring lines, and to enclose the shake-out equipment, and treat the exhaust gas using wet or dry dedusting.

Permanent mould casting

Due to the different nature of the process, the environmental issues for permanent mould casting require a different focus than those for lost mould techniques, with water as a more prominent item. Emissions to air are in the form of an oil mist, rather than the dust and combustion products encountered in the other processes. BAT therefore focusses on prevention measures involving minimisation of the water and release agent consumption. BAT is to collect and treat run-off water and leakage water, using oil interceptors and distillation, vacuum evaporation or biological degradation. If oil mist prevention measures do not allow a foundry to reach the BAT associated emission level, BAT is to use hooding and electrostatic precipitation for the exhaust of HPDC machines.

BAT for chemically-bonded sand preparation is analogous to the elements mentioned for lost mould casting. BAT for used sand management is to enclose the de-coring unit and to treat the exhaust gas using wet or dry dedusting. If a local market exists, BAT is to make the sand from de-coring available for recycling.

BAT associated emission levels

The following emission levels are associated to the BAT measures stated above.

Activity	**Type**	**Parameter**	**Emission level (mg/Nm³)**
Finishing of castings		Dust	5 – 20
Ferrous metal melting	General	Dust [(1)] PCDD/PCDF	5 – 20 ≤ 0.1 ng TEQ/Nm^3
	Hot Blast Cupola	CO SO_2 NO_x	20 – 1000 20 – 100 10 – 200
	Cold Blast Cupola	SO_2 NO_x NM - VOC	100 – 400 20 – 70 10 – 20
	Cokeless Cupola	NO_x	160 – 400
	Electric Arc Furnace	NO_x CO	10 – 50 200
	Rotary Furnace	SO_2 NO_x CO	70 – 130 50 – 250 20 – 30
Non-ferrous metal melting	General	Dust	1 – 20
	Aluminium melting	Chlorine	3
	Shaft furnace for Al	SO_2 NO_x CO VOC	30 – 50 120 150 100 – 150
	Hearth type furnace for Al	SO_2 NO_x CO TOC	15 50 5 5
Moulding and casting using lost moulds	General	Dust	5 – 20
	Core shop	Amine	5
	Regeneration units	SO_2 NO_x	120 150
Permanent mould casting	General	Dust Oil mist, measured as total C	5 - 20 5 - 10
(1) the emission level of dust depends on the dust components, such as heavy metals, dioxins, and its mass flow.			

Emissions to air associated with the use of BAT for the various foundry activities

All associated emission levels are quoted as an average over the practicable measuring period. Whenever continuous monitoring is practicable, a daily average value is used. Emissions to air are based on standard conditions, i.e. 273 K, 101.3 kPa and dry gas.

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 limit values for any specific case will need to be determined taking into account the objectives of the IPPC Directive and the local considerations.

Emerging techniques

Some new techniques for minimisation of the environmental impacts are currently still in the research and development phase or are only just beginning to enter the market these are considered to be emerging techniques. Five of these techniques are discussed in Chapter 6, namely: the use of low combustible materials in cupola melting, the recycling of metal-bearing filter dust, amine recovery by waste-gas permeation, the separate spraying of release agent and water in aluminium die-casting, and inorganic binder material for core-making. The latter technique was especially pointed out by the TWG as promising, although the current limited scale of testing and implementation does not allow it to be yet incorporated as a technique to consider in the selection of BAT.

Concluding remarks on the exchange of information

Information exchange
The BREF document is based on more than 250 sources of information. Foundry research institutes provided an important share of this information and played an active role in the information exchange. Local BAT notes from various Member States gave the information exchange a firm basis. The majority of the documents provided in the information exchange dealt with processes and techniques as applied in ferrous foundries. Throughout the writing of the BREF the non-ferrous foundry processes have been underrepresented. This is reflected in a lower level of detail in the BAT conclusions for non-ferrous foundries.

Level of consensus
A good general level of consensus was reached on the conclusions and no split views were recorded. The industry representation added a comment, expressing their doubt on the ease of implementation of secondary measures for dioxin abatement.

Recommendations for future work
The information exchange and the result of this exchange, i.e. this document, present an important step forward in achieving the integrated prevention and control of pollution from the foundry industry. Future work could continue this purpose by focusing on the collection and assessment of information that was not provided during this information exchange. In particular, in future work should cover in more detail the following topics:

- *Techniques for VOC abatement*: There is a need for data and information on methods applied for the efficient capture and treatment of VOC-laden exhaust gases from foundries. The use of alternative binder and coating materials may prove to be an important prevention measure in this respect
- *Waste water treatment*: There is a need for data from a broad range of water treatment systems in foundries, this should also show emission levels in relation to the inputs and treatment techniques applied

- *Melting of non-ferrous metals*: Emission data for non-ferrous foundries are presented in this document only for some specific installations. There is a need for more complete information on both guided and fugitive emissions from non-ferrous metal melting in foundries. This should be based on operational practice and expressed both as emission levels and mass flows..
- *Economic data for BAT techniques*: There is a lack of economic information for many of the techniques presented in Chapter 4. This information needs to be collected from projects dealing with the implementation of the presented techniques.

Suggested topics for R&D projects

The information exchange has also exposed some areas where additional useful knowledge could be gained from research and development projects. These relate to the following subjects:

- *Dioxin monitoring and abatement:* There is a need for a better understanding of the influence of process parameters on the formation of dioxins. This requires the monitoring of dioxin emissions for various installations and under varying conditions. Additionally, there is a need for research on the use and effectiveness of secondary measures for dioxin abatement in the foundry industry
- *Mercury emissions:* The high volatility of mercury may cause gaseous emissions, which are not related to dust. In view of the implementation of a European policy on mercury emissions, there is a need for research into the emissions of mercury from melting processes in general and from (non-ferrous) foundries in particular
- *Oxygas burners and their use in cupola furnaces:* The TWG reported that new applications have been set-up as a result of ongoing research. There is scope for further research and development here, to bring this technique up to a development level that allows its further dissemination.

PREFACE

1. Status of this document

Unless otherwise stated, references to "the Directive" in this document mean the Council Directive 96/61/EC on integrated pollution prevention and control. As the Directive applies without prejudice to Community provisions on health and safety at the workplace, so does this document.

This document forms part of a series presenting the results of an exchange of information between EU Member States and industries concerned on best available technique (BAT), associated monitoring, and developments in them. *[It is published by the European Commission pursuant to Article 16(2) of the Diective, and must therefore be taken into account in accordance with Annex IV of the Directive when determining "best available techniques".]

*Note: brackets will be removed once the procedure of publication by the Commission is completed.

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 in this preface. This description is inevitably incomplete and is given for information only. It has no legal value and does not in any way alter or prejudice the actual provisions of the Directive.

The purpose of the 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 Community objectives such as the competitiveness of the Community's industry thereby contributing to sustainable development.

More specifically, it provides for a permitting system for certain categories of industrial installations requiring both operators and regulators to take an integrated, overall look at the polluting and consuming potential of the installation. The overall aim of such an integrated approach must be to improve the management and control 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 that operators should take all appropriate preventative measures against pollution, in particular through the application of best available techniques enabling them to improve their environmental performance.

The term "best available techniques" is defined in Article 2(11) 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(11) goes on to clarify further this definition as follows:

"techniques" includes both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned;

"available" techniques are 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 most effective in achieving a high general level of protection of the environment as a whole.

Furthermore, Annex IV of 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 16(2).

Competent authorities responsible for issuing permits are required to take account of the general principles set out in Article 3 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 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 best available techniques.

3. Objective of this Document

Article 16(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 25 of the Directive, which states that "the development and exchange of information at Community level about best available techniques will help to redress the technological imbalances in the Community, will promote the worldwide dissemination of limit values and techniques used in the Community and will 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 16(2) 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 16(2).

The aim of this series of documents is to reflect accurately the exchange of information which has taken place as required by Article 16(2) 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, including in particular the expertise of the groups established to assist the Commission in its work, and verified by the Commission services. All contributions are 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 chapter of the document.

Chapters 1 and 2 provide general information on the industrial sector concerned and on the industrial processes used within the sector.

Chapter 3 provides data and information concerning current emission and consumption levels, reflecting the situation in existing installations at the time of writing.

Chapter 4 describes 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.

Chapter 5 presents 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. For 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 Chapter 5 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.

Since the best available techniques change over time, this document will be reviewed and updated as appropriate. All comments and suggestions should be made to the European IPPC Bureau at the Institute for Prospective Technological Studies at the following address:

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Best Available Techniques Reference Document on Smitheries and Foundries

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SCOPE

This document reflects the exchange of information on the activities covered by Annex I categories 2.3 (b), 2.4 and 2.5 (b) of the IPPC Directive, i.e.

"2.3. Installations for the processing of ferrous metals:
(b) smitheries with hammers the energy of which exceeds 50 kilojoule per hammer, where the calorific power used exceeds 20 MW

2.4. Ferrous metal foundries with a production capacity exceeding 20 tonnes per day

2.5. Installations
(b) for the smelting, including the alloyage, of non-ferrous metals, including recovered products, (refining, foundry casting, etc.) with a melting capacity exceeding 4 tonnes per day for lead and cadmium or 20 tonnes per day for all other metals."

In setting up the working scope for this document, the TWG considered the possible interpretation of the threshold values. The TWG compared the pre-defined IPPC scope to the actual existence of installations that meet the above descriptions, in the European Union and in the Candidate Countries. This comparison resulted in a working scope which covers the following:

- the casting of ferrous materials, e.g. grey cast iron, malleable and ductile iron, steel
- the casting of non-ferrous materials, e.g. aluminium, magnesium, copper, zinc, lead and their alloys.

Smitheries were excluded from the scope of the document since no European smitheries were reported which meet the conditions stated in Annex I 2.3 (b), i.e. "Smitheries with hammers the energy of which exceeds 50 kJ per hammer, (and) where the calorific power used exceeds 20 MW". Accordingly, cadmium, titanium and precious metals foundries, as well as bell and art casting foundries were excluded on capacity grounds.

Continuous casting (into sheets and slabs) has already been covered in the BREF documents on iron and steel production and on non-ferrous metal industries. Therefore it is not dealt with in this document.

Smelting, alloying and the refining of non-ferrous metals are covered in the BREF document on non-ferrous metal industries and will therefore be excluded from the scope of this document. In covering non-ferrous metals in this document, the process is considered to start with the melting of ingots and internal scrap or with liquid metal.

From a process point of view, the following foundry process steps are covered by the scope of this document:

- pattern making
- raw materials storage and handling
- melting and metal treatment
- mould and core production, and moulding techniques
- casting or pouring and cooling
- shake-out
- finishing
- heat treatment.

1 GENERAL INFORMATION ON FOUNDRIES

1.1 Sector overview

1.1.1 Foundry industry

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

The European foundry industry is the third largest in the world for ferrous castings and the second largest for non-ferrous. The total production of castings in various European countries are given in Table 1.1 and Table 1.2. Data for Northern Ireland, Luxemburg and some of the Accession Countries have not been provided, however it is known that activity in these regions is low compared to the listed regions. Germany, France and Italy are the top three production countries in Europe, with a total annual production of over two million tonnes of castings each. In recent years Spain has taken over the fourth position from Great Britain, with both having a production of over one million tonnes of castings. Together, the top five countries produce more than 80 % of the total European production.

The total European production tonnage of ferrous castings has been stable over the past five years, although some fluctuations have occurred for individual countries. For instance, the figures for Great Britain indicate a general declining trend in production output, whereas the trend for Spain is one of growth. The non-ferrous foundry sector has undergone steady growth since 1998. The total figure for 2001 is obscured by the lack of data from Great Britain. In general, it can be seen from Table 1.2 that in most countries production has risen. This holds not just for the major producing countries but also for those countries with low amounts of production.

Country	1998	1999	2000	2001	2002	2000:2001	2001:2002
						% change	
Austria	190.1	181.7	191.4	192.4	181.2	0.5	-5.8
Belgium	144.4	149.3	149.8	149.5	143.7	-0.2	-3.9
Czech Republic	493	379.1	390.3	415.3	381.6	6.4	-8.1
Denmark	85.8	86	96.4	85.7	87.3	-11.1	1.9
Estonia	n.d	n.d	0.94	1.07	1.1	13.8	2.8
Finland	122.6	109	117.6	119.5	112.5	1.6	-5.8
France	2250.8	2146.6	2283.1	2147.4	2128.6	-5.9	-0.9
Germany	3662.9	3555.2	3758.2	3801.4	3749.7	1.1	-1.4
Great Britain	1076.3[a]	949.2[a]	968.2[a]	906.3[a]	886.3[a]	-6.4	-2.2
Hungary	78.1	68.7	74.8	62.8	67.9	-16.0	8.2
Ireland	450	480	520	275	n.d	-47.1	
Italy	1508.4	1492.6	1516.4	1433.3	1460.9	-5.5	1.9
Netherlands	140.6	121	136	132.3	123.7	-2.7	-6.5
Norway	65.3	67.7	70.1	73.4	67.3	4.7	-8.3
Poland	675	610.2	671.2	673	598.0	0.3	-11.1
Portugal	98.6	97.7	102.3	100	96.7	-2.2	-3.3
Slovakia	n.d	n.d	n.d	47.5	n.d		
Slovenia	89.8	81.9	86.9	96.3	n.d	10.8	
Spain	706.6	759.3	950.5	955.7	992.9	0.5	3.9
Sweden	264.2	253.2	266.7	244.7	234.6	-8.2	-4.1
Switzerland	122.8[b]	122[b]	119.9[b]	105.5[b]	81.8[b]	-12.0	-22.5
Total	**12225**	**11710**	**12471**	**12018**	**11396**		
Full total [c]				***12018***	***11815***		

a) Without steel castings
b) Without steel and malleable iron castings
c) Full total calculated by taking most recent available number for the years for which no data are given

Table 1.1: European production data for ferrous castings, i.e. iron, steel and malleable iron castings (in kilotonnes)
[168, CAEF, 2002], [202, TWG, 2002]

For ferrous foundries, the progress of material substitution in recent years has caused the share of iron castings in the output total to decline slightly, dropping from 58.9 % in 2001 to 58.2 % in 2002. At the same time, producers of nodular-iron castings held a share of 34.3 % in the production total in 2002, marking an increase of 0.5 percentage points compared to 2001. Producers of malleable castings were able to expand their share from 1.1 % in 2001 to 1.3 % in 2002, while the share of steel castings in the output total ranged around 5.8 % in 2002 (5.9 % in 2001).

Country	1998	1999	2000	2001	2002	2000:2001	2001:2002
						% change	
Austria	90.4	92.4	105.9	113.3	116.2	7.0	2.6
Belgium	25.3	23.8	27.2	26.3	26.7	-3.3	1.6
Czech Republic	44.8	48	57.7	58.1	59.6	0.7	2.6
Denmark	1.7[a]	4	4	4.8	4.6	20.0	-3.2
Estonia	n.d	n.d	0	0	0		
Finland	10.5	10	10	10	9.7	0.0	-3.3
France	338.2	343.8	373.9	394.7	390.3	5.6	-1.1
Germany	783.9	777	842.1	849.6	845.8	0.9	-0.4
Great Britain	121[a]	n.d	n.d	n.d	n.d		
Hungary	24.8	35	44.8	58.4	68.3	30.4	16.9
Ireland [b]	25.8	25.8	26	26.6	n.d	2.3	
Italy	832.3	832.1	959.1	960	979.7	0.1	2.1
Netherlands	n.d	n.d	n.d	n.d	n.d		
Norway	22.2	25.2	26.4	30.9	26.7	17.0	-13.5
Poland	66.5	84	84	72.2	76.3	-14.0	5.7
Portugal	17.5	21.2	22.6	25.4	25.6	12.4	0.6
Slovakia	n.d	n.d	n.d	7.6	n.d		
Slovenia	15.9	17.3	23.6	24.8	n.d	5.1	
Spain	140.7	153.6	121.1	142.1	149.9	17.3	5.5
Sweden	51.8	55.7	58.5	53.3	52.9	-8.9	-0.8
Switzerland	22.3	22.9	25.1	24.1	21.1	-4.0	-12.3
Total	**2636**	**2572**	**2812**	**2481**	**2853**		
Full total [c]				***2602***	***3033***		

a) Only aluminium
b) Only lead sheet production
c) Full total calculated by taking most recent available number for the years for which no data are given

Table 1.2: European production data for non-ferrous metal castings (in kilotonnes) [168, CAEF, 2002], [202, TWG, 2002]

The output of non-ferrous metal alloys is still dominated by light metal castings at a share of 75.1 %, despite a decline by 3.5 percentage points compared to the year before. The share of copper alloys went down from 10.1 to 9.8 %, and the share held by the producers of zinc alloys similarly shrank from 8.7 to 7.3 %. The difference was absorbed by miscellaneous non-ferrous metals and processes that are not detailed in the statistics.

Data on the number of foundries are given in Table 1.3 and Table 1.4. These data show that there has been a general decline in the number of foundries since 1998, with the loss of about 5 % of the existing foundries each year. This decline is also reflected in the employment numbers, as given in Table 1.5 and Table 1.6.

Country	1998	1999	2000	2001	2002	2000:2001	2001:2002
						% change	
Austria	28	26	25	24	41	-4.0	70.8
Belgium	40[a]	25	24	21	21	-12.5	0.0
Czech Rep.	n.d	n.d	n.d	140	143		2.1
Denmark	n.d	n.d	12	12	12	0.0	0.0
Estonia	n.d	n.d	1	1	1	0.0	0.0
Finland	19	23	20	19	19	-5.0	0.0
France	169	167	167	163	159	-2.4	-2.5
Germany	324	310	299	288	273	-3.7	-5.2
Great Britain	228[b]	214[b]	198[b]	188[b]	179[b]	-5.1	-4.8
Hungary	34	34	32	33	n.d	3.1	
Ireland	n.d	n.d	n.d	1	n.d		
Italy	310	307	293	291	281	-0.7	-3.4
Netherlands	22	n.d	n.d	28	n.d		
Norway	12	12	12	11	11	-8.3	0.0
Poland	234	230	230	220	190	-4.3	-13.6
Portugal	62	61	61	61	61	0.0	0.0
Slovakia	n.d	n.d	n.d	12	n.d		
Slovenia	n.d	n.d	n.d	n.d	n.d		
Spain	224	221	105	102	98	-2.9	-3.9
Sweden	48	49	49	49	50	0.0	2.0
Switzerland	23	23	23	22	20	-4.3	-9.1
Total	**1777**	**1702**	**1551**	**1686**	**1559**		
Full total [c]			***1732***	***1686***	***1633***		

a) Only members
b) Without steel castings
c) Full total calculated by taking most recent available number for the years for which no data are given

Table 1.3: Number of foundries (production units) for iron, steel and malleable iron casting [168, CAEF, 2002], [202, TWG, 2002]

Country	Total		Pressure Die Casting		Other Light casting		Other Heavy metal alloy casting	
	2001	**2002**	**2001**	**2002**	**2001**	**2002**	**2001**	**2002**
Austria	63	61	20	21	28	25	15	15
Belgium	12	10	3	3	6	5	3	2
Czech Rep.	58	63	39[a]	40	n.d	n.d	n.d	23
Denmark	8	8	n.d	n.d	n.d	n.d	n.d	
Estonia	0	0	0	0	0	0	0	0
Finland	22	25	4	6	11	12	7	7
France	288	283	n.d	n.d	n.d	n.d	n.d	n.d
Germany	414	400	n.d	n.d	n.d	n.d	n.d	n.d
Great Britain	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Hungary	78	n.d	23	n.d	35	n.d	20	n.d
Italy	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Netherlands	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Norway	10	13	3	3	7	6		4
Poland	290	280	n.d	n.d	n.d	n.d	n.d	n.d
Portugal	67	54	38	32	12	9	17	13
Slovakia	7	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Slovenia	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Spain	55[b]	57	n.d	n.d	n.d	n.d	n.d	n.d
Sweden	84	84	43	n.d	29	n.d	12	n.d
Switzerland	49	48	15	14	23	23	11	11
Total	**1505**	**1386**	**149**	**119**	**151**	**80**	**85**	**75**

a) Incl. all light casting
b) Only members

Table 1.4: Number of foundries (production units) for non-ferrous metal casting [168, CAEF, 2002], [202, TWG, 2002]

Country	1998	1999	2000	2001	2002	2000:2001	2001:2002
						% change	
Austria	3465	3314	3342	3936	3067	17.8	-22.1
Belgium	2823	2299	3260	1847	1936	-43.3	4.8
Czech Republic	n.d	n.d	n.d	17536	14847		-15.3
Denmark	n.d	n.d	1481	1393	1290	-5.9	-7.4
Estonia	n.d	n.d	125	133	129	6.4	-3.0
Finland	2326	2058	2027	2090	2045	3.1	-2.2
France	26407[a]	25714	25613	24871	24651	-2.9	-0.9
Germany	46944	45157	44896	44796	42748	-0.2	-4.6
Great Britain	24000[b]	20000[b]	18000[b]	16500[b]	15900[b]	-8.3	-3.6
Hungary	3485	3285	3175	2734	n.d	-13.9	
Ireland	502	503	509	309	n.d	-39.3	
Italy	22050	22200	22100	21400	20630	-3.2	-3.6
Netherlands	2462	2122	2119	2148	1830	1.4	-14.8
Norway	1864	1706	1730	1754	1564	1.4	-10.8
Poland	33600	28500	26800	26370	24500	-1.6	-7.1
Portugal	2649	2800	2782	2780	2710	-0.1	-2.5
Slovakia	n.d	n.d	n.d	1925	n.d		
Slovenia	n.d	n.d	n.d	n.d	n.d		
Spain	13860	14040	11803	11006	11385	-6.8	3.4
Sweden	3650	3650	3650	3800	3800	4.1	0.0
Switzerland	2400	2300	2400	2400	1930	0.0	-19.6
Total	**192487**	**179648**	**175812**	**189728**	**174962**		
Full total [c]			***195273***	***189728***	***179930***		

a) Break in continuity of series
b) Without steel castings
c) Full total calculated by taking most recent available number for the years for which no data are given

Table 1.5: Employment in the foundry industry for iron, steel and malleable iron casting [168, CAEF, 2002], [202, TWG, 2002]

Country	1998	1999	2000	2001	2002	2000:2001	2001:2002
						% change	
Austria	4029	4179	4349	4585	4398	5.4	-4.1
Belgium	1824	803	800	n.d	558		
Czech Republic	n.d	n.d	n.d	5083	5374		5.7
Denmark	n.d	n.d	377	372	349	-1.3	-6.2
Estonia	n.d	n.d	0	0	0		
Finland	708	744	884	718	730	-18.8	1.7
France	17926	17821	17651	17932	17720	1.6	-1.2
Germany	32000	33000	33000	34500	34390	4.5	-0.3
Great Britain	n.d	n.d	n.d	n.d	n.d		
Hungary	3208	3941	5503	4702	n.d	-14.6	
Ireland[a]	70	70	70	70	n.d	0.0	
Italy	n.d	n.d	n.d	n.d	n.d		
Netherlands	n.d	n.d	n.d	n.d	n.d		
Norway	1271	1411	1483	1491	1307	0.5	-12.3
Poland	4433	6500	6200	4130	4100	-33.4	-0.7
Portugal	1200	1230	1280	1380	1350	7.8	-2.2
Slovakia	n.d	n.d	n.d	845	n.d		
Slovenia	n.d	n.d	n.d	n.d	n.d		
Spain	5650	5620	4810	5034	4994	4.7	-0.8
Sweden	3700	3700	3700	3700	3700	0.0	0.0
Switzerland	1900	2000	2100	2200	1900	4.8	-13.6
Total	**77919**	**81019**	**82207**	**86742**	**80870**		
Full Total [b]			***88135***	***87300***	***86487***		

a) Only lead
b) Full total calculated by taking most recent available number for the years for which no data are given

Table 1.6: Employment in the foundry industry for non-ferrous casting [168, CAEF, 2002], [202, TWG, 2002]

The tables show that European production levels are relatively stable or are slightly rising but that this production now results from fewer units and less employees. This can be explained by progressive upscaling and automation in the foundry units. The relationship between unit size, production and employment is well illustrated in Figure 1.1. This shows that the larger West-European producers (Germany, France) are attaining higher productivities with fewer people. The more labour-intensive units are found in the Eastern and Southern part of Europe (Poland, Hungary, Portugal).

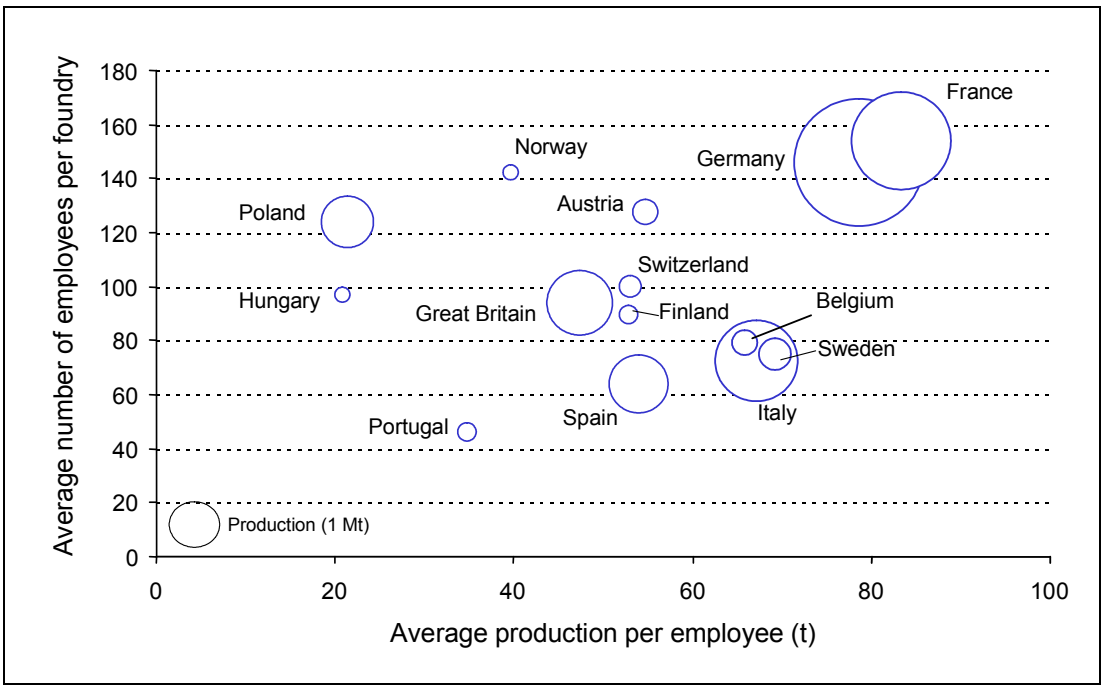


Figure 1.1: Ferrous foundry productivity data for various European countries the size of the circle represents the total production in the specified country

The casting of metal is an ancient activity, dating back to more than 3000 BC. The development of the European foundry industry is linked with the development of both the metal and the automotive industries. Present foundries often have a history dating back to the beginning of the 20th century. Originally they were usually located on the outskirts of towns, but as villages and cities have grown around them they are now often surrounded by habitation. The foundry industry is basically an SME industry, with 80 % of companies employing less than 250 people. Since castings in general are semi-finished products, foundries are located close to their customers.

1.1.2 Foundry markets

The main markets served by the foundry industry are the automotive, general engineering and construction sectors. The relative shares of these sectors as markets for the foundry industry are given in Figure 1.2. The high dependence on the automotive sector has a major influence on activities in the foundry sector, and concerns various aspects, such as economy, location, quality standards, environmental standards, new developments, etc. One example of this dependency is that the automotive industry's shift towards lighter vehicles, is reflected in the foundry industry by an increased demand (and thus market) for aluminium and magnesium casting, thus enabling the growth of these sectors.

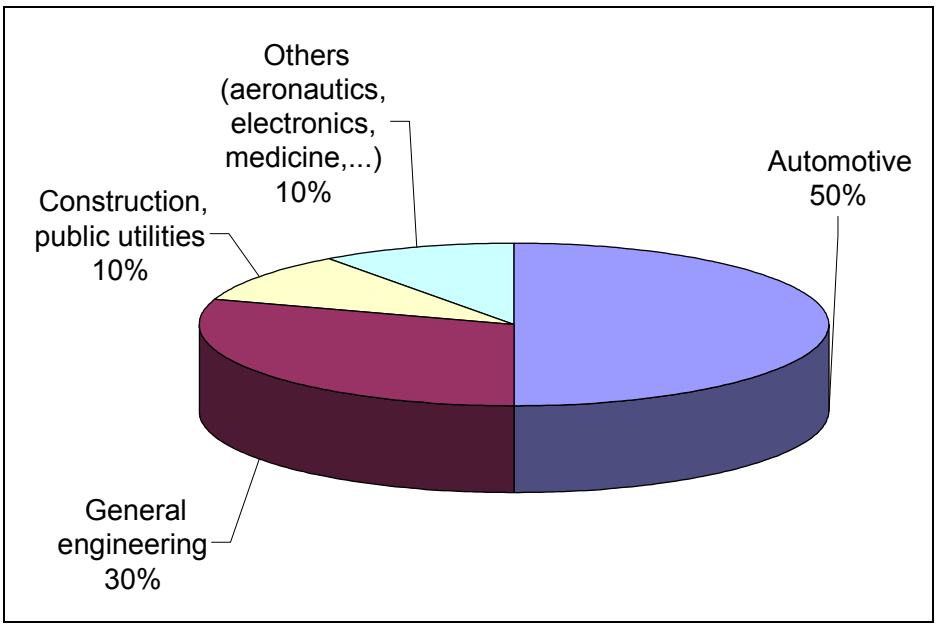


Figure 1.2: Relative sectoral market shares

The market shares differ according to the type of metal. This is illustrated by data from the Spanish foundry market, as shown in Figure 1.3 and Figure 1.4. The automotive sector takes up more than 60 % of all iron castings from Spanish foundries. Steel castings on the other hand (including low alloyed as well as stainless and other alloys) are used for machine parts and in valve making, and therefore serve a broader range of sectors. Indeed, the largest share of the market for valve making is taken up by stainless castings.

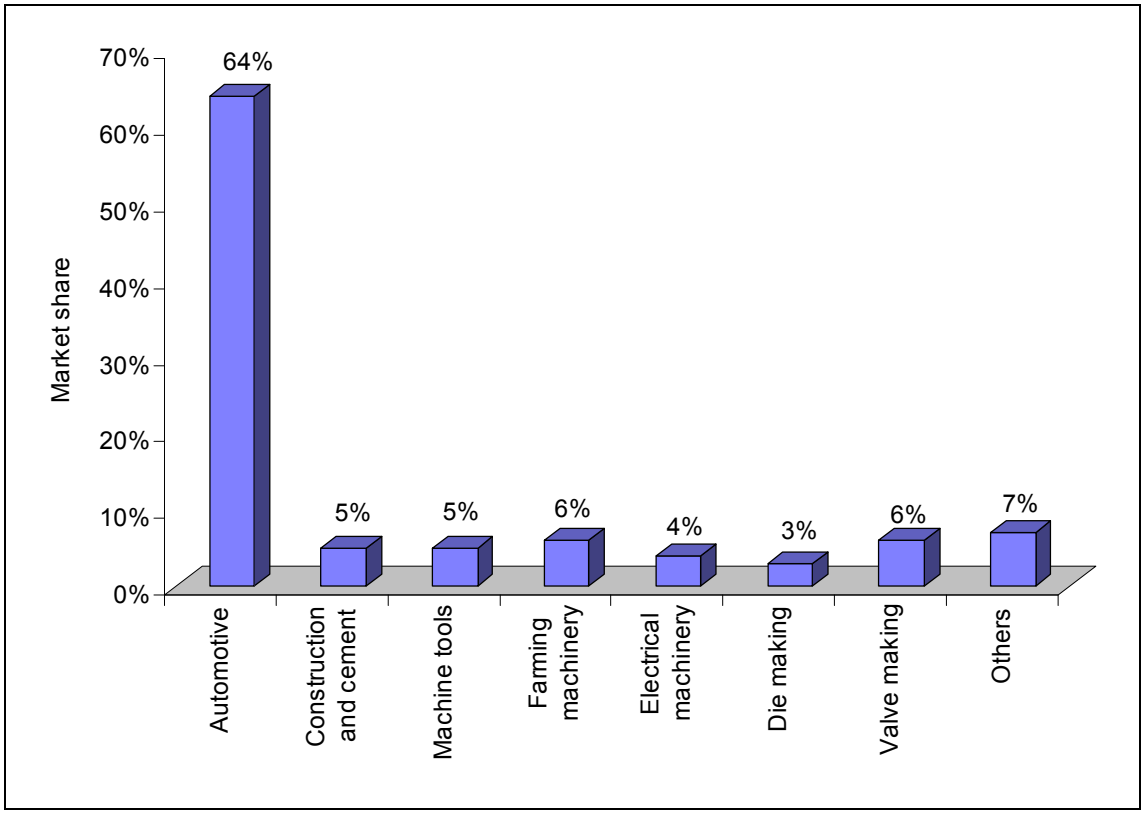


Figure 1.3: Market shares for iron castings (data for Spanish market)
[108, FEAF, 1999]

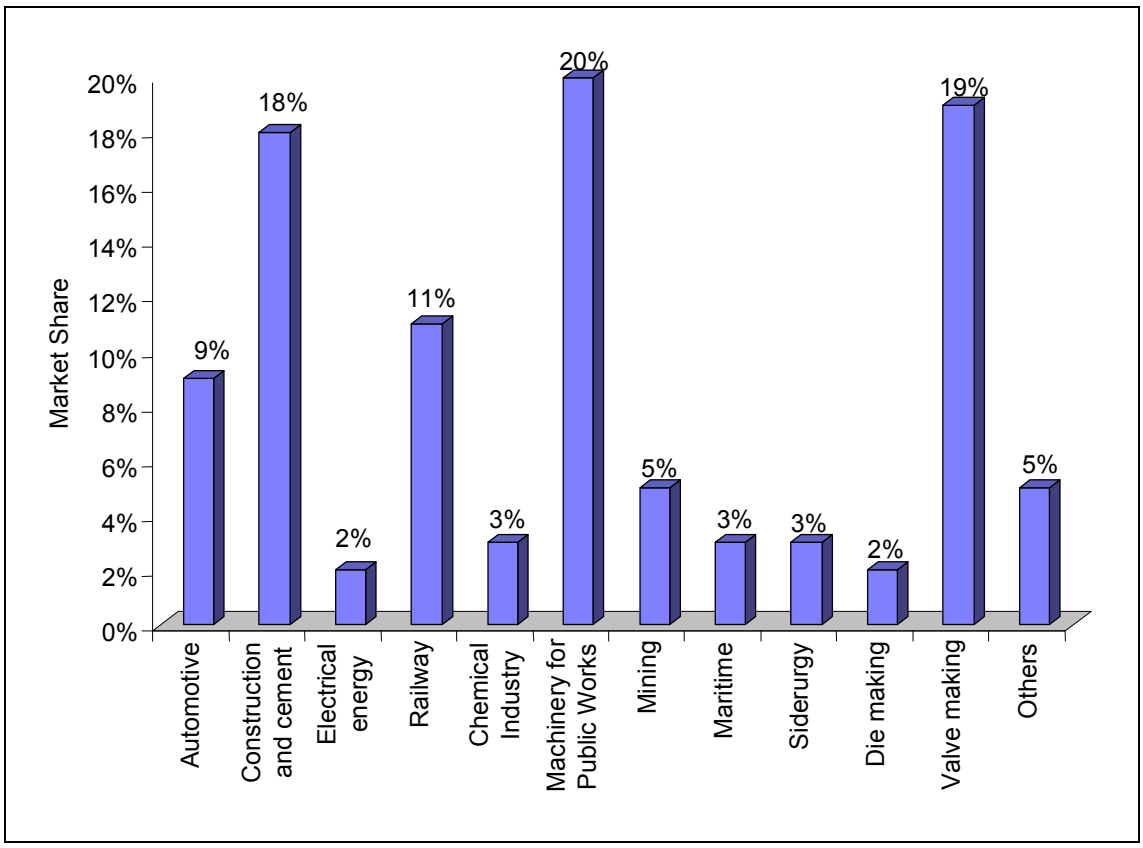


Figure 1.4: Market shares for steel castings (data for Spanish market) [108, FEAF, 1999]

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

1.1.3 Foundry types

Besides the metal type (i.e. ferrous/non-ferrous) the foundry layout is largely dependent on the size of castings and the series size. A small series foundry is termed a 'jobbing foundry' and a large series one is termed a 'series foundry'. Foundries may be also be classified according to the type of metal manufactured, i.e. either a ferrous or a non-ferrous foundry. There is a large difference between a zinc foundry producing a large series of frames for toy cars and a cast iron foundry producing rotor housings for wind turbines. Foundries apply different degrees of automation according to their series size and the repeatability of the work. Concerning applied techniques, the main distinction is made by the type of melting furnace used (e.g. cupola, electrical, rotary, …) and the type of mould (e.g. sand moulding, die-casting). These will be described and discussed further in Chapter 2.

1.2 Environmental issues

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

1.2.1 Air

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

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

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

In the foundry process, emissions to air are not limited to one (or several) fixed point(s). The process involves various emission sources (e.g. from hot castings, sand, hot metal). A key issue in emission reduction is not only to treat the exhaust and off-gas flow, but also to capture it.

1.2.2 Residues

Sand moulding involves the use of large sand volumes, with sand-to-liquid-metal weight ratios generally ranging from 1:1 up to 20:1. At the end of the moulding process the used sand can be regenerated, re-used or disposed off. Additional mineral residues such as slag and dross are generated in the melting stage when removing impurities from the melt. These should also be considered for either re-use or disposal.

1.2.3 Energy

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

1.2.4 Water

In most foundries, water management involves an internal circulation of water, but a major part of the water still evaporates. The water is generally used in the cooling systems of electric furnaces (induction or arc) and cupola furnaces. In general, the outgoing waste water stream is therefore very small. For (high) pressure die-casting, a waste water stream is formed, which needs treatment to remove organic (phenol, oil) compounds before disposal.

2 APPLIED PROCESSES AND TECHNIQUES IN FOUNDRIES

2.1 Overview

2.1.1 The foundry process

A general flow chart of the foundry process is depicted in Figure 2.1. The process can be divided into the following major activities:

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

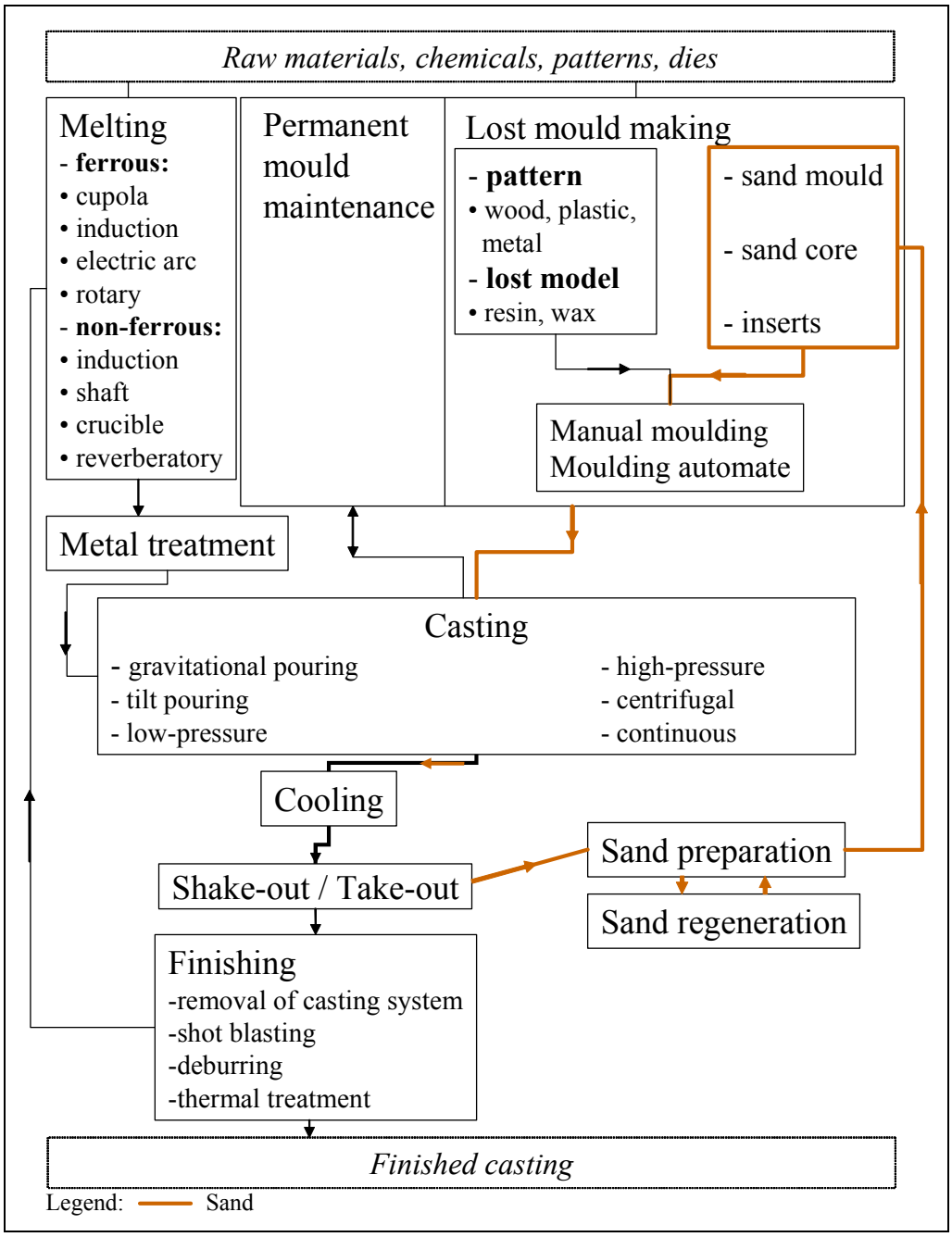


Figure 2.1: The foundry process

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

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

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

- aluminium
- magnesium
- copper
- zinc
- lead.

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

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

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

For medium-sized series (<1000 parts), mechanised moulding and casting lines are used. Lost mould foundries utilise mould making machines. This implies the use of green sand, which allows fast mould making. The size of the mould making machine limits the maximum size of the castings. Casting can be performed manually or by using a pouring machine. Auxiliary side processes, such as sand preparation, are operated in a semi-automated way with remote control. Both continuous furnaces (cupola, shaft) and batch furnaces are used. For non-ferrous alloys, die-casting techniques are applied.

Large series of small castings are made in flaskless green sand moulding. For specific applications, die-casting also can be used in ferrous foundries if the final casting quality requires it, although in reality the technique finds only limited implementation. The main difference for medium-sized series is the further automation of the finishing, the quality control and the mould assembly. For die-casting in non-ferrous alloy facilities, further automation is often applied, this is especially the case in pressure die-casting shops.

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

2.1.2 Iron casting

Cast iron is an iron-carbon alloy, containing usually between 2.4 and 4 % carbon. The minimum carbon content is 1.8 %. Silicon, manganese, sulphur and phosphorus are also present in various amounts. Special grades of iron are produced which contain various levels of nickel, chrome and other metals. Due to its high carbon content, cast iron has a low melting point and a good casting ability as compared to steel. Its ductility is low and does not allow rolling or forging. Variations in properties can be achieved by varying the ratio of carbon to silicon, by alloying, and by heat treatment.

Depending on the concentration and form of the carbon (lamellar, spheroidal or compact), various types of cast iron may be defined:
- lamellar iron: carbon in the form of flakes
- nodular iron: carbon in spheroidal form
- compact graphite iron: carbon in bonded form.

The classification of cast iron is often made according to its material properties:
- grey iron: iron with a grey fracture surface. Although this applies for lamellar, nodular and compact graphite iron, the term is commonly used as a synonym for lamellar iron
- ductile iron: cast iron with an increased ductility. This is one of the effects caused by nodularisation, but it also applies to malleable iron. The term is commonly used as a synonym for nodular iron
- malleable iron: iron that is capable of extension or of being shaped under the hammer. This property is related to a low carbon content, which leaves most of the carbon in bonded form.

Cast iron can be melted in the cupola furnace, induction furnace (generally of coreless type, but very occasionally can be the channel type) or in the rotary furnace. The electric arc furnace is only very rarely used for the preparation of cast iron. Figure 2.2 gives process flow diagrams for the melting and metal treatment of cast iron in the three different furnace types. The process generally consists of melting – tapping – metal treatment – pouring. The various aspects of melting and metal treatment are discussed in the following sections. Metal treatment involves various steps such as desulphurisation, nodularisation, inoculation and deslagging. The desulphurisation step in cupola melting may also be incorporated into the nodularisation, e.g. by using a nodularisation process which simultaneously takes up the sulphur, such as the core wired process.

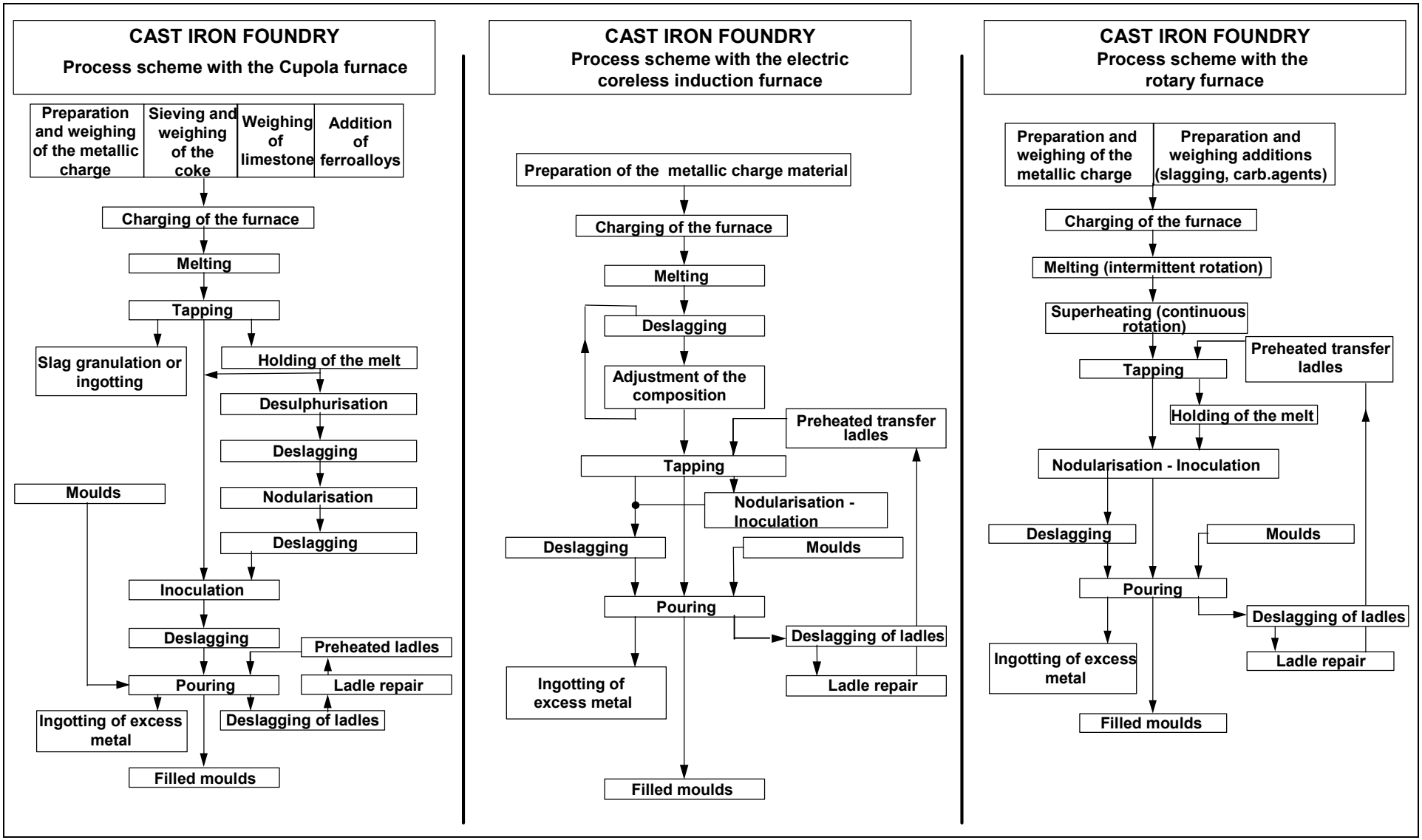


Figure 2.2: Process flow diagrams for the melting and metal treatment of cast iron [32, CAEF, 1997]

The cupola is the leading device for re-melting iron in Europe. It is responsible for some 55 % of the tonnage of iron castings produced in Western Europe. Nowadays, the cupola is increasingly facing major challenges to its market domination. This is partially due to its flue-gas quality, which requires treatment. Faced with the possible financial burden of investing in, and then depreciating, a stack gas treatment installation, many small and medium sized units have turned to electric or oxygas melting units. Thus the number of cupolas used in foundries is falling, but their average size is increasing. There have been major changes in the market for cupolas in Europe in recent years, particularly due to the restructuring of the coke industry, leading to a decreased number of suppliers and a need to import coke into Europe. Another major change is the smaller number of cupola manufacturers, with one German firm having a quasi-monopoly in the hot blast type.

The majority of repetitive iron castings are made in green sand moulds with resin-bonded cores. The cold-box amine and hot-box techniques are most widely used. The 'Croning resin shell' moulding process is used where a high precision and good surface finish are needed. The Lost Foam process is used to a limited extent, for repetition castings. Castings made in smaller numbers are made in chemically-bonded sand moulds. Special sand processes, such as vacuum moulding and full moulding are used for certain iron castings. There are also a few permanent moulding (die-casting) foundries making iron castings, but the short die-life of a mould limiting it to making only a few thousand components has restricted the use of ferrous die-casting.
[156, Godinot, 2001], [174, Brown, 2000]

2.1.3 Steel casting

Steel is a material of which the (mass) content of iron is bigger than that of any other element, with a carbon content generally lower than 2%, and which also usually contains other elements. A limited number of chromium steel types may contain over 2 % carbon, but 2 % is the usual cut-off limit used to distinguish steel from cast iron [201, CEN, 2000]. One particularly useful aspect of steel is that it can be hot worked. Low alloy cast steel contains elements such as Mn, Cr, Ni, and Mo in amounts less than 5 %. High alloy steel includes more than 5 % of alloying elements, e.g. 12 % Cr and 8 % Ni. Special steel grades are produced with enhanced properties, such as higher strength; higher magnetic permeability; better resistance to corrosion, fatigue or wear; and improved behaviour during welding or at high or low temperatures.

Cast steel is normally melted in electric arc furnaces (EAF) or in coreless induction furnaces (IF). Once melted, the liquid metal can be refined (i.e. removal of carbon, silicon, sulphur and or phosphorus) and deoxidised (i.e. reduction of metallic oxides), depending on the base material and the quality requirement of the finished product . Figure 2.3 gives process flow diagrams for the melting and metal treatment of cast steel in the different furnace types.
[32, CAEF, 1997]

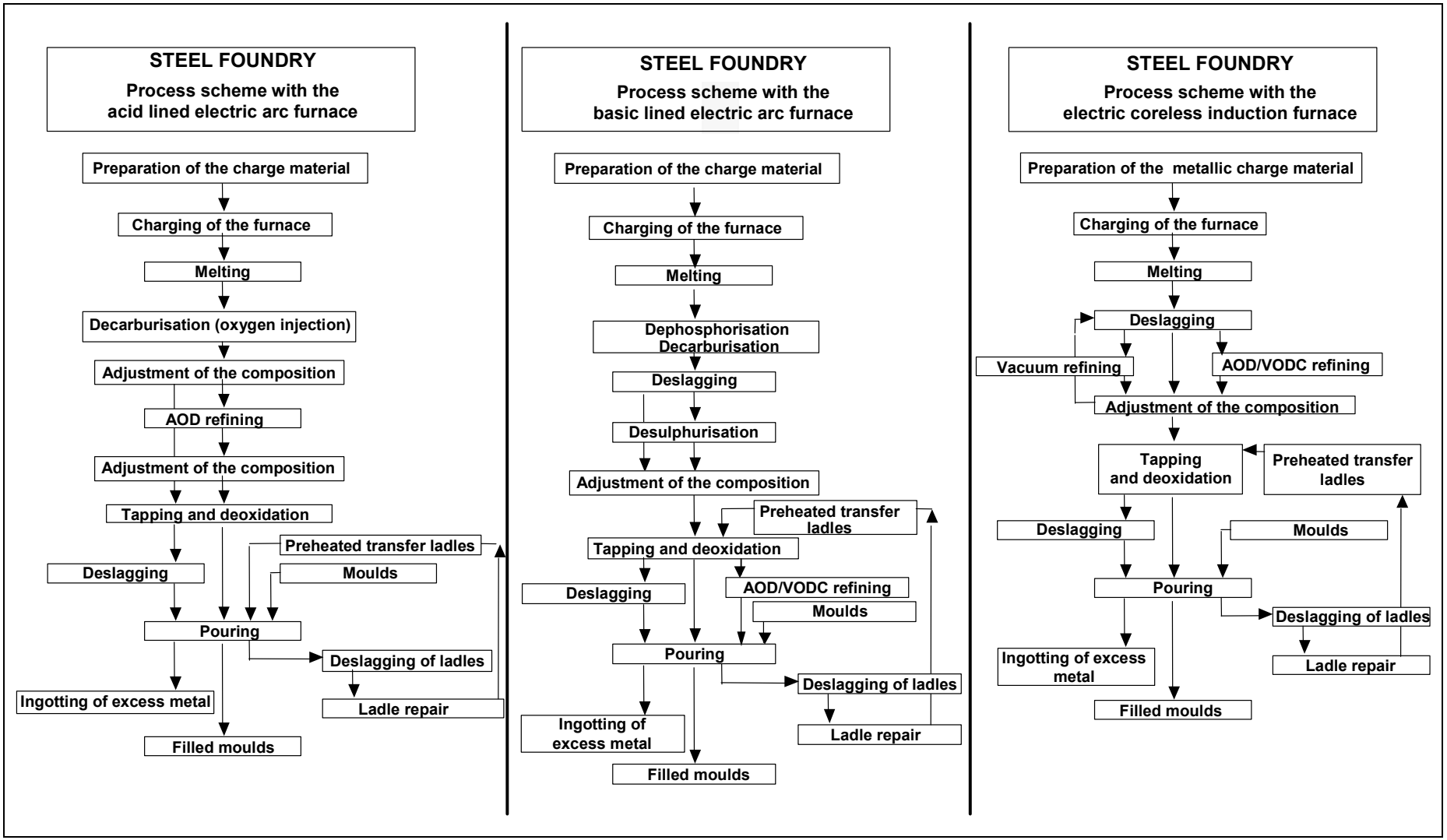


Figure 2.3: Process flow diagrams for the melting and metal treatment of steel [32, CAEF, 1997]

2.1.4 Aluminium casting

About two-thirds of all aluminium castings are used in the automotive industry, e.g. in cars, buses, lorries, trains and aircraft. The need to reduce vehicle fuel consumption and weight has increased the interest in aluminium. The total mass of aluminium in a European car roughly doubled between 1990 and 2000. This growing use of aluminium in its major user sector clearly has an effect on the overall number of castings produced.

Aluminium is mainly cast into permanent moulds. The relative shares of applied casting techniques for Al are given in Table 2.1:

Casting type	Relative share (%)
Pressure die-casting	59
Low-pressure die-casting & gravity casting	37
Sand casting	3
Others	1

Table 2.1: Relative shares of applied casting techniques for Al [143, Inasmet and CTIF, 2002], [225, TWG, 2003]

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

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

Aluminium melting in foundries generally uses alloyed ingots as a starting material, although in some cases the metal is delivered already as a liquid. The secondary melting of aluminium scrap is usually not performed in foundries and falls outside the scope of this document. It is discussed in the BAT reference document for the non-ferrous metals industries.
[48, ETSU, 1994] [148, Eurofine, 2002], [155, European IPPC Bureau, 2001]

2.1.5 Magnesium casting

Magnesium alloy castings are used for aerospace, automotive and electronic applications. The main advantage for using them is their light weight; typically magnesium alloys have a density of 1.8 g/ml compared with 2.7 g/ml for aluminium alloys. Aluminium is the principle alloying constituent of magnesium-based casting alloys, with zinc and manganese also present in small amounts. Pressure die-casting is the most commonly used casting process, due to the low casting temperature (650 – 700 ºC); both hot chamber and cold chamber die-casting machines are used. Sand moulding is applied to a lesser extent. Magnesium die-castings can be made with thinner walls than aluminium, but their use is limited by stiffness problems. The thinner walls allow the overall weight of the components to be substantially reduced, thus compensating for the higher alloy cost per kilogram. Gravity die-casting and sand casting are also used, particularly for more highly stressed castings. The use of magnesium alloy die-castings in automotive components is growing rapidly, with some vehicles already containing 10 – 20 kg of

Mg components. The most popular parts made at present are instrument panel substrates, cross car beams, wheeldrives and seat frames.

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

Due to its very easy oxidation, magnesium alloys are melted under a cover using a cleansing flux or cover gas, to avoid oxidation losses and to prevent inclusions. Inhibitor powders are used to cover any exposed metal during holding and pouring, and are added to moulding-sand to prevent chemical reactions. The fluxless melting of Mg alloys requires another form of melt protection. For this purpose, sulphur hexafluoride (SF_6) is used, as it promotes the formation of a protective film on liquid magnesium, which prevents oxidation. It is used at low concentration (<0.3 vol %) in a mix with air or air/CO_2. SF_6 is a greenhouse gas, considered harmful to the atmosphere and falls under the Kyoto protocol, which requires its use to be minimised. Austria and Denmark have issued regulations to ban the use of SF_6 by 2003 and 2006, respectively.

Magnesium alloys benefit from grain refinement, which is carried out by inoculation with carbonaceous materials. This used to be done with hexachloroethane, but since 1 July 2003 this product is banned in Europe generally to ensure environmental protection and for health and safety reasons. This applies both for magnesium and aluminium alloys.
[175, Brown, 1999], [225, TWG, 2003]

2.1.6 Copper casting

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

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

- *Copper-Nickels*: Cu-Ni-alloys, where Ni is the major alloying element. These are used for e.g. pipework for marine applications in severe conditions
- *Copper-beryllium alloys*: Beryllium is cast as a copper-beryllium alloy for the production of parts that require resistance to corrosion and very high mechanical characteristics. These include plunger tips for die-casting machines, precision parts for the electrical and mechanics industry, in watchmaking, for tooling, and for measurements instruments. Two alloy types are used: a copper-beryllium alloy with 2 % Be, and a copper-cobalt-beryllium alloy with 0.5 % Be. There is a tendency to reduce or exclude beryllium in alloys due to its known carcinogenic character. Casting is done in permanent moulds using pressure or gravity die-casting. For precision parts casting, the investment casting technique is used.

[175, Brown, 1999]

2.1.7 Zinc casting

Zinc casting almost exclusively uses the pressure die-casting technique. In the EU, there are mainly two alloys in use, their compositions are given in Table 2.2. They are also referred to as Zamac, which in origin is a trade name. The basis of these alloys is pure zinc.

Symbol	Alloy number	Al	Cu	Mg
ZnAl4Cu1	ZP0410	3.7 – 4.3	0.7 – 1.2	0.025 – 0.06
ZnAl4	ZP0400	3.7 – 4.3	0.25	0.025 – 0.06

Table 2.2: Most common zinc alloys, contents in %

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

Zinc alloys have comparable material properties to aluminium. The main differences are the lower melting point and the higher density of the zinc alloys (6.7 g/cm³ versus 2.6 – 2.7 g/cm³). They are mostly used for small pieces requiring high precision and a low wall thickness. They also allow a higher casting speed to be utilised and result in a 10 times longer die life (800000 to 1200000 shots), which makes them more suitable for large series (of small pieces). The zinc alloys are melted in an electrically or fuel heated cast iron crucible and cast using hot-chamber die-casting machines. The products are used in e.g. automotive and electronics components and in machine construction applications.

2.1.8 Lead casting

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

2.1.9 Casting of superalloys

The superalloys are typically Ni, Ni-Fe, and Co based alloys with Cr, Ti, W, Al additions. They were originally used for high temperature applications (over 810 ºC) or in severe corrosive media. Superalloys can be distinguished from high alloyed steels (see definition in Section 2.1.3). Since iron is not the major compound (as defined in [201, CEN, 2000]), they are considered non-ferrous materials. The casting of superalloys may occur in certain investment casting foundries, as well as partly in foundries which specialise in high alloyed steel qualities.

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

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

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

Initially superalloys were developed for high temperature applications. However, their field of application continues to expand and now covers areas such as cryogenic temperature appliances and orthopaedic and dental prostheses. In general, superalloys are mainly used in aircraft and industrial gas turbines, in nuclear reactors, in aircraft and spacecraft structures, in petrochemical production and in medical applications.
[202, TWG, 2002]

2.2 Pattern making

2.2.1 General pattern making

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

Patterns (Figure 2.4) and corebox materials (Figure 2.5) are typically metal, plastic, wood or plaster. Wax and polystyrene are used in the investment and Lost Foam casting processes, respectively. Pattern makers have a wide range of tools available to them, including woodworking and metal machining tools. Mechanical connectors and glues are used to join pattern pieces together. Wax, plastic or polyester putty is used as a filler to fill or round the inside of square corners.
[42, US EPA, 1998]

Figure 2.4: Wooden pattern
[237, HUT, 2003]

Figure 2.5: Coreboxes
[237, HUT, 2003]

2.2.2 Rapid prototyping (RP)

Rapid prototyping is a technique to pass very quickly from a product concept to a cast prototype. The term 'Rapid Prototyping' includes all technical and organisational measures from the formulation of the concept of a product to the manufacture of the product. Rapid prototyping can be used for every stage of product development, i.e. for concept models, geometrical prototypes, functional prototypes or for technical or sales prototypes. All the currently available techniques allow the fabrication of a prototype part from a three-dimensional drawing. They are also used for the direct sintering of sands for the production of moulds or cores. The technique consists of building an object to a design pattern by joining particles or layers of raw material such as polymer resin, wax, paper or ceramic powder. An example picture of a wax pattern is given in Figure 2.6

Figure 2.6: Thermopolymer (wax) patterns in an RP machine
[237, HUT, 2003]

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

The advantages of Rapid Prototyping, particularly for complex forms, include:
- shorter development time and the possibility of rapid modifications during the development
- saving of costs, materials and time
- early error detection.

[202, TWG, 2002], [203, Linxe, 2002]

A survey of available techniques is given in Table 2.3.

Process	Principle	Materials	Special features
Liquid – solid	Polymerisation by local UV exposure of a photosensitive resin	Photosensitive resins Acrylates, epoxydes	- shrinkage and deformations - model needs supports
Solid – solid	Contours of a layer are cut out from a foil	Paper, metals, polymers	- no supports - consumption of base material
	Deposition of a material showing thermal fusion	ABS, wax, elastomers	- model needs supports
	Material jet	Waxes, polymers	- model needs supports
Powder – solid	Agglomeration of powder by sintering	Metals, ceramics, sand, polystyrene, nylon, polyamide, wax	- no supports - porosity - shrinkage
	Agglomeration of powder by binder projection	Alumina	- no supports - porosity

Table 2.3: Description of rapid prototyping techniques
[203, Linxe, 2002]

2.3 Raw materials and raw material handling

The main flows of raw materials entering the foundry are metal ingots, foundry scrap and sand. A distinction can be made between ferrous and non-ferrous foundries. Non-ferrous foundries generally melt only internal return material and alloy ingots (Figure 2.7). The re-melting of external scrap is generally considered a separate activity, usually forming part of the secondary metal production. If external scrap is acquired, it is first subjected to a spectroscopy analysis in order to determine the alloy type. Ferrous foundries use pig iron and selected iron and steel scrap as starting materials, besides internal return material. The various qualities of metal feeds are stored in separate areas in order to allow the controlled feeding of the melting furnace.

Figure 2.7: Aluminium scrap(l.) and ingots (r.)
[237, HUT, 2003]

Raw materials, including fluxes in lump and powder form; foundry cokes for cupola furnaces; deoxidants; and refractories are normally stored under cover. Following delivery, handling is kept to a minimum. Powdered materials may be stored in sealed silos and conveyed pneumatically or kept and handled in sealed bags, as displayed in Figure 2.8.

Figure 2.8: Pneumatic conveyors and silos for powdered materials
[237, HUT, 2003]

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

Liquid binders and oil products are delivered in drums, by bulk container or by road tanker. They are stored in their delivery containers or, in the case of rail tankers, discharged direct into a dedicated storage. The containers are connected by pipe directly to the sand/resin/catalyst-mixing unit. Some catalysts and co-reactants are used in a gaseous form, but these are also

delivered as liquids and handled in a similar fashion before being vaporised and mixed with a carrier gas. Evaporation is enclosed and may be carried out by a variety of methods.

Refractories, release agents and other minor deliveries are stored indoors.

Coarse solid residues, such as used refractories and slags, are stored on separate heaps, in a subdivided storage area or in boxes. They are moved and handled using small lift trucks. Fine solid residues are collected at the filter unit into big bags or containers, which may be stored intermediately before transport for disposal. In order to avoid soil contamination from the various classes of materials, specific measures are taken. Potential impacts are listed in Table 2.5.

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

Additional alloying elements can be added to the charge as ferro-alloys such as FeSi, FeMn, FeCr, or pure such as Cu, C, Ni. However most alloys are added to the molten metal to prevent metallic losses due to oxidation. Alloying elements are usually present in the foundry in small quantities and are always stored inside the building, preferably close to the melting installation. [32, CAEF, 1997].

Activities	Contaminants of Concern		Potential Impact
Raw materials storage			
Scrap storage – external, often on soil	Loose materials from scrap - metals and coatings		Localised contamination of soil surface
	Oils - may include: - PAH from combustion engine oils - PCBs from capacitors (mainly in shredded scrap, unless PCB phase-out has taken place successfully)		Leaching into groundwater and nearby surface waters
	Cutting fluids - may be chlorinated		
Liquids in underground tanks	Petroleum products, e.g. fuel oil diesel		Leakage into soil with leaching into ground and surface waters
Raw materials handling, transfer and use			
Chemical binder products – accidental spillage or leaks	Phenolic resins	Free phenol content of 0.5 to 5 %	Water-soluble; can leach into groundwater. Rapid degradation if less than 400 ppm. Concentrated larger volume spills will be slower to degrade due to toxicity to bacteria
	Solvent carriers in resins	e.g. methanol, up to 20 % volume	Mostly water-soluble, can leach into groundwater
	Urethane resins	Aromatic solvents[1]	Solvents could leach into groundwater
	Furan hardeners	Toluene-, Xylene-, Benzene-sulphonic acids	Could leach into groundwater or alter soil properties, e.g. mobilisation of metals
	Urea-based resins	Ammonia	Can leach into ground and surface waters
	Silicate resins	Alkaline pH	Could leach into groundwater or alter soil properties, e.g. mobilisation of metals
Mould coatings	Isopropyl alcohol (IPA)		Water-soluble, can leach into groundwater
Fuels, maintenance products: - accidental spillage or leaks (particularly around filling points) - deliberate disposal to ground	Fuel oils, diesel, petrol with PAH & SO_4^{2-} post-combustion; Lubrication & hydraulic oils; Quench oils; Transformer oils (potential for PCBs)		Oils can leach into ground and surface waters. Air deposition of PAH and SO_4^{2-} from the combustion of fuel oils. SO_4^{2-} will leach down soil profile. PAH, PCBs will tend to absorb onto soils
[1] Former formulations contained PAH (mainly naphtalene), but naphtalene depleted formulations have been developed, which have eliminated this contaminant.			

Table 2.4: Potential soil contamination from ferrous foundry raw materials [140, EU Thematic Network Foundry Wastes, 2001], [225, TWG, 2003]

2.4 Melting and metal treatment

The selection of a melting furnace is an important aspect in the setting up of a foundry process. Each furnace type has its own properties concerning feed requirements and alloying possibilities, which in turn will have repercussions on the full foundry process. On the other hand, the type of metal to be melted determines which furnace may or may not be used. The applicability of the various furnace types is given in Table 2.5.

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

Table 2.5: Applicability of furnace types, for melting (m) and holding (h)

Iron foundries require metal of a controlled composition and temperature, supplied at a rate sufficient to match the varying demand of the moulding line. The metallic charge to be melted usually consists of foundry returns, iron and steel foundry scrap and pig iron, with alloying additions such as e.g. ferrosilicon, ferrophosphorus or ferromanganese. The charge is usually melted in a cupola or in an electric induction furnace. Induction furnaces are gradually gaining higher market preference compared to the cupola type. Coreless induction furnaces are used for melting. Channel induction furnaces are only used for holding, their main application being in combination with the cupola furnace, in the so-called duplex configuration. Gas-fired and oil-fired rotary furnaces can also be used, although their use is less common. Short-term holding, transport and metal treatment are performed in ladles.

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

The melting furnace used in non-ferrous melting is dependent on the foundry size. Non-ferrous foundries often use a variety of different alloys and/or have a limited melting capacity. Melting is done in small volume furnaces, for which the crucible furnace is most suited. Additionally, die-casting is the major casting technique. In this case, there often is no need for a centralised melting, as the melting (and holding) furnace is integrated into the casting machine. Non-ferrous foundries with a higher capacity and a need (or reason) for centralised melting typically use induction, hearth type or shaft furnaces for melting, and then distribute the molten metal to holding furnaces and casting crucibles.
[174, Brown, 2000], [225, TWG, 2003]

2.4.1 Cupola furnaces

2.4.1.1 Cold blast cupola furnace

2.4.1.1.1 Description

The cupola is a refractory lined shaft furnace where the metal charge is heated by the combustion of coke, which takes place in the lower part of the shaft (the "hearth"). Combustion air, supplied by fans, is injected in the hearth through a number of exhaust nozzles ("tuyères"). A ring and control valve allows a controlled and evenly distributed flow of combustion air through the tuyères. The metal (pig iron, steel scrap, scrap iron, foundry returns), coke, alloying elements (e.g. FeSi, SiC), slag forming (SiO_2) and fluxing agents (e.g. $CaCO_3$) are added to the shaft through a charging door at the upper part of the shaft. The combustion gases move upward from the hearth and exchange heat with the charge, before leaving the furnace through the cupola stack.

When the preheated charge reaches the combustion zone, the metallic parts melt due to the high temperatures, and the charged coke starts to burn in the presence of oxygen. The molten metal droplets run through the coke bed and gather in the zone called the well, which is below the combustion zone. All the impurities are trapped in the slag, which is mostly formed by SiO_2, CaO, Al_2O_3 and FeO. Fluxing agents lower the melting point and the viscosity of the slag. Due to its lower density, the slag floats on the molten metal in the well. Once the liquid metal in the well has reached a certain level, a tap-hole is opened. The metal flows discontinuously through the tap hole, via a refractory lined channel or launder into a separate collection vessel or ladle. Alternatively, the molten metal can be continuously directed to a holding furnace.

The slag is tapped separately by means of a dam and a slag spout placed at a higher level. It is collected discontinuously in pots, or continuously granulated in a water stream, or in a special installation for dry granulation.

In its basic configuration, the cupola is called a **cold blast cupola (CBC).** This is a cupola which uses the blast at atmospheric pressure and at normal environmental temperature.

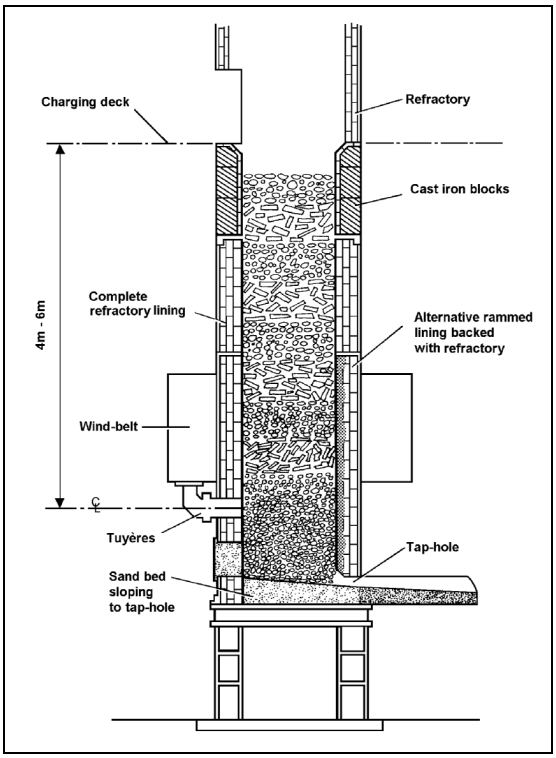


Figure 2.9: Schematic outline and miniature model of a (cold blast) cupola furnace [44, ETSU, 1993], [237, HUT, 2003]

In order to reduce the CO-emission and increase the energy efficiency, the conversion of cold blast furnaces to hot blast furnaces may be considered (see Section 4.5.2). However, for medium-sized foundries handling less than 2000 tonnes/month of good castings, the hot blast cupola will be difficult to consider because of the large investment it requires. The use of a hot blast cupola is also restricted to continuous melting, otherwise the running costs are too high. The cold blast cupola prevails for some types of production, e.g. enamelled iron castings, kitchenware, heating appliances, counterweights. These types of castings allow a high level of old cast irons to be used in the melting bed; a charge material still plentiful in the countries of the old industrial Europe and one that is well suited to the cold blast cupola.
[44, ETSU, 1993], [156, Godinot, 2001], [202, TWG, 2002]

2.4.1.1.2 Maintenance

One specific feature of the cupola furnace is that the lining material (quartz-clay-mixture) of the furnace at the melting and heating zone only lasts for one melting campaign. The intense heat and the presence of slag results in a chemical dissolution and mechanical wearing of the lining, which consequently converts it into slag. Cupola furnaces are therefore normally constructed in pairs. While one furnace is melting, the second one can be lined with new refractory material, with the operation being switched around the next day of use.
[110, Vito, 2001]

2.4.1.1.3 Advantages:

- the investment cost is EUR 125000 – 150000 per tonne installed per hour, inclusive of a dedusting installation
- different kinds of (cheap) scrap can be used due to the cleaning and carburising operation
- the thermal efficiency is acceptable if appropriate measures are utilised.

2.4.1.1.4 Disadvantages:

- the production regime is not flexible
- difficult production management because of the slowness of the system
- expensive charge with pig iron, and little steel scrap
- no quick alloy change possible
- sulphur pick-up/take-up in the cupola
- an environmental burden is caused by the foundry; i.e. lots of dust, slag and refractory lining
- big dedusting installations are needed because of the high flue-gas rate.

[110, Vito, 2001]

2.4.1.2 Hot blast cupola furnace

2.4.1.2.1 Description

In order to optimise the efficiency of the cupola furnace, the combustion air may be preheated. This principle is used in the **hot blast cupola** (HBC), i.e. a cupola which uses a preheated blast.

The advantages of the hot-blast operation may be summarised as follows:
- reduced coke consumption
- increased metal temperature
- increased melting rate
- reduced sulphur pick-up
- reduced melting losses
- increased carbon pick-up and hence the ability to substitute steel scrap for pig iron in the furnace charge.

It should be noted that not all these advantages can be attained at the same time. For example, an increase in the proportion of steel scrap in the furnace charge may require an increase in the proportion of coke for recarburisation; this in turn will reduce the melting rate and increase the sulphur pick-up.

Two methods of heating are:

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

The combination of these two heating methods, permits the superheating of the blast air up to 1000 ºC. These high temperatures, however, require the use of more expensive refractory materials and may cause too high a melt temperature.

Recuperative systems offer increased energy and thermal efficiencies. The effect of air preheating on thermal efficiency and coke use is depicted in Figure 2.10. It should be noted that the coke quality may affect the overall blast efficiency.

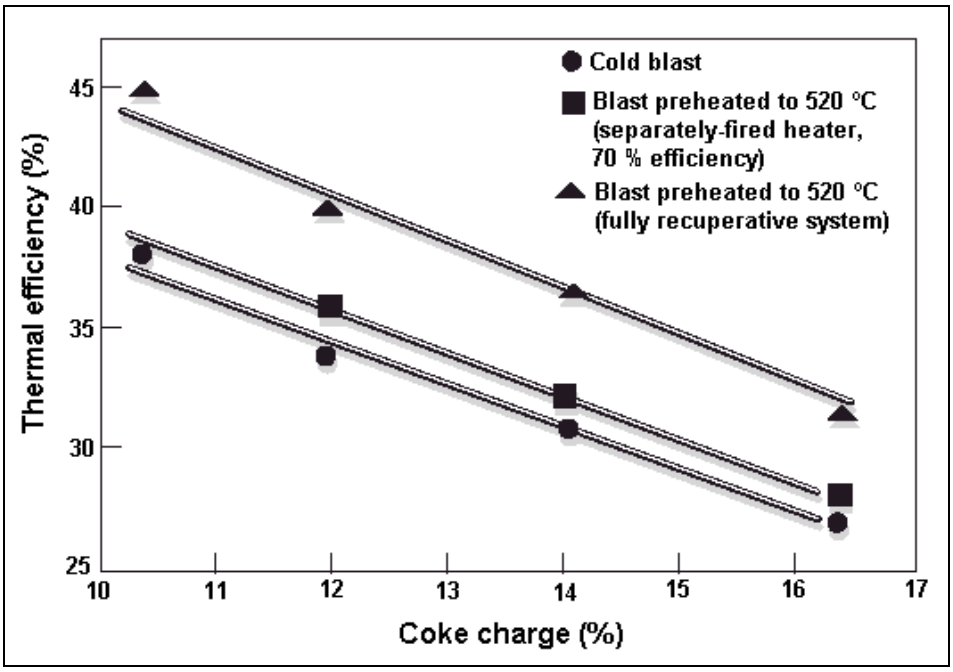


Figure 2.10: Effect of air preheating on blast furnace efficiency
[44, ETSU, 1993]

For medium-sized foundries producing up to 2000 tonnes/month of good castings, the hot blast cupola is difficult to consider, in particular because of the large investment it requires. In these instances, the cold blast cupola prevails for some types of production. The hot blast cupola remains the most widely applied melting device for mass production foundries, e.g. for parts for the automobile industry, centrifugal casting, road accessories.
Hot blast cupolas are normally set up for long campaign operation, in order to minimise process switch overs and maintenance time and effort.
[32, CAEF, 1997], [44, ETSU, 1993], [156, Godinot, 2001]

2.4.1.2.2 Advantages:

- reduced coke consumption
- high tap temperature
- high melting capacity
- less sulphur pick-up in the cupola
- possibility to use different kinds of cheap lower grade ferrous scrap
- more scrap steel can be used because of the higher pick-up of the carbon by pig iron.

2.4.1.2.3 Disadvantages:

- very expensive investment, due to the additional environmental measures required
- production regime is not flexible
- difficult production management because of the slowness of the system
- limited to iron alloys only, no quick alloy change possible
- environmental burden caused by the foundry, e.g. lots of dust, slag and refractory lining
- big dedusting installations are needed because of the high flue-gas rate.

[110, Vito, 2001]

2.4.1.3 Long campaign cupola

A **long campaign cupola** is usually a water-cooled refractory lined cupola that may be hot blast or cold blast. Such cupolas are operated daily for one, two or three shifts and are very often used only as a single unit. This form has a campaign life of several weeks or months. The liningless cupola allows a much longer campaign life but heat losses through the furnace shell can be significant. Further developments in refractories and operating practices are continually being made which improve the life and cost effectiveness of the long campaign cupola. A schematic representation of a long campaign cupola with an in-shaft afterburner is given in Figure 2.11.

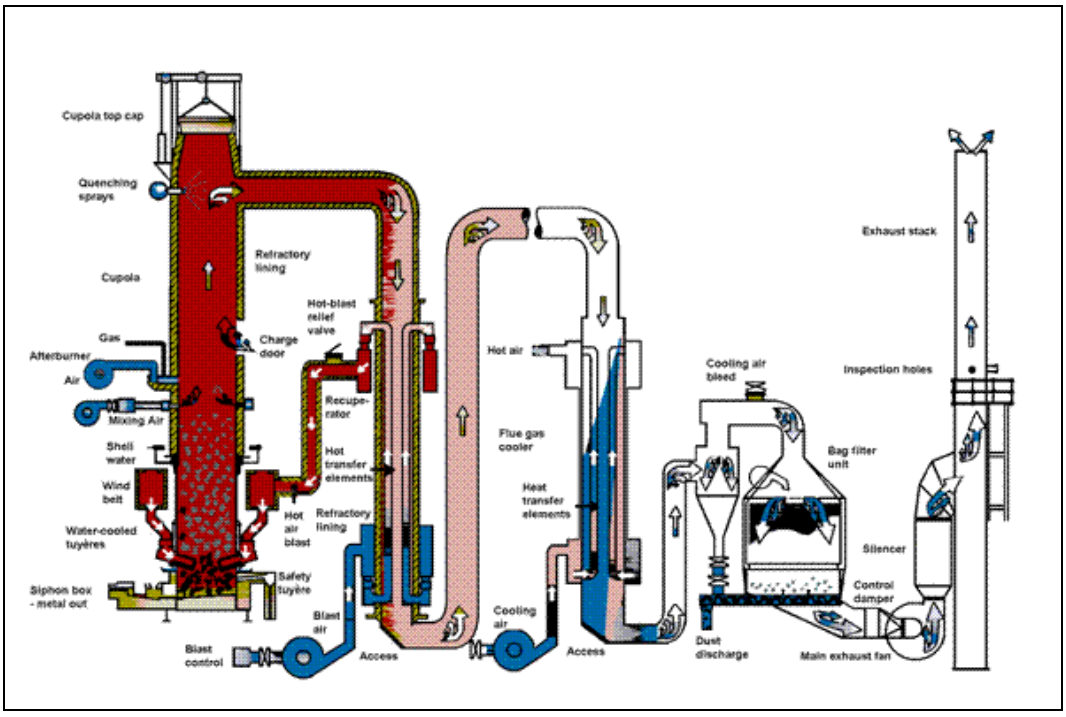


Figure 2.11: Schematic representation of a long campaign cupola
[150, ETSU, 1998]

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

In the liningless operation, the charge is in direct contact with the water-cooled steel furnace shell. Liningless operation is only used on relatively large capacity cupolas, melting for long campaigns. This results in the following advantages:
- only one cupola is required
- the cupola only requires internal repairs after one, or several, week's operation
- daily bed-coke consumption is reduced
- monitoring is easier throughout the campaign, because of the constant diameter and the more consistent melting conditions.

A specific type of long campaign cupola is the cokeless cupola. This is discussed in Section 4.2.1.8.
[32, CAEF, 1997], [44, ETSU, 1993], [110, Vito, 2001], [150, ETSU, 1998]

2.4.1.4 Nature of atmospheric emissions

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

During melting, abrasion of the charge against the refractory lining will also generate dust.

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

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

Carbonaceous smoke is airborne matter formed by the incomplete combustion of organic matter in the cupola. Scrap contaminants such as oil and grease, wood, textiles and, rubber will form oily vapours in the stack gases. Vapours and partially burnt organic matter may carry unpleasant smells.

Again, scrap cleanliness and its nature significantly effect the nature of the emissions. The burning of coke creates odorous gas emissions containing CO_2, CO and SO_2. Decreasing the proportion of the coke charge (by increasing the thermal efficiency) or (partial or complete) substitution of the coke by natural gas can help reduce the levels of these substances.

2.4.2 Electric arc furnace (EAF)

2.4.2.1 Description

The EAF is a batch-melting furnace consisting of a large bowl shaped refractory lined body with a dish shaped hearth. The wide furnace shape allows the handling of bulky charge material and leads to efficient reactions between the slag and metal. Typically the shell diameter is 2 to 4 m. As shown in Figure 2.12, the furnace is covered by a refractory roof, which has ports for three graphite electrodes. The electrodes are supported by arms, which allow movement up and down. Most furnaces use roof charging: by moving the roof and electrodes aside, the furnace can be charged using a drop bottom charging bucket or a magnet. The metal charge is heated by an electric arc, which is created by a three phase alternate electrical current between the three graphite electrodes. These are positioned above the charge, which itself acts as the neutral.

Figure 2.12: EAF furnace
[237, HUT, 2003]

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

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

Electric arc furnaces are almost exclusively used for the melting of steel. Only in a few cases are they used for cast iron production, which requires an addition of coal dust to the melt. Electric arc furnaces designed for steel foundries' purposes usually range from 2 to 50 tonnes capacities. They can be run intermittently and are suitable for a wide range of steel analyses. They can provide steel at high temperatures, with typical meltdown times of about one to two hours, while achieving high thermal efficiencies of up to 80 %[1]. Power consumption varies from 500 to 800 kWh/tonne of molten steel, depending on the furnace capacity, the hot metal consumption, and the refining techniques, tapping temperature and pollution control equipment applied. The total melt time is typically 1 to 4 hours.

[1] Without taking into account the efficiency of electric power generation.

2.4.2.2 Melting and refining with the acidic lined EAF

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

The decarburisation starts by injecting oxygen into the metal bath. This creates a strong stirring action during which carbon in the melt is burned. At the same time the "boiling" burns out Si, and flushes out H_2 and N_2 from the metal bath. All impurities (oxides) are trapped in the slag. During melting, sand (SiO_2) may be added to bring the slag to the proper consistency. When the carbon reaches the proper concentration, oxygen injection is stopped, and silicon and manganese are added to halt the boiling reaction.

After slag removal the metal composition is controlled and adjusted if necessary. Finally the metal is deoxidised by adding aluminium or other agents into the melt stream during tapping, to prevent the formation of CO bubbles during solidification. Additional desulphurisation and or dephosphorisation refining can be executed in an AOD or VODC converter (see Section 2.4.9 and 2.4.10).
[32, CAEF, 1997], [161, UK Environment Agency, 2002]

2.4.2.3 Melting and refining with the basic lined EAF

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

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

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

After refining the metal composition is controlled and adjusted if necessary. Finally the metal is deoxidised by the addition of aluminium or other agents in the metal bath prior to tapping, to prevent the formation of CO bubbles during solidification. Further metal treatment, using an AOD or VODC converter (see Section 2.4.9 and 2.4.10) may be applied if the final alloy composition requires it.
[32, CAEF, 1997], [161, UK Environment Agency, 2002]

2.4.2.4 Nature of atmospheric emissions

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

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

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

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

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

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

2.4.3 Induction furnace (IF)

Induction furnaces are used to melt both ferrous and non-ferrous metals. There are several types of induction furnaces available, but all operate by utilising a strong magnetic field created by passing an electric current through a coil wrapped around the furnace. The magnetic field in turn creates a voltage across, and subsequently an electric current through, the metal to be melted. The electrical resistance of the metal produces heat, which in turn melts the metal. Induction furnaces are made in a wide range of sizes. Because there is no contact between the charge and the energy-carrier, the induction furnace is suited for the melting of steel, cast iron and non-ferrous metals, so long as a suitable lining material can be found.

Proper functioning of the water cooling circuits is crucial to prevent the coil from overheating. The water cooling systems are therefore designed to provide the highest level of reliability, and thus incorporate various thermostats and flow-meters.
[42, US EPA, 1998], [47, ETSU, 1992], [110, Vito, 2001]

2.4.3.1 Coreless induction furnace

2.4.3.1.1 Description

The coreless IF is a batch-melting furnace containing a water-cooled copper coil, the inside of which is internally refractory lined. The outside is insulated and enclosed in a steel shell. The furnace body is mounted in a frame equipped with a tilting mechanism. A coreless induction furnace is normally a refractory-lined bucket-shape refractory, the top of which is open for charging and deslagging operations (see Figure 2.13).

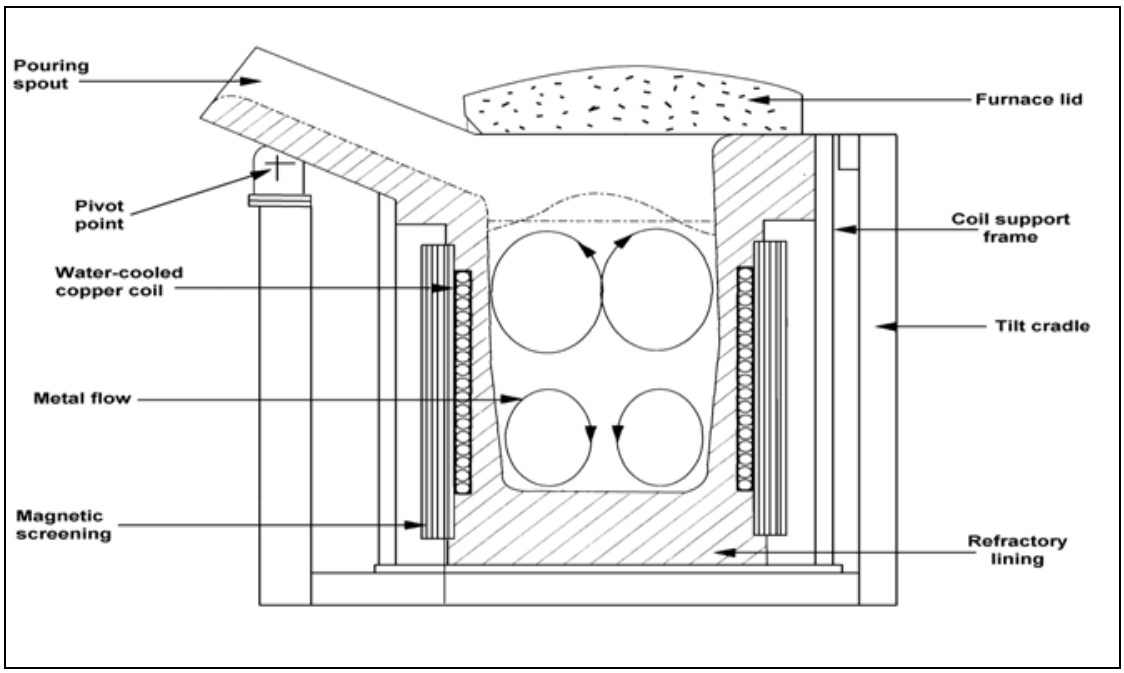


Figure 2.13: General arrangement of coreless induction furnace [47, ETSU, 1992]

According to the capacity, the furnace is charged by a lifting magnet, bucket skips, a vibrating conveyor or manually. A large number of foundries use induction furnaces for producing relatively small lots in a large variety of compositions. Furnace capacities range from 10 kg up to 30 tonnes. The core is fed by mains, medium or high frequency alternating current (50, 250 or 1000 Hz, respectively).

Depending on the installed power density and the melting practice the thermal efficiency can exceed 80 %[2], but usually ranges from 60 to 70 %. If the efficiency of the electric power generation is taken into account, an overall efficiency of 15 – 20 % results, which is rather low in comparison with other furnace types.

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

The frequency of operation also affects the current penetration. The higher the frequency, the lesser the penetration depth. This affects the minimal charge piece size and the effective furnace size. 50 Hz furnaces are not practicable at capacities below 750 kg. At 10 kHz, charge pieces less than 10 mm in diameter can be heated, so furnaces as small as 5 kg capacity can be used. The availability of reliable frequency converters has allowed the development of application specific units, as given in Table 2.6. Frequencies are usually limited to 250 to 350 Hz (in the case of variable frequencies), as at higher frequencies metal homogenisation becomes insufficient. Higher frequencies are used in special cases, such as with very small furnaces. Figure 2.14 shows coreless induction furnaces of various sizes.

[2] Without taking into account the efficiency for electric power generation.

Frequency (Hz)	Application
70	Brass swarf
100	Aluminium scalpings
100 – 150	Cast iron borings
250	Aluminium extrusion scrap
250	Iron from foundry returns and steel scrap
500 and 1000	Steel melting and melting of wet cast iron borings
1000 and 3000	Wide variety of copper alloys
3000	Investment casting
10000	Jewellery trade

Table 2.6: Field of application of available induction furnaces as related to their frequency [174, Brown, 2000]

Figure 2.14: Coreless induction furnaces [237, HUT, 2003]

Water cooling systems are essential for operation of the coreless induction furnace. Cooling the coil protects both the coil and the insulation from thermal damage, not only during normal operation but also during the cool-down period when the power has been switched off and the furnace emptied. Several types of cooling are available, using closed circuits with heat-exchangers or open evaporative systems. The availability of a cooling system opens up the possibilities for internal energy recovery.
[32, CAEF, 1997], [47, ETSU, 1992], [110, Vito, 2001], [174, Brown, 2000], [176, ETSU, 1998], [202, TWG, 2002]

2.4.3.1.2 Melting practice

The coreless induction furnace is used for melting but cannot be used for refining. Therefore, in steel foundries the induction furnace has to be charged with raw materials of the 'correct' chemical composition, i.e. that corresponding to the required composition of the melt; hence steel scrap is mainly used. If necessary, the metal can be refined after melting in an AOD converter or in special treatment ladles (see Section 2.4.12).

High powered furnaces allow melting following the "tap and charge" method. Here the furnace is tapped completely empty and charged with cold material to start the next melting cycle. The "molten heel" method is used on low powered (mains frequency) furnaces where approximately one third of the melt is tapped before the cold charge material is added. Because of the better electromagnetic coupling between the melt liquid and the coil compared to a less dense solid (cold) charge, the production rate increases significantly when using the latter method on low powered furnaces.

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

Induction furnaces are excellent melting units, but in general they are less efficient holders. When they are used for melting only, the molten metal is mostly moved to an efficient holding furnace as soon as it has reached the desired temperature. Many types of coreless induction furnaces are available, with fixed or removable crucibles. For aluminium, both channel and coreless induction furnaces are available for melting and holding. However, the channel type is seldom used, due to difficulties in keeping the channel open and due to the need to maintain a molten heel at all times.
[32, CAEF, 1997], [48, ETSU, 1994]

2.4.3.1.3 Advantages:

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

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

2.4.3.1.4 Disadvantages:

- because of the monopoly of the local electricity supplier, the operator is fully dependent on the connection conditions of the local electricity grid, the energy costs and any possible extra costs (peak control, etc.)
- the energy costs are more expensive than the costs of using fossil fuels
- the cleaning action of the induction furnace on the melt is limited because of the small amount of slag and the relatively small contact area between the slag and melt. This requires the use of a high quality, and thus, more expensive charge than cupola or EAF furnaces
- the installation requires a high investment, although the operator can save on additional environmental investments. The net cost per tonne installed furnace content is around EUR 375000
- other melting techniques are more suitable for capacities >15 tonnes per hour. Depending on the intended alloy, the hot cupola or electric arc furnace may be considered
- it has a low efficiency during holding because of the heat losses in the water-cooled induction coil.

[110, Vito, 2001]

2.4.3.2 Channel induction furnace

2.4.3.2.1 Description

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

The channel induction furnace consists of a big, thermally isolated bucket, equipped with an isolated top-lid for introduction of the charge (Figure 2.15). The bottom is equipped with one or more U-channels. Around these channels is a water-cooled induction coil, which heats and circulates the metal. The induction current has the frequency of the local electricity grid. The furnace is generally mounted in an hydraulically tiltable frame for tapping or maintenance operations. Pressurised and non-tilting furnaces are also in use.

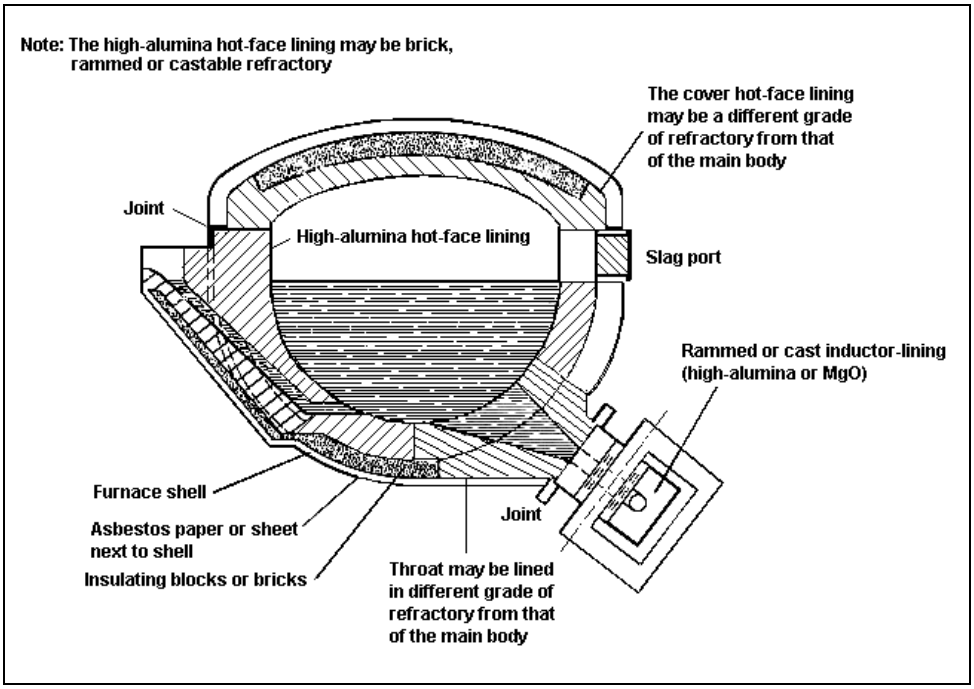


Figure 2.15: Typical construction of a bath channel furnace [55, ETSU, 1993]

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

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

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

Figure 2.16: Channel induction furnace
[237, HUT, 2003]

The channel induction furnace finds its main application as a holding furnace in iron foundries. An example picture is given in Figure 2.16. It is the furnace of choice for duplex operation with cupola furnaces. The capacity varies between 5 and more than 100 tonnes. The holding furnace serves as a buffer between the melting and casting shop. It is important to assess foundry and production requirements fully when considering whether to use a holding furnace. There may be more cost-effective and energy efficient methods of achieving the requirements, and it is advisable to investigate thoroughly all possible solutions before a decision is made. For aluminium, the channel type is seldom used, due to difficulties in keeping the channel open and due to the need to maintain a molten heel at all times.

Output requirements are an important consideration when deciding the size of a channel furnace. The choice of a smaller furnace may be advantageous. Although a smaller furnace is less efficient, the loss in efficiency will be offset by its reduced annual power consumption compared with larger furnaces.
[48, ETSU, 1994], [55, ETSU, 1993], [110, Vito, 2001],

2.4.3.2.2 Advantages:

- high thermal efficiency as a holding furnace
- minimal burn-out of the alloy elements
- little maintenance.

2.4.3.2.3 Disadvantages:

- a minimum amount of molten iron, but which may be a substantial part of the furnace capacity, has to be maintained in the furnace body in order to guarantee proper electrical functioning
- the furnace cannot perform a cold start because of the limited power density that can be achieved in the loop
- difficult to monitor the channel wear
- potential danger of accidental leaks, because of the induction coil on the bottom
- contact between the cooling water and metal is difficult to prevent.

[110, Vito, 2001]

2.4.3.3 Nature of emissions

Since no coal or fuel is burned in the induction furnace and no refining procedures are executed, the emissions solely depend on the cleanliness and the composition of the charged material. Two major categories of emissions can be distinguished. The first, and major, category relates to the charge cleanliness, e.g. rust, dirt, foundry sand, paint, oil, galvanised or soldered metal, all of which are elements which give rise to the emission of dust and fumes (organic or

metallic). The second category relates to chemical reactions at high temperatures, (e.g. while holding or adjusting the metal composition), which can give rise to metallurgical fume due to oxidation.

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

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

2.4.4 Radiant-roof furnace (resistance heated)

The radiant-roof furnace is a low-energy holding furnace with a heavily insulated box design with banks of resistance elements in a hinged, insulated roof. They are mainly used in non-ferrous (aluminium) pressure die-casting shops with centralised melting facilities. Typical units have a capacity of 250 – 1000 kg with a 5 kW to 12 kW connected load. Bale-out and charge wells are separated from the main bath by refractory walls with connectors at the bottom to allow clean metal to pass from one area to another. Figure 2.17 gives a schematic view of the radiant-roof principle.

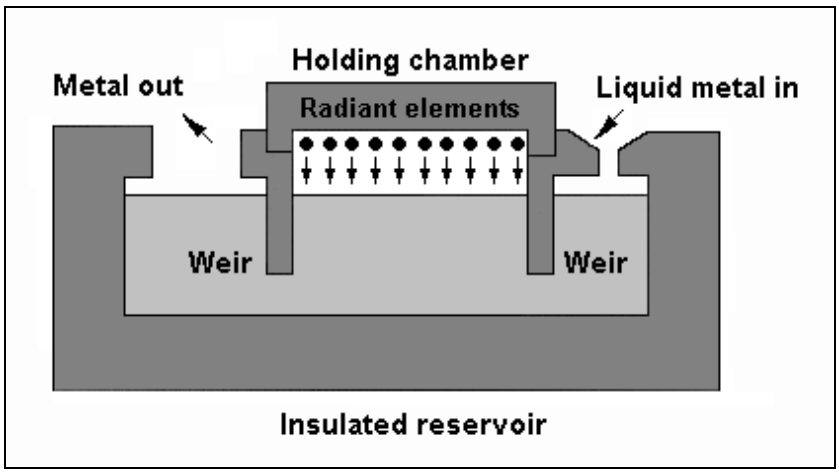


Figure 2.17: Radiant-roof furnace
[48, ETSU, 1994]

The advantages of radiant-roof furnaces are:
- no crucible required
- very low energy costs
- close temperature control
- clean, cool, silent working conditions.

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

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

2.4.5 Rotary furnace

2.4.5.1 Description

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

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

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

A melting cycle spans 1½ to several hours. For continuous molten metal production, foundries install 2 to 4 rotary furnaces, which are operated consecutively. The thermal efficiency of the rotary furnace is very high, i.e. at 50 to 65 %[3], depending on the capacity. This high yield is achieved by using pure oxygen instead of air as the combustion medium.
[32, CAEF, 1997]

2.4.5.2 Melting practice

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

The lifespan of the refractory is largely dependent on the overheating temperature and the charge composition. In the charging operation, mechanical shocks and cold start-ups need to be prevented. The furnace atmosphere, the holding time, rotational speed and the burner position also affect the refractory life. In normal conditions the refractory life is 100 to 300 melting cycles.
[32, CAEF, 1997], [110, Vito, 2001]

2.4.5.3 Metallurgy

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

[3] That is providing the energy for oxygen production is not taken into account. With oxygen production, the efficiency will be 10 to 15 % less.

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

2.4.5.4 Application

Due to its batch character, the rotary furnace provides an equal flexibility as the coreless induction furnace in the cast iron foundry. The investment costs however are lower. A 5 tonne furnace costs EUR 500000 – 600000, of which 30 % are for the exhaust system and dedusting. The rotary furnace is also a good alternative for the small-scale cold blast cupola, due to its higher flexibility and lower environmental costs. Rotary furnaces are used for melting volumes of 2 to 20 tonnes, with production capacities of 1 to 6 tonnes per hour.
[110, Vito, 2001]

2.4.5.5 Advantages:

- quick change of alloy possible
- melting without contamination, e.g. without sulphur pick-up
- low investment costs
- small dedusting system because of low flue-gas rate
- easy to maintain.

2.4.5.6 Disadvantages:

- easy burn-out of C, Si, Mn
- gas and oxygen use can be high if not operated continuously
- the energy consumption increases if more steel is added to the charge.

[110, Vito, 2001]

2.4.6 Hearth type furnace

The hearth type furnace is also known as a reverberatory or bale-out furnace. It is a static furnace with direct heating. Hot air and combustion gases from oil or gas burners are blown over the metal (melt) and exhausted out of the furnace. The hearth type furnace finds its main application in non-ferrous metal melting. A typical furnace design is given in Figure 2.18.

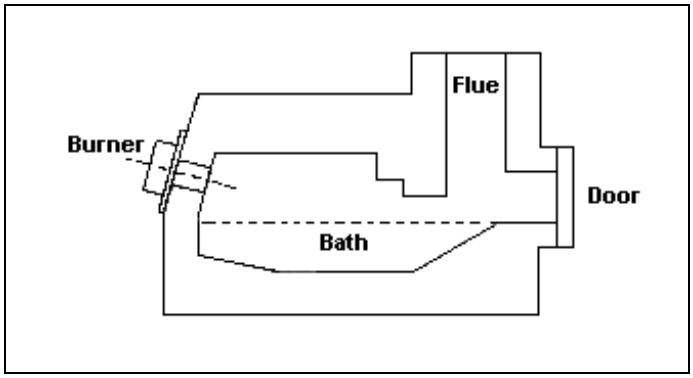


Figure 2.18: Cross-section of a hearth type furnace
[175, Brown, 1999]

This is a refractory lined, rectangular or circular bath furnace that is fired by wall or roof-mounted burners. Varieties of fuels are used and additionally oxy-fuel burners can be used to increase the melting rate. Extraction and treatment of the combustion gases is typically carried out and for this the furnaces are partially sealed. Hoods and covered launders provide extraction during tapping and charging. The furnace can be constructed in a number of configurations depending on the particular metal and application, variations include the provision of sloping hearths and side wells for specific melting purposes, tuyères and lances for the addition of gases. The furnaces can sometimes be tilted to pour or blow metal.

The melting efficiency of a hearth type furnace is usually not great because of the poor heat transfer from the burner. The efficiency has been improved in practice by the use of oxygen enrichment or by using combinations of gas and solid fuel to extend the flame length. These furnaces are used for batch melting, refining and for holding a variety of metals. Hearth type furnaces are mainly used to melt large quantities of non-ferrous metals [155, European IPPC Bureau, 2001].

Large hearth type furnaces give rapid melting and can handle bulky charge materials, but the direct contact between the flame and charge may lead to high metal losses, gas pick-up and to considerable oxide contamination. Temperature control can also be difficult. These difficulties can be overcome to some extent by good practice. For example, dross can be removed by applying suitable fluxing practice, and applying modern burners reduces problems with the temperature control. After tapping, filtering and degassing, further treatments can be applied as the metal is transferred to holding furnaces.
[42, US EPA, 1998], [48, ETSU, 1994], [155, European IPPC Bureau, 2001], [175, Brown, 1999]

2.4.7 Shaft furnace

2.4.7.1 Description

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

The furnace is used to melt pure metal, but occasionally metal that is contaminated with organic material may be used. If oily metal is fed into the furnace, it passes through a temperature gradient existing between the charging area and the burners. The low temperature can produce a mist of partially burned organic material. The shaft furnace is also used to preheat the charge material before smelting. A typical representation of this furnace is given in Figure 2.19.

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

Modern furnace types with computer controlled burner systems reach an energy use of 650 kWh/tonne of melted Al. (at 720 ºC). The theoretical energy needed is 320 kWh/tonne. The thermal efficiency therefore is 50 %.

The shaft furnace is a continuous melting furnace with high capacity, ranging from 0.5 to 5 tonnes per hour and with a holding capacity of up to 50 tonnes. Due to its holding function, a change of alloy is difficult.
[48, ETSU, 1994], [155, European IPPC Bureau, 2001]

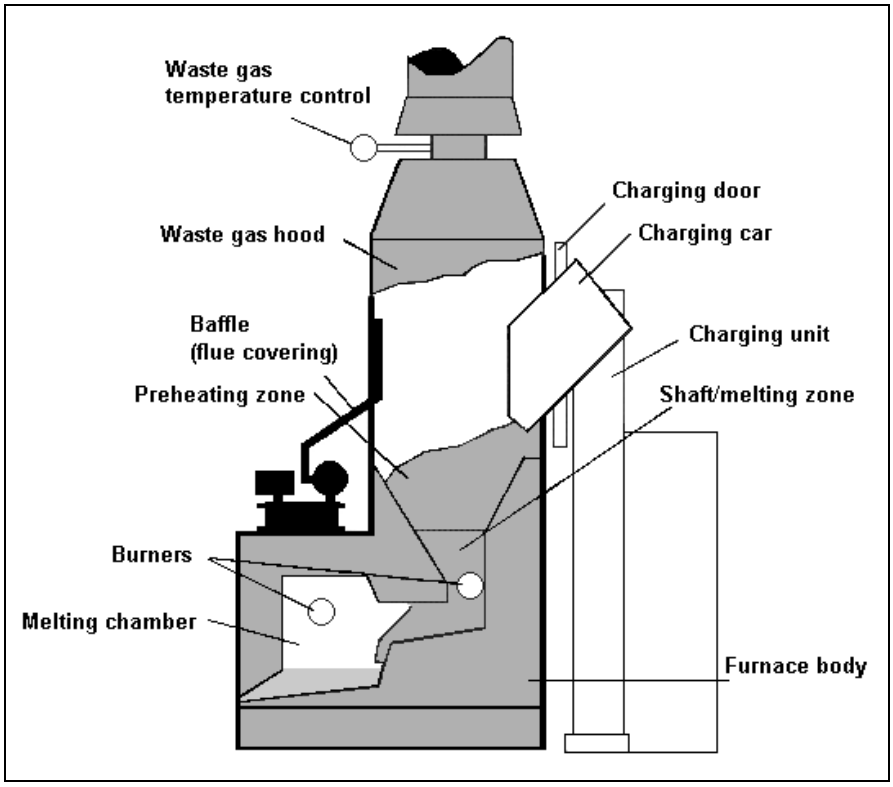


Figure 2.19: Shaft furnace
[48, ETSU, 1994]

2.4.7.2 Advantages:

- due to the long preheating, the charge is very well dried before the melting starts. This makes the furnace well suited for Al, due to the reduced risk of hydrogen uptake
- relatively low investment and operating costs. Operating costs are kept low by the effective preheating, automatic control and long refractory life
- technical advantages are: low gas pick-up, excellent temperature control and low metal loss.

2.4.7.3 Disadvantages:

- no flexibility regarding a possible change of alloy.

[110, Vito, 2001]

2.4.8 Crucible furnace

2.4.8.1 Description

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

This furnace type is only used for non-ferrous metal melting. Due to the indirect heating (through the crucible wall) no burn-off or gas take-up can take place. These furnaces are used for the production of small amounts of molten metal (less than 500 kg per batch) and for low production capacities. Example furnaces are displayed in Figure 2.20.

Figure 2.20: Crucible furnaces
[237, HUT, 2003]

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

Crucibles used for holding, transport and metal treatment in ferrous foundries are called ladles. [110, Vito, 2001], [126, Teknologisk, 2000], [225, TWG, 2003]

2.4.8.2 Melting practice

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

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

Thermal efficiencies are 750 – 3000 kWh per tonne of aluminium, i.e. 15 - 30 % efficiency.
[34, Binninger, 1994], [110, Vito, 2001], [126, Teknologisk, 2000]

2.4.8.3 Advantages:

- simple technology
- low maintenance
- flexibility regarding change of alloy.

2.4.8.4 Disadvantages:

- low efficiency and production capacity.

[110, Vito, 2001]

2.4.9 Argon Oxygen Decarburisation (AOD) converter for steel refining

The AOD converter is a special vessel for refining steel. The molten metal is transferred directly from the melting furnace (generally electric arc or induction) into the converter. As shown in Figure 2.21, oxygen (for the removal of carbon, silicon) and argon gas (for the stirring action) can be injected into the converter by means of tuyères positioned in its lower part, to refine the metal. The converter is equipped with a tilting mechanism in order to allow filling and emptying. Steel with a precise chemistry can be produced using AOD, but at a high cost. This system is not widely used in steel foundries outside the US.

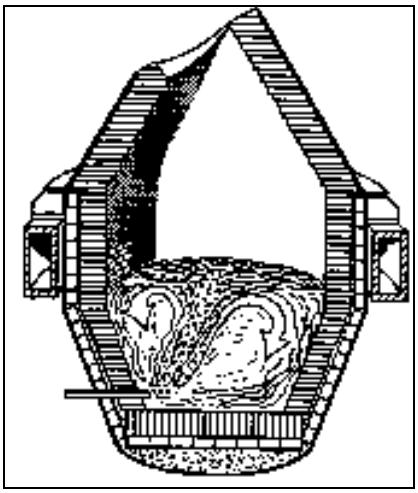


Figure 2.21: AOD converter
[237, HUT, 2003]

The first phase of the refining process consists of a decarburisation, through the injection of oxygen into the converter. This is a refining operation that holds the carbon content of the charge material within a specific range, as required. Decarburisation is initiated by injecting oxygen into the metal bath. This creates a strong stirring action during which carbon in the melt is burned. At the same time the "boiling" burns out silicon, and flushes out hydrogen and nitrogen from the metal bath. All impurities (oxides) are trapped in the slag. During melting, lime may be added to bring the slag to the proper basicity. When the carbon reaches the required concentration, oxygen injection is stopped and silicon and manganese are added to halt the boiling reaction, especially in the production of stainless steels. A dilution of the oxygen with argon or nitrogen assists the oxidation of carbon in preference to metallic elements such as iron, chromium, etc., leading to very good metallic yields. Consequently Al or Si and limestone are added to the metal and argon is injected in order to remove sulphur. The continuous gas injection causes a violent stirring action and an intimate mixing of slag and metal which can lower sulphur values to below 0.005 %. The residual gas content of the treated metal (hydrogen and nitrogen) is very low. All impurities are trapped in the slag and removed with it. After temperature and alloy adjustment the metal is transferred to ladles for pouring.
[174, Brown, 2000], [32, CAEF, 1997]

2.4.10 Vacuum Oxygen Decarburisation converter (VODC) for steel refining

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

First, the steel is decarburised by introducing oxygen into the melt. At the same time, some argon is injected from the converter base. The converter uses vacuum pumps to lower the partial pressure of carbon monoxide, to such an extent that effective decarburisation can be carried out without oxidising too much of the chromium. This first process is similar to AOD decarburisation, but less argon is needed thanks to the lower total gas pressure and the process is much more efficient. The oxidised chromium is reduced back to liquid steel with aluminium.

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

Low alloyed steels are normally only degassed.

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

2.4.11 Metal treatment of steel

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

- *Deoxidation*: Oxygen dissolves in liquid steel, in the form of FeO. During solidification, the oxygen can then combine with C in the steel to form CO. This process can thus change the composition of the steel and generate porosity. Deoxidation is therefore always necessary. Deoxidation is performed with an element that preferentially binds the oxygen. Silicon, calcium silicide, titanium, zirconium and aluminium are possible deoxidants, with aluminium being the most powerful and the one that is most generally used. Aluminium is added in the form of a stick or wire (see Figure 2.22). The treatment is usually performed in the furnace and in the ladle. The produced aluminium oxide is insoluble in the melt and mixes with the slag.

Figure 2.22: Deoxidation, using an aluminium wire
[237, HUT, 2003]

- *Sulphide formation*: As the tensile strength of steel increases, the harmful effect of sulphur increases. Sulphur is soluble in liquid steel, but on solidification it precipitates as MnS. Precipitates can take various forms and have different effects. The form of the sulphides is related to the residual aluminium content after deoxidation. The residual amount of Al should allow the formation of type III sulphides.

[110, Vito, 2001], [174, Brown, 2000]

2.4.12 Cast iron treatment

2.4.12.1 Alloying

During melting, some elements in the melt oxidise and are lost to the slag. At the end of the melting period a correction of the composition needs to be performed, in order to guarantee the appropriate final quality. For unalloyed cast iron, this is needed for: C, Si, Mn, S and P. If special properties are desired, specific alloying elements can be added, ranging from aluminium to zirconium, in concentrations of less than 1 % to more than 30 %. In general these are added as ferrous alloy blocks or grains. The additions are made to the liquid iron, since this reduces the risk of oxidation losses.

The addition is performed in the furnace, in the molten metal flow during pouring, or by putting the additives in the transport ladle before pouring the molten metal into it.
[110, Vito, 2001]

2.4.12.2 Homogenisation

The addition of alloying elements can introduce impurities such as oxides, sulphides or carbides into the iron. In order to reduce the negative effects from these compounds, the metal is overheated at 1480 ºC to 1500 ºC. Nevertheless overheating can affect graphite precipitation during solidification. Homogenisation has the following positive effects:

- reduction of oxides (FeO, SiO_2, MnO) by C, generating CO-bubbles. On their way through the melt these bubbles remove H_2 and N_2 from the melt
- at high temperature and under intense bath movements, impurities coagulate and rise to the melt surface more quickly, where they are then taken up by the slag.

[110, Vito, 2001]

2.4.12.3 Desulphurisation and recarburisation of cupola melted iron

Due to the intimate contact of the liquid metal with the coke, cupola melted iron shows a relatively high sulphur content. Sulphur pick-up in the cupola gives rise to a lower viscosity of the liquid metal, which is an advantage in some cases, e.g. for thin walled grey iron castings.

However, if the cast iron is to be treated with Mg (as described in the next section) to produce a nodular cast iron quality then the sulphur should be neutralised, to prevent excessive Mg consumption. This is performed by using one of a number of methods. In the porous plug method, nitrogen or argon gas is used to agitate the metal and CaC_2 powder is added to the metal. Upon contact with the liquid metal CaS is formed and removed as slag. The treated metal then flows to a holding ladle from which it is tapped for further treatment.

2.4.12.4 Nodularisation treatment of the melt

Nodular cast iron is obtained by the addition of Mg, either pure or as a FeSiMg or NiMg alloy, to the molten metal. Prior to this, a desulphurisation treatment may be necessary to guarantee successful nodularisation. The presence of Mg in the melt provokes a solidification of the graphite phase in the shape of microscopic spheres. This gives rise to higher mechanical properties, such as strength and ductility.

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

- *The pour over technique*: This is the simplest method, whereby the liquid metal is poured over the Mg alloy in the bottom of the ladle
- *The sandwich method*: Here Mg alloy is placed at the bottom of a specially designed ladle and covered with steel sheets or FeSi, as shown in Figure 2.23. The metal is poured into the ladle and after melting of the cover the Mg reaction takes place
- *The Tundish Cover*: This is an improved sandwich technique, whereby the ladle is covered by a lid after the Mg alloy has been placed at the bottom of the ladle. The metal is poured in the concave lid and flows through a hole in the ladle, where the reaction takes place
- *The plunging method*: Using a plunger bell, the Mg alloy is submerged in the liquid metal until the reaction is finished. During the treatment the ladle lid is closed, to prevent MgO fume emissions
- *The G Fischer converter*: This process uses a special ladle that is closed tightly with a lid after the metal is poured into the converter in the horizontal position. The converter is then tilted into a vertical position, allowing the Mg alloy to react with the metal. Once the reaction is finished the converter is turned back into the horizontal position and is tapped after opening the lid
- *The core wire injection*: Here very fine powdered Mg alloy is rolled in tin steel sheet, forming a filled wire. This wire is then injected, by a controlled mechanism, into a slender shaped ladle, where the Mg is released
- *The flow through treatment*: Here the metal is poured into a special designed reaction chamber in which the Mg alloy was put earlier
- *The ductilator*: In this method the metal is poured into a reaction chamber where the flow is forced to form a vortex. The Mg alloy is injected into the vortex with an inert carrier gas. The treatment can be performed on large quantities of metal or during mould filling
- *The inmold process*: In this process the Mg alloy, shaped as a tablet, is put directly into the mould cavity (gating system). The reaction takes place during mould filling, ensuring a high yield.

Figure 2.23: The sandwich method for nodularisation
[237, HUT, 2003]

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

2.4.12.5 Inoculation of the melt

The presence of coarse shaped graphite in a metal matrix leads to poor mechanical properties of the material. In order to get a fine crystalline metallurgical structure, inoculation of the melt is necessary prior to casting. This process introduces seeds for crystal growth into the metal melt. Usually FeSi alloys are used for this purpose. Ca, Al and rare earth materials are often included in the inoculant.

Again, several techniques can be used to inoculate the molten metal:
- *Injection during tapping*: Here the inoculant is injected directly into the metal flow during tapping
- *Injection during pouring*: Here the inoculant is injected directly into the metal flow during pouring of the mould (see Figure 2.24)
- *Filled wire injection in the melt* (see Section 2.4.12.4)
- *Inmold process* (see Section 2.4.12.4).

Figure 2.24: Inoculation during pouring
[237, HUT, 2003]

2.4.13 Non-ferrous metal treatment

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

- *Degassing*: Molten aluminium dissolves hydrogen, which is then expelled upon cooling and can thus lead to porosity in the finished casting. Hydrogen therefore needs to be removed. This is done by bubbling an inert gas through the melt. Good degassing methods provide bubbles with high residence time and high surface area. The degassing of aluminium is mostly performed using an impeller station. This treatment uses a rapid-spinning mixer and nitrogen injection into the melt. Degassing is often combined with a cleaning of the melt. Cleaning is performed to remove alkali or alkaline earth metals, such as Ca. Cleaning can be done by Cl_2-gas. The use of HCE for this purpose has been banned in the EU *(Dir. 97/16/EC)*. A mixture of nitrogen with 3 % Cl_2 is generally used, for simultaneous degassing and cleaning. Alternative degassing methods use tablets, a lance with a porous head, or a porous stone in the holding furnace
- *Modification and grain refining*: For aluminium alloys this usually involves the addition of small amounts of metal to the melt. These additions control the grain size and modify the microstructure of the solidifying metal and thus enhance the casting mechanical properties. Sodium or strontium are used for the modification, while grain refinement is achieved with titanium, titanium boride, zircon or carbon. This treatment is mostly performed in combination with degassing in a dedicated metal treatment station
- *Fluxing*: This usually involves the addition of solid fluoride based fluxes to the melt, to remove solid contaminants.

[164, UK Environment Agency, 2002], [175, Brown, 1999], [178, Wenk, 1995]

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

- *Grain modification*: Grain modifiers for magnesium alloy processes are usually in the form of zirconium or formerly hexachloroethane. The use of HCE for this purpose has been banned in the EU *(Dir. 97/16/EC)*
- *Fluxing*: This usually involves the addition of alkali, earth alkali, chloride and fluoride proprietary fluxes to the melt to remove solid contaminants
- *Degassing*: For magnesium processes, nitrogen or argon gas sparging may take place for degassing and oxide removal. The degassing of magnesium alloys may also be effected by a mixture of argon and chlorine gases, when argon is used as a carrier gas
- *Oxidation control*: The presence of beryllium within the melt grain modifies and stops oxidation. Finished magnesium alloys may contain up to 15 ppm beryllium by weight. A master alloy of aluminium/beryllium, containing up to a nominal 5 % beryllium, may be added to the molten magnesium alloy to give it this beryllium loading. Oxidation control may also be achieved by blanketing the surface of the metal with a carrier gas, such as carbon dioxide or argon, containing up to 4 % sulphur hexafluoride. To date, the only flux-free alternative to SF_6 is SO_2. SO_2 is significantly cheaper then SF_6 but its main drawback is its toxicity, and as a result operations need to be enclosed better. Up to the present, only 1/3 of the foundries in Europe have been using SO_2. Occasionally oxidation control may be achieved by sprinkling sulphur powder on the surface of the melt. This issue is discussed in Section 4.2.7.1.

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

- *Deoxidation*: Deoxidation is performed by adding a reagent which binds the oxygen and forms a fluid slag. Care must be taken to prevent the deoxidation products from being entrained in the solidified casting and the residual deoxidant from adversely affecting the alloy properties. Phosphorus is the most commonly used deoxidation reagent. Alternatives are magnesium, manganese, calcium, silicon and boron
- *Degassing*: Hydrogen is removed from the melt by bubbling an inert gas through it. Both argon and nitrogen may be used. The technique is comparable to aluminium degassing
- *Fluxing*: Aluminium in alloys can oxidise and generate oxide skins. These can cause problems upon casting. In non-aluminium alloys, traces of aluminium can cause defects. Therefore they need to be removed, using fluxing agents. Fluxes are also used to cover the surface in order to prevent oxidation, zinc loss and hydrogen pick-up during melting. Specific fluxing agents exist for each type of treatment.

[165, UK Environment Agency, 2002], [182, Closset, 2002]

2.5 Mould and core production

Moulding consists of making a mould in which the molten metal will be poured. Some moulds may need to have special properties to produce high quality castings, which, for example:

- reproduce exactly and with a high dimensional precision the shape of the casting model
- give a smooth skin to the casting in order to avoid excessive fettling
- avoid any casting defects such as cracks, worming, pinholes, etc.

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

Moulds may be classified in two large families:

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

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

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

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

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

The production of patterns and dies is generally carried out by specialised external suppliers. These activities are found in the metal and plastics treatment sectors.
[2, Hoffmeister, et al., 1997], [32, CAEF, 1997], [110, Vito, 2001]

2.5.1 Raw materials

2.5.1.1 Refractory materials

Whatever binder applied, the physical and chemical properties of the refractory material used to make the moulds or cores affects their characteristics and their behaviour during pouring. This is not surprising as these materials make up 95 to 99 % of the products used.

The purchase price of each sand type has four main components – extraction, preparation, packaging and transportation. Transportation costs will vary for different regions. The main factor however in the price is the sand type. The average purchase price for the various types varies widely. From a 1995 UK questionnaire, the tonnage price of chromite and zircon sand were respectively a factor 9 and 14 times higher than that of silica sand. In Portugal the cost of sand varies according to the amount purchased, but sand is generally cheaper in Portugal than in Spain, France or Italy. Portuguese prices (year 2003) range between EUR 20 - 25 per tonne of dry sand AFS 55, plus transport. Prices in the Czech Republic (year 2003) for silica sand range between EUR 10 and 20 for silica sand, with the price depending on the volume, packaging and treatment of the sand. The price for chromite sand is EUR 250 – 300/t, and for zircon sand EUR 250 – 400/t.
[72, ETSU, 1995], [225, TWG, 2003]

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

2.5.1.1.1 Silica sand

This type of sand is the most commonly used, mostly because of its wide availability and its relatively low cost. Silica sand is composed of the mineral "quartz" (SiO_2), which is more or less pure and clean, depending on its origin. Its dry piece specific weight fluctuates between 2.5 to 2.8 kg/dm³. The dry bulk density (or loose volume weight) of silica sand is 1.4 to 1.6 kg/dm³.

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

Silica sand is neutral and is compatible with all binders and normal cast alloys. The respirable particulate matter (RPM) fraction of quartz is classified by IARC as carcinogenic [233, IARC, 1997]. This is a health and safety issue. Studies are ongoing to determine whether or not an air pollution issue also exists. The amount of quartz in dust is defined by the content of quartz in the input materials.

In green sand moulding technology, control of the grain size distribution is very important. Figure 2.25 shows a typical grain size distribution for silica sand. The grain size distribution is used to calculate the AFS-number (AFS = American Foundry Society). This gives the overall fineness of the sand. The higher the AFS-number, the finer the sand. An alternative classification system is the middle grain number or MK.

A finer sand grade will have more grains per gram, and thus a higher surface area. This requires more binder addition for an equal mould strength. Operators therefore try to use the coarsest sand, but one that still gives a good surface finishing aspect. Standard AFS-numbers are 50 – 60. For very smooth surfaces a fine sand is needed, typically one with an AFS of 90 – 110 is used. Fine sands are also used in some instances to replace mould coatings.
[110, Vito, 2001], [202, TWG, 2002], [225, TWG, 2003]

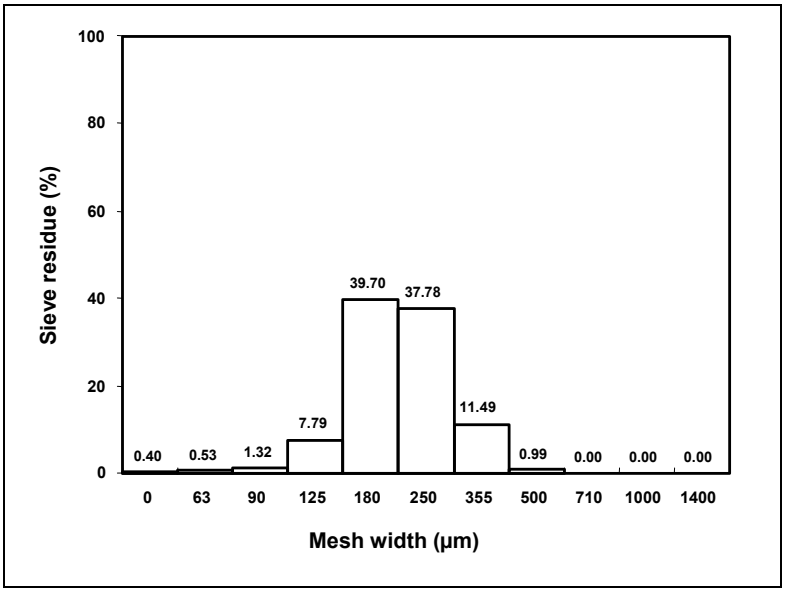


Figure 2.25: Typical grain size distribution for silica foundry sand [110, Vito, 2001]

2.5.1.1.2 Chromite sand

Chromite is a chrome ore, with the theoretical formula $FeO.Cr_2O_3$, which contains other components such as magnesium and aluminium oxides. For its use in foundries, its silica content must be lower than 2 % in order to prevent sintering at low temperatures. Its characteristics are as follows:

- density: 4.3 to 4.6, cf. 2.65 for silica sand
- theoretical melting point: 2180 ºC, but the presence of impurities can lower this to 1800 ºC
- thermal diffusivity: more than 25 % higher than that of silica sand
- thermal expansion: regular, without a transition point, and lower than that of silica sand
- pH: rather basic, from 7 to 10.

Chromite sand is more refractory than silica. It is more thermally stable and has a greater chilling power. Chromite sand provides a better surface finish on large castings. It is therefore used for the production of large castings and in areas of the mould where chilling is required.
[32, CAEF, 1997]

2.5.1.1.3 Zircon sand

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

- density: 4.4 to 4.7, cf. 2.65 for silica sand
- melting point: higher than 2000 ºC
- thermal diffusivity: more than 30 % higher than that of silica sand
- thermal expansion: regular, without a transition point, and lower than that of silica sand.

The general characteristics of zircon sand are similar to that of chromite, but zircon sand produces a better finish as a finer grade is used. These physical and thermal properties account for its use for moulding or core-making in difficult cases, in spite of its very high price.
[32, CAEF, 1997], [72, ETSU, 1995]

2.5.1.1.4 Olivine sand

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

- melting point: forsterite: 1890 ºC, fayalite: 1205 ºC
- density: 3.2 to 3.6
- pH: around 9.

The basic pH makes this type of sand not suitable for use with acid catalysed binder systems.

Olivine sand is produced by crushing natural rocks, which explains its diverse characteristics. It is usually used for moulding and core-making in manganese steel casting. The presence of manganese prohibits the presence of silica as these two components react to give a very fusible compound. The reported purchase price in Spain is EUR 130/tonne (2002).
[32, CAEF, 1997], [210, Martínez de Morentin Ronda, 2002]

2.5.1.2 Binders and other chemicals

2.5.1.2.1 Bentonite

Bentonite is a smectite clay, which has a lamellar structure. By adding water, the clay structure swells due to the adsorption of water molecules. The clay then becomes workable and can be spread to coat the sand grains during mixing.

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

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

Pouring molten metal into a green sand mould subjects the moulding-sand to considerable heat. This heat removes moisture from the sand and destroys the clay-bonded structure (and additives). If during pouring and cooling bentonite stays below the deactivation temperature, the lamellar structure is maintained as well its ability to swell and develop cohesion. The deactivition temperature varies with the bentonite type.

Prices for bentonite range between EUR 70 – 250/t, depending on the packaging and product type (Czech Republic, 2003).
[32, CAEF, 1997], [73, ETSU, 1995], [202, TWG, 2002], [225, TWG, 2003]

2.5.1.2.2 Resins

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

- cold-setting resins
- gas-hardened resins
- hot-curing resins.

The various resin types will be discussed under Section 2.5.6. In Table 2.7 a survey of the applicability of the various resins is given.

Hardening	Resin type ("commercial name")	Mould production	Core production	Curing temperature	Hardening time (*)	Metal types	Size of series
Cold-setting	Furan	Medium to large	Some	10 – 30 ºC	10 – 120 min	Ferrous + non-ferrous	Small to large
	Phenolic	Large	No	10 – 30 ºC	10 – 180 min	Ferrous	Small to large
	Polyurethane (“Pepset/Pentex")	Small to medium	Some	10 – 30 ºC	5 – 60 min	Ferrous + non-ferrous	Small to large
	Resol - ester ("Alfaset")	Small to Large	Some	10 – 30 ºC	5 – 400 min	Ferrous + non-ferrous	Small to large
	Alkyd oil	Large	Some	10 – 30 ºC	50 min	steel	Small
	Silicate - Water glass	Medium to large	No	10 – 30 ºC	1 – 60 min	Ferrous + non-ferrous	Small to medium
Gas-hardening	Phenolic/Furan[1] ("Hardox")	Small	Yes	10 – 30 ºC	<60 s	Ferrous + non-ferrous	All
	Polyurethane ("Cold-box")	Small	Yes	10 – 30 ºC	<60 s	Ferrous + non-ferrous	All
	Resol ("Betaset")	Small	Yes	10 – 30 ºC	<60 s	Ferrous + non-ferrous	All
	Acryl/Epoxy ("Isoset")	No	Yes	10 – 30 ºC	<60 s	Ferrous + non-ferrous	All
	Silicate	Small	Yes	10 – 30 ºC	<60 s	Ferrous + non-ferrous	All
Thermosetting	Oil	Small	Yes	180 – 240 ºC	10 – 60 min	Ferrous	Small
	"Warm-box"	Seldom	Yes	150 – 220 ºC	20 – 60 s	Ferrous	Medium to large
	"Hot-box"	Seldom	Yes	220 – 250 ºC	20 – 60 s	Ferrous + non-ferrous	Medium to large
	"Croning"	Yes	Yes	250 – 270 ºC	120 – 180 s	Ferrous + non-ferrous	Large

(*) i.e. the release time - the time in which the mould/core has gained sufficient strength to be released from the pattern
[1] Not applied for capacities <20 tonnes/day

Table 2.7: Survey of various resin types and their applicability [110, Vito, 2001]

2.5.1.2.3 Coal dust

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

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

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

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

Various types of coal dust replacements exist. These consist of blends of high volatile, high lustrous carbon materials blended with clays. They are generally more environmentally acceptable than coal dust, i.e. producing less fume during casting, although some coal dust replacements will generate more PAH in the sand.
[174, Brown, 2000], [225, TWG, 2003]

2.5.1.2.4 Cereal binders

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

Starches can help to reduce expansion defects, since as they burn out, they allow the sand grains to deform without deforming the mould. Cereals increase the green strength, dry strength and toughness but can reduce the flowability. Dextrines improve the flowability and moisture retention, preventing moulds from drying out and edges becoming friable.

Cereal additions do not improve the erosion resistance of the sand nor its resistance to metal penetration.
[174, Brown, 2000], [175, Brown, 1999]

2.5.1.2.5 Iron oxide

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

2.5.1.3 Running, gating, feeding and filtration

The different parts of the running and gating system are shown in Figure 2.26. The system carries out the following functions:

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

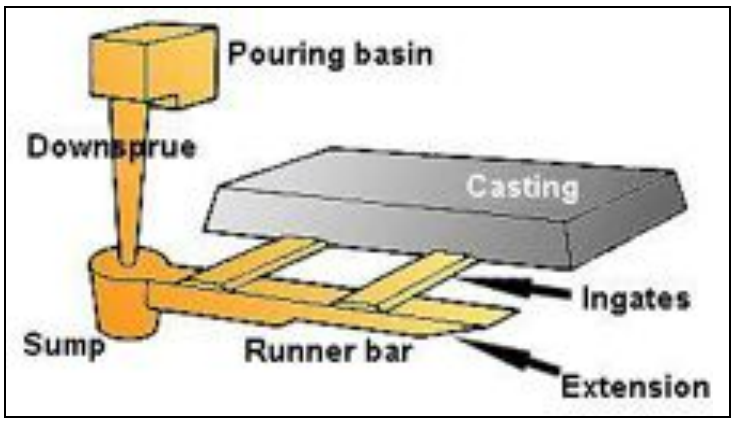


Figure 2.26: Components of the running and gating system
[237, HUT, 2003]

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

- in lamellar iron, some furnace slag may be present but the melt is not subject to inclusions due to oxidation
- nodular iron contains magnesium silicate and sulphide dross, arising from the nodularisation treatment
- steel is susceptible to oxidation and slag formation
- aluminium alloys (and aluminium bronzes) are all subject to dross formation, whereby a film of oxide forms immediately on any metal surface exposed to air.

Inclusions in steel can arise from slag entrapment, the erosion of furnace or ladle linings or refractories, or from deoxidation. Filtration is now widely used to reduce the presence of inclusions. The introduction of ceramic filters has even enabled simplifications to be made in the design of running and gating systems. Various types of filters are shown in Figure 2.27.

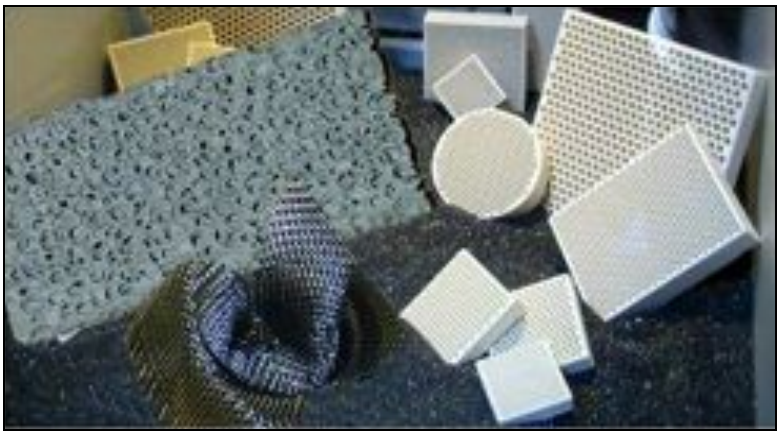


Figure 2.27: Various types of filters
[237, HUT, 2003]

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

2.5.2.1 Sand conditioning for green sand moulding

One of the major advantages in using green sand moulding is that the sand from the moulds can be reconditioned for multiple re-use. The layout of a typical green sand plant is depicted in Figure 2.28, and some examples of sand mixers are shown in Figure 2.29.

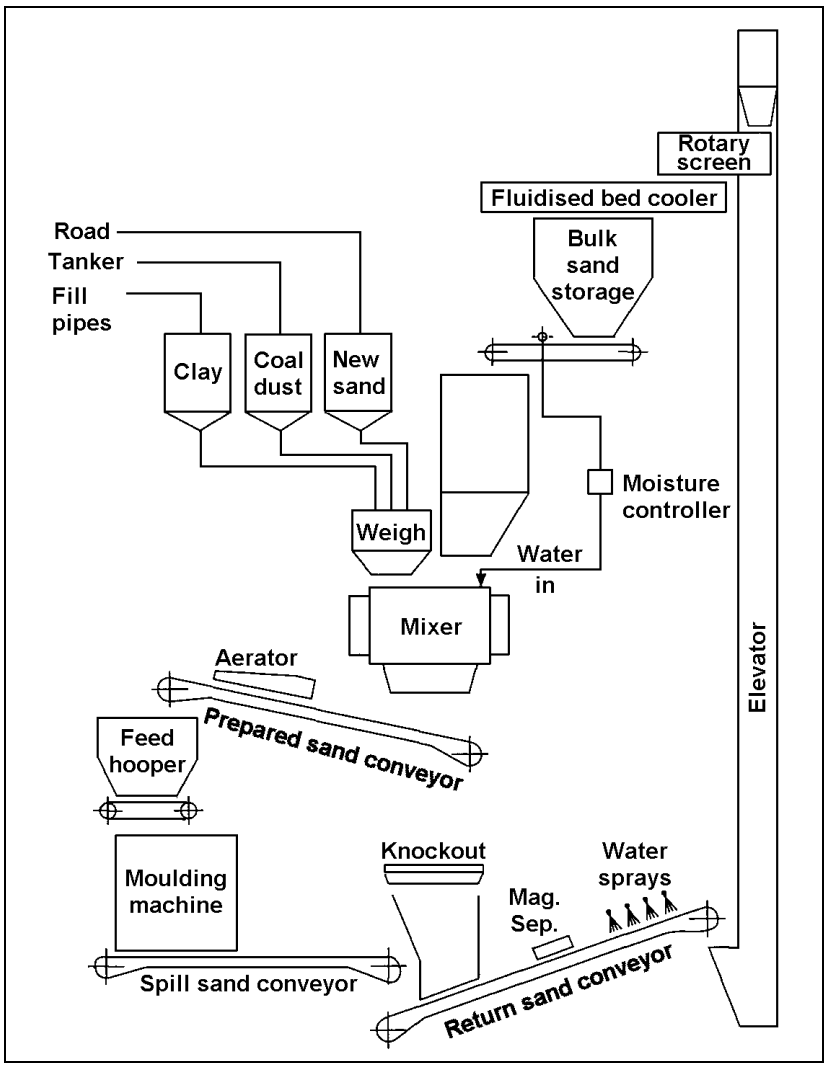


Figure 2.28: Flow diagram for a typical green sand plant
[174, Brown, 2000]

Figure 2.29: Various types of sand mixers
[237, HUT, 2003]

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

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

The sand is then screened to remove the remaining lumps and stored before mixing with the required amounts of additives, say clay, water, etc. to prepare the green sand for re-use.
[32, CAEF, 1997], [174, Brown, 2000]

2.5.3 Moulding with natural sand

Some foundries use naturally bonded sand. This is sand which contains a natural percentage of clay. Only water needs to be added in order to activate the binding capacity. If needed, some additives may be mixed as well. The approximate composition of natural sand is given in Table 2.8.

Compounds	Approximate %
Quartz sand	80
Clay	15
Water	5

Table 2.8: Composition of natural sand
[126, Teknologisk, 2000]

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

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

Green sand moulding is the most common moulding process. Green sand is generally not used to make cores. Cores are formed using a chemical binding system. Green sand is the only process that uses a moist sand mix. The mixture is made up of about 85 to 95 % silica (or olivine or zircon) sand; 5 to 10 % bentonite clay; 3 to 9 % carbonaceous materials such as powdered (sea) coal, petroleum products, corn starch or wood flour; and 2 to 5 per cent water. The clay and water act as the binder, holding the sand grains together. The carbonaceous materials burn off when the molten metal is poured into the mould, creating a reducing atmosphere which prevents the metal from oxidising as it solidifies. Table 2.9 gives a survey of the additives used for various types of metal castings.

Metal	Additives for green sand preparation
Nodular cast iron casting Lamellar iron casting Malleable iron casting	Bentonite Cereal binder* Coal dust
Steel casting	Bentonite Cereal binder*
Light metal and aluminium casting	Bentonite Cereal binder*
Magnesium-alloyed-aluminium casting	Bentonite Boric acid
Magnesium casting	Bentonite Powdered sulphur Boric acid
Heavy metal casting (copper alloys)	Bentonite Cereal binder* coal dust
* Optional additive	

Table 2.9: Composition of additive mix for green sand preparation (excl. water) [36, Winterhalter, et al., 1992]

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

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

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

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

Flaskless moulding, with both vertical and horizontal parting, achieves impressive production efficiencies. High mould accuracies can be achieved, but this process requires an effective set-up and high quality patterns to achieve the desired objective.
[32, CAEF, 1997], [42, US EPA, 1998]

2.5.5 Moulding with unbonded sand (V-process)

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

The production of a half mould is illustrated in Figure 2.30. The successive steps of the process are as follows:

- the pattern is fixed to an airtight chamber which is connected to a vacuum pump. The pattern is vented by small diameter holes connecting through the airtight chamber
- a thin film of polyethylene vinyl acetate (PEVA), 75 to 100 microns thick, is heated up to 85 ºC
- this film, which is expanded under heat, is applied on the pattern and fixed by vacuum applied through the airtight chamber
- a moulding box, in which a vacuum can be created, is placed on the pattern, and filled with dry sand
- this sand is compacted by vibration, made even, and then a second film of PEVA is applied to the sand
- air is extracted from the moulding box and at the same time, the vacuum is released in the airtight chamber; the vacuum stiffens the sand and the half mould can then be stripped off
- the second half mould is made in the same way and both are assembled and closed, with the vacuum still being applied
- the metal can now be poured, the two moulding boxes remaining under vacuum until the casting is cool enough to be shaken out
- shake-out occurs simply by shutting off the vacuum: the sand flows out from the box through the grid and may be recycled after dedusting and separation of the unburned plastic sheets.

[174, Brown, 2000]

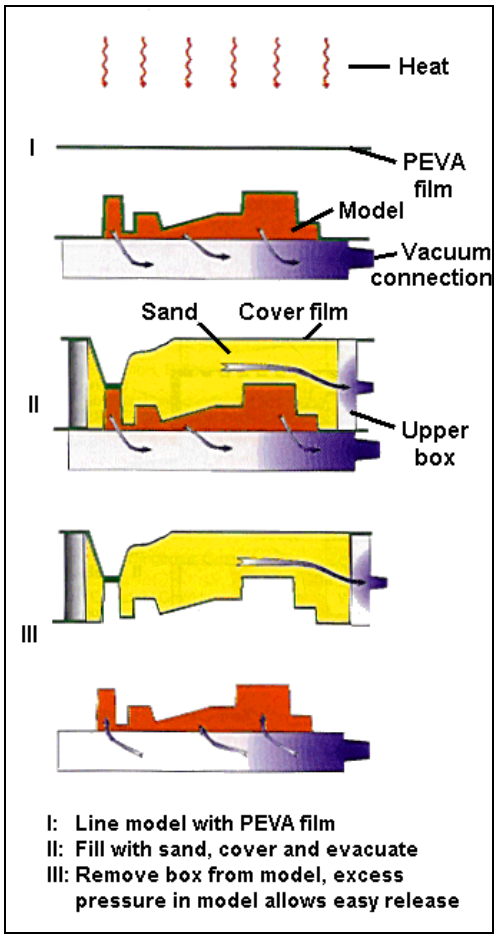


Figure 2.30: Vacuum moulding
[179, Hoppenstedt, 2002]

2.5.6 Moulding and core-making with chemically-bonded sand

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

Table 2.10 gives the relative share of the various core-making processes in German automobile foundries in 1991. This shows that the amine cold-box and hot-box systems dominate the market. Over 90 % of the automobile foundries use the amine cold-box system. The other processes (croning, CO_2-silicate) are mainly used for supplementary use, i.e. making cores with specific requirements (size, thickness,…).
[42, US EPA, 1998], [174, Brown, 2000]

System	Number
Amine cold-box	44
Hot-box	10
Shell/croning	9
CO_2 – silicate	3

Table 2.10: Core-making processes used in 48 automobile foundries in Germany, 1991 [174, Brown, 2000]

2.5.6.1 Cold-setting processes

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

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

2.5.6.1.1 Phenolic, acid catalysed

This process has been in use since 1958. As the components are relatively cheap, it is mainly used for the production of large parts. It is applicable for all alloy types. The hardening of these resins is more difficult and less regular compared to the furan resins.

The resins are either phenol-formaldehyde (PF), or urea-formaldehyde/phenol-formaldehyde copolymers (UF/PF), both being "resols", with a formaldehyde/phenol ratio higher than one.
The catalysts are strong sulphonic acids, such as paratoluene, xylene or benzene-sulphonic, with sometimes an addition of sulphuric acid, usually used in a diluted form.

2.5.6.1.2 Furan, acid catalysed

These binders, firstly introduced in foundries in 1958, are commonly used for the moulding and core-making of medium and large sized parts, for small and medium batch production and for all alloy types. Only certain types are used for steel casting, as cracks, fins or pinholes may

occur. The process allows good flexibility in application and properties. Furfuryl alcohol (FA) has the disadvantage of being a (strategic) basic product, which leaves it subject to market price variations. Furan binders are comparable to phenolic binders in that their setting mechanism and the acid catalysts used are the same for both processes. Some examples of furan cores are shown in Figure 2.31.

Figure 2.31: Furan cores
[237, HUT, 2003]

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

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

A silane is nearly always added to enhance the resin-sand bond. The catalysts are strong sulphonic acids, such as paratoluene, xylene or benzene-sulphonic, sometimes with an addition of sulphuric or phosphoric acid, usually used in a diluted form.
[110, Vito, 2001]

2.5.6.1.3 Polyurethane (phenolic isocyanate)

This process is used to a minor extent for moulding and core-making, with restrictions for steel casting, as cracks or pinholes may occur. These can be prevented however, by the addition of iron oxide and by drying the moulds and cores. In some countries (e.g. Sweden) this type of binder has not been used for 25 years, mainly because of its effect on the working environment.

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

2.5.6.1.4 Resol – ester (alkaline phenolic ester hardened)

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

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

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

2.5.6.1.5 Alkyd oil, unbaked

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

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

2.5.6.1.6 Ester silicate

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

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

2.5.6.1.7 Cement

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

2.5.6.2 Gas-hardened processes

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

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

2.5.6.2.1 Cold-box (amine hardened phenolic urethane)

This process is commonly used to make cores of up to 100 kg and more, and small moulds. It provides a very smooth surface finish, and the dimensional accuracy is very high. The core removal properties are excellent and the sand can easily be reclaimed. This process is the most commonly used in core-making. An example cold-box core is shown in Figure 2.32.

Figure 2.32: Cold-box core
[237, HUT, 2003]

The chemistry of this polyurethane based process is very similar to the polyurethane cold-setting one, e.g.: it involves a phenolic resin and an isocyanate (MDI). Only the catalyst is different; here a tertiary amine is used, such as triethylamine (TEA), dimethylethylamine (DMEA), dimethylisopropylamine (DMIA) or dimethylpropylamine (DMPA). The amine is applied as a vapour, using compressed air, nitrogen or CO_2 as a carrier gas. Both resin and isocyanate are in solution in aromatic and/or polar solvents that have high boiling points. Contamination by water must be strictly avoided as it reacts strongly with isocyanate and weakens the binder.

The amine is delivered either by a generator, in which a supporting gas, preferably inert, is saturated with amine vapours, or by an injector, which measures out just the right amount of amine required for the operation, this latter being carried to the sand by compressed air or gaseous nitrogen. The addition rate for the binder varies from 1.0 to 2.0 % based on the sand weight, with resin and isocyanate in a 50:50 ratio.

The amine is just a catalyst and is not consumed in the reaction. After curing, it remains in the sand of the mould or core and has to be purged. The purging period currently lasts 10 to 15 times longer than the injection of the amine. The amount of amine required for curing is about 0.05 % based on the sand weight, but typically 0.10 to 0.15 % is used.

In a variant of the process called the 'Cold-box Plus' process the corebox is heated to 40 – 80 ºC using circulating hot water. This yields cores with even better mechanical properties, but results in higher interval times.
[110, Vito, 2001]

2.5.6.2.2 Resol – ester (alkaline phenolics methyl formate hardened)

This process is relatively new. Its advantages and disadvantages are similar to those of the cold-setting process from which it is derived. As its price is relatively high, the process is mostly used for core-making. Even though difficulties in recycling used sand have been reported, this process is widely used, mainly because of its shake-out properties; the ability to prevent cracking, veining and pinholes; and because of its low odour emissions. The process can be

used for all types of series and alloys but is mainly used for light and super light alloys (easy shake-out) and steel (low crack risk).

The resin is an alkaline phenolic resol, which reacts with methyl formate to produce methanol and an alkaline formate. The phenolic resin is precipitated as a gel that binds all compounds together. Further cross-linking leads to even higher strength on storage.

Methyl formate is liquid at ambient temperature, the boiling point being 32 ºC, but it is gasified by air typically heated up to 80 ºC; which also acts as the carrier in the process. The gassing period is always followed by an air purge, the purpose of which is to evenly distribute the methyl formate throughout the mass of sand.

2.5.6.2.3 SO_2 hardened furan resins

This process is no longer in widespread use, although it is suitable for a large range of applications in the manufacturing of small to medium sized moulds and cores in any alloy. The sulphur catalyst may cause some metallurgical problems on the surface of ductile iron castings. The major advantages it provides are long lifetime of the prepared sand, good mechanical properties and shake-out performance, and the prevention of cracks. Nevertheless its effective implementation is limited due to the adhesive character of the resin and due to concerns in using sulphur dioxide as a hardener.

This process uses furan resins, which contain about 80 % furfuryl alcohol. Both resins polymerise under acid conditions. These resins need to be mixed with the sand and with oxidising agents, such as organic peroxides or hydrogen peroxide. The reaction between these peroxides and the injected sulphur dioxide then generates sulphuric acid, which causes a rapid polymerisation. The gassing period is always followed by a purging period, the purpose of which is to remove the excess unreacted sulphur dioxide from the mass of sand.
[32, CAEF, 1997], [174, Brown, 2000]

2.5.6.2.4 SO_2 hardened epoxy/acrylic (free radical curing)

This process offers many advantages: good compaction ability; long bench lifetime of the prepared sand (the mixers or shooting heads do not need to be cleaned); good mechanical properties; no nitrogen, phenol or formaldehyde; good shake-out performance; and no crack formation. However, the higher cost of binder constituents is one major disadvantage though.

This process is characterised not by the type of resin, but by the principle of its cross-linking, which occurs through free radicals. The resin must contain carbon double bonds: polyester - acrylic, polyester - urethane or polyester - epoxy resins may be used. These resins generally have a low molecular weight and are diluted with organic solvents at nearly 50 % by weight, though solvent free types are also available. They are mixed with an organic peroxide, which acts as a reaction initiator. For curing, sulphur dioxide is carried by an inert gas, such as carbon dioxide or nitrogen, through the sand.
The gassing period is always followed by purging with the same inert gas that was used for curing, the purpose of which is to remove the unreacted excess sulphuric dioxide from the sand mass.

2.5.6.2.5 CO_2 hardened sodium silicate (water glass)

This process presents real advantages: it is cheap, easy to handle and environmentally clean. Also for workers health and for reliability of operation, this technique has advantages over organic binders. Its use however, has declined in popularity due to technical reasons, such as poor compaction ability and problems with collapsibility, poor mechanical strength, sensitivity

to crumbling, moisture pick-up and poor reclaimability. Furthermore, the use of water glass can lead to increased cleaning costs. The cores reach their full strength only after a drying period. This reduces their applicability in automated processes. The technique therefore finds its main application in small scale foundries.

The silicate generally used is sodium silicate, defined by its concentration (dry solid content) and modulus (silica soda ratio SiO_2/Na_2O). This modulus ranges from 2.0 to 2.8, the most common being 2.0 to 2.3. This silicate is mixed with the sand at a concentration of between 2 to 4 %. Shake-out and de-coring additives are commonly used and are usually pre-mixed with the silicate.

Curing occurs by gassing with carbon dioxide, due to its slightly acidic character. The CO_2-ratio should not exceed 1 to 2 % of the mass of sand, with a gassing time in the range of 10 to 60 seconds. The cured moulds and cores do not require purging.
[126, Teknologisk, 2000], [152, Notzon and Heil, 1998]

2.5.6.2.6 CO_2 hardened alkaline phenolic

This process was introduced for the first time in 1989 and has been undergoing improvements ever since. It is now commercially available and is in use in a few locations, but its use is not yet widespread.

The resin is an alkaline phenolic one, containing a linking substance stabilised at a high pH, approximately 14. Curing occurs by gassing with carbon dioxide, which dissolves in the water solvent of the resin, so lowering its pH and activating the linking substance.

2.5.6.3 Hot curing processes

In these processes, curing takes place by heating the sand-resin mix or, more often, by allowing it to come into contact with the heated pattern equipment. They all provide a high dimensional accuracy, which can only be achieved by means of using high quality (metal) patterns, which can be very expensive. For this reason, hot curing processes are used for the production of cores of limited size, mostly in mass production processes. Their use, very widespread for years, is now on the decline, as they are being replaced by gas cured processes.

Hot curing processes are characterised by major emission problems: when heated, the resins and catalysts emit noxious chemicals including ammonia and formaldehyde that can be the source of odour nuisance. A number of abatement techniques have been tried to solve these problems, such as scrubbing, combustion or biological abatement, but none of these has proven to be effective.

2.5.6.3.1 Hot-box, phenolic and/or furan based

This process can produce cores of a high dimensional accuracy and good mechanical strength, but to achieve these, the operators need a very good knowledge and control of the production process. The limits of the process are set by its cost, principally for the resin, energy and pattern equipment, and by the poor internal working conditions caused. It is currently used in the manufacturing of small or medium sized cores in mass production.

A resin binder and a heat activated catalyst are pre-mixed with sand and the mixture is blown into a heated corebox or pattern, where it is cured for approximately 5 to 60 seconds.

A wide range of resins may be employed, such as:

-	urea - formaldehyde	UF
-	urea - formaldehyde - furfuryl alcohol	UF - FA
-	phenol - formaldehyde	PF
-	phenol - formaldehyde - furfuryl alcohol	PF - FA
-	urea - formaldehyde - phenol - formaldehyde	UF - PF
-	urea - formaldehyde - phenol - formaldehyde - furfuryl alcohol	UF - PF – FA.

The catalysts are ammonium salts of mineral acids, sometimes with urea additions to reduce free formaldehyde. Additionally, other additives are used, such as silanes, iron oxides, preservatives and silicon oil.

The addition ratio for the resin varies from 1.2 to 3.0 % based on sand weight, with an average of about 1.8 %. The addition ratio for the catalyst varies from 10 to 25 % based on resin weight, with most formulations being optimised at 20 %. The temperature mostly used for the pattern ranges from 230 ºC to 290 ºC, with the optimum range being 220 ºC to 250 ºC. If excessive heat is used in an attempt to accelerate the curing time, the core surface can be burnt, producing brittleness during pouring.

2.5.6.3.2 Warm-box

This process is very similar to the hot-box process and uses the same production techniques. Only the type of resin differs, allowing curing at a lower temperature. However, this kind of resin is significantly more expensive than those in use in the hot-box process. Therefore the warm-box process, in spite of some real advantages, is not generally find widespread use.

The binder is furfuryl alcohol-based, with a typical composition containing around 70 % furfuryl alcohol or a low polymer of furfuryl alcohol. The catalysts are copper salts derived from aromatic sulphonic acids, in water or an alcohol solution. The distinctive feature of these catalysts is their excellent stability at ambient temperature and their relatively low dissociation temperature, which is 150 - 170 ºC. Accordingly, the tool temperature can be held at around 180 ºC, which leads to major energy savings of about 15 to 25 % compared to the hot-box.

2.5.6.3.3 Shell (Croning)

This process is the only one among all moulding and core-making processes that can use pre-coated sand, directly available from suppliers and ready for use, although pre-coating of the sand may also be performed at the foundry.

The sand is cured by heating it in a metallic pattern, producing a hardened surface layer. The unheated or uncured sand may be discarded by turning the pattern upside down and then re-used. The cured sand forms a "shell", which has given its name to the process.

This process gives high dimensional accuracy and a good surface finish to the castings, good shake-out and de-coring properties and allows a nearly unlimited storage time for the pre-coated sand. The process limits are the price of the pre-coated sand and the pattern equipment costs. Its use is restricted to the production of small or medium sized moulds and cores in mass production. Example cores and mould are shown in Figure 2.33.

Figure 2.33: Croning cores (top) and moulds (bottom)
[237, HUT, 2003]

The resin used for pre-coating is a phenolic "novolac", with a formaldehyde/phenol ratio lower than 1. Hexamethylenetetramine is added to the resin as a hardener. 'Hexa' decomposes at 160 ºC into its 2 basic components: formaldehyde and ammonia. When pre-coated sand contacts the heated pattern, the hexamethylenetetramine decomposes and the formaldehyde cross-links the resin binder to form the characteristic strong bond.

2.5.6.3.4 Linseed oil

This ancient process is probably the oldest one processing chemically-bonded sands. It is very easy to use, does not need sophisticated patterns and has a good resistance to veining and cracking. It is still in widespread use for specialised small cores.

These sands are bonded with a mixture of drying oils, these usually being to a great extent linseed oil, often with an addition of dextrin and a few per cent water. The addition rate of oil varies from 0.8 to 4 %, based on sand weight. Drying agents may also be added. Curing occurs by cross-linking of the unsaturated fatty acids contained in the drying oils, induced by atmospheric oxygen and accelerated by heating in a drying-oven at a temperature between of 190 and 260 ºC for 1 to 2 hours.

2.5.6.3.5 Alkyd oil, baked

This process is similar to the previously described unbaked alkyd oil process, the only difference being in this case heat treatment of the parts in order to accelerate the curing.

2.5.6.4 Coating of chemically-bonded sand moulds and cores

The skill of the founder is to produce high quality castings, without defects, and requiring only minimal finishing and repair. To achieve this, the ideal is to minimise all the interactions that may occur between mould, core and metal during pouring. These effects may be generated by different causes, such as sand expansion, ramming defects, abrasion of sand, metal penetration, chemical decomposition or by interaction between the binders, etc.

For these reasons, it is often beneficial to coat the mould or the core with a refractory lining, in order to give a smooth surface finish to the casting and to reduce fettling cost.

2.5.6.4.1 Composition of coatings

Coatings are available as ready-to-use products or as a mass to dilute with water or alcohol. They usually contain the following components:

- one or more refractory fillings, such as talc, pyrophyllite, mica, zircon, magnesite, quartz, etc., or blacking
- a make-up liquid, which may be an alcohol (e.g. isopropanol, ethanol) or water
- high temperature bonding agents, such as bentonites, resins, boric acid
- rheological agents, such as bentonites or synthetic polymers
- additives, such as surfactants, foam breakers, fungicides, etc.

2.5.6.4.2 Coating process

The coating may be applied on the mould or on the core by different means:

- by brushing, for small cores or for localised application
- by dipping, for complex shaped cores; this process often being automated
- by spraying, usually airless
- by flow-coating, for large or medium sized moulds or cores.

If alcohol-based coatings are applied, the working area needs to be ventilated in order to prevent the danger of fire or explosion. The coated moulds and cores are mostly burnt out, which limits the emissions. If they are not burnt out then drying is carried out under exhaust with the VOC emissions maintained under control. Flow coating with alcohol-based coatings and subsequent firing or drying is presented in Figure 2.34.

Figure 2.34: Flow coating with alcohol-based coating, followed by firing or drying [237, HUT, 2003]

The drying of water-based coatings occurs by heating in a drying furnace using hot air, infrared or microwaves. The dip-coating of cores and subsequent hot air drying is presented in Figure 2.35. Water-based coatings do not generate emission problems, neither during coating nor during drying. For these reasons, water coatings are now increasingly replacing alcohol-based

ones. However, their application faces technical constraints in terms of the coating quality continuity and drying constraints. A full discussion of water-based versus alcohol-based coatings is provided in Section 4.3.3.5.
[143, Inasmet and CTIF, 2002]

Figure 2.35: Dip-coating with water-based coatings, followed by drying in a hot-air furnace [237, HUT, 2003]

2.5.7 Expendable pattern casting

In expendable pattern casting, the pattern is not removed from the mould before pouring. The pattern, which is made of expanded material, is a single-use one, which is destroyed when poured. These expandable patterns may be embedded either in chemically-bonded sands or in binderless sand, hardened by vibration.

This process, commonly called "Lost Foam casting", was developed 30 years ago and its commercial growth was initially rather slow. However, during the last 10 to 15 years, it is has become used more often, primarily for the mass production of automotive parts or similar products, in spite of significant set-up difficulties.

2.5.7.1 Unbonded sand – Lost Foam process

The Lost Foam process (Figure 2.36) starts with the 3D-CAD design and production of a precision moulded foam pattern, made from expanded polystyrene (EPS) or PMMA, produced by automated injection moulding machines. These patterns can be made from one piece or by assembling a number of parts by adhesives. Here usually, a number of patterns, dependent on size, are fixed to a runner-down gating system, made from the same material as the pattern, thereby generating a cluster.

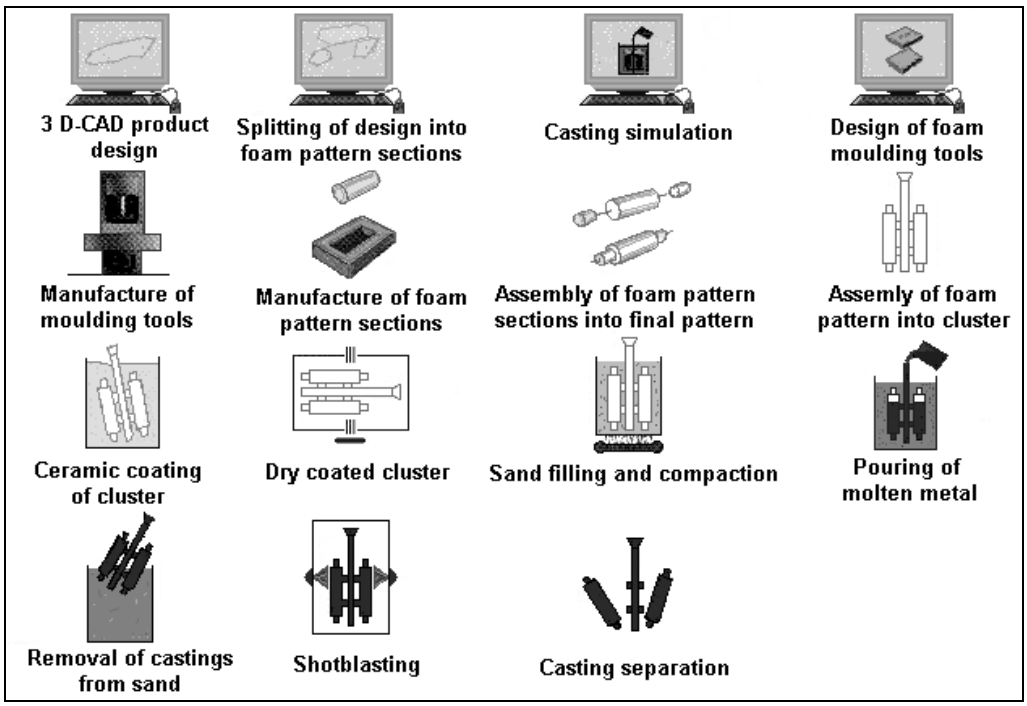


Figure 2.36: The Lost Foam process
[110, Vito, 2001]

The clusters are dipped in a water-based refractory type coating, which creates a barrier between the molten metal and the sand during pouring. After drying, the cluster is positioned in a moulding flask, which is filled with unbonded sand. A low-viscosity resin may be added to the sand, in order to prevent deformation during compaction. The sand is compacted by triaxial vibration around the patterns, penetrating the holes and reproducing exactly all the details, thus making the core and core-making equipment unnecessary. Upon pouring, the molten metal causes a pyrolysis of the polystyrene and fills the emptied space.

The sand, mostly quartz, needs to be very permeable, in order to ensure the evacuation of the pyrolysis gases. Sand with an AFS-number of 35 – 50 is used. Interruption of the pouring may cause a collapse of the sand mould. Therefore an automatic casting system is often used.

The cast pieces are characterised by a very good dimensional precision, as shown in Figure 2.37. The technique can be used for any type of alloy and is used for medium to large sized series production. The process is environmentally friendly during the moulding but produces gaseous emissions during pouring and shake-out, due to the vaporisation of the expendable patterns. Lost Foam casting enables metal casters to produce complex parts which would often not be possible using other methods. The process allows designers to develop more complex shapes, to reduce machining need and to minimise assembly operations. Proper controls must be exercised in each step of the process to ensure consistent high quality castings. A lack of in-depth industry-wide knowledge on how to set up proper control measures has slowed adoption of the Lost Foam casting process.
[32, CAEF, 1997], [110, Vito, 2001], [144, US Dept. of Energy, 1998]

Figure 2.37: Expendable polystyrene pattern (r.) for the Lost Foam process and an example of a casting produced by the Lost Foam method (l.)
[237, HUT, 2003]

2.5.7.2 Chemically-bonded sand – Full mould process

The Lost Foam process can also be used to produce single-piece prototypes, thereby permitting a shortening of the delivery time. Furthermore the technique can be applied for the production of very big pieces, such as bases for metal processing machines, or presses, etc. in cast iron, steel or non-ferrous alloys. The wall thickness may range from 5 mm up to 1000 mm. Pieces of up to 50 tonnes have been cast using this technique. For the production of these bigger pieces, the application of a (furan) binder is needed in order to attain the necessary mould strength.

The Lost Foam process with chemically-bonded sand, in this case also called the 'full mould process', is mostly used for producing middle or large sized castings, in single production or in small batch series.

The patterns are made from low density expanded materials, such as:
- white, foamed polystyrene, with a density of 16 to 20 g/dm^3
- blue, foamed polystyrene, also called "poresta-blue", with a density of 18 to 22 g/dm^3
- foamed polymethylmetacrylate, also called PMMA, with a density of 25 g/dm^3.

These materials are cut out as various parts, which are then assembled and stuck together with hot melt glue, thus creating the final shape of the casting, also taking into consideration any possible shrinkage of the metal.

The assembled pattern, with its gating and feeding system, has to be coated, mostly with a water-based coating system, and thoroughly dried before being embedded in the sand. The binding process of the sand has to be specially selected in order to avoid any moisture pick-up by the pattern before pouring.

This process, as far as moulding is concerned, is very environmentally friendly, but produces gaseous emissions during pouring and shake-out, due to the vaporisation of the expandable patterns and destruction of the sand binder.

As with the unbounded process, uninterrupted casting is very important in order to prevent the mould form collapsing. For the casting of big pieces, pouring is performed using two (or more) pouring ladles and two (or more) entry holes simultaneously.

The full mould process has the following advantages:
- high size precision
- production of complex geometries, especially internal cavities
- integration of several parts into one casted piece
- reduction or exclusion of release edges
- possibility of thermal sand regeneration.

Despite the fact that the Lost Foam and full mould techniques have been known for a long time, they are not widely applied in Europe. This is primarily because their optimisation requires a lot of research and development. The main difficulties are:

- definition of the product range: determining which pieces can be made more easily as compared to traditional methods
- selection of the compaction technique: application of the sand in order to perfectly fill all cavities
- choice of coating and sand type: these should have a sufficient gas permeability to allow the combustion gases to escape.

[110, Vito, 2001]

2.5.8 Permanent (metal) moulds preparation

Permanent moulds are made from metallic elements adapted to the shape of the casting, whose assembly allows the moulding, pouring and stripping of the casting. These metal moulds are used for gravitational casting, high pressure die-casting, centrifugal casting, continuous casting and for low pressure casting. Unlike sand moulds, they can be re-used many times and for this reason, they are called permanent moulds.

If the shape of the casting cannot be easily made by the use of metallic core pins, sand cores may be used. For instance, sand cores are used to form the widening-out of centrifugal cast pipes.

Permanent moulds are generally coated with a "white or black wash"; these water-based release agents are refractory based in the case of the white one and graphite based for the black one. Their function is to provide protection of the die, to regulate die cooling by water evaporation, and to provide lubrication. They also act as parting compounds.

In a few cases, blackening is provided by burning acetylene in the absence of air, producing acetylene black that partially sticks to the die. The non-adhesive black then has to be collected and filtered before emission.

Permanent moulds (or dies) are generally not made in the foundry, although die-casting foundries do have a workshop for die assembly, maintenance and repair. This type of operation, however, does not generate any environmental effects.

2.5.9 Investment casting and ceramic shell

This process is used to produce intricate, thin section parts with high dimensional accuracy, fine details, and very smooth surfaces.

The process steps are depicted in Figure 2.38. They begin with the manufacture of expendable wax patterns, by injecting molten wax into an aluminium or epoxy die to form a pattern that is virtually an exact replica of the desired casting. The wax may contain fillers. For smaller castings, several wax patterns are attached to a wax gating system. Water soluble die release agents are used to facilitate the wax model take-out.

The wax patterns are cleaned with water or organic solvent and coated with a wetting agent, which helps the ceramic slurry to adhere to the wax. The cluster is then dipped in a liquid ceramic slurry, stuccoed with granular silica, zircon or alumina/silica refractories and then dried before the application of the next coat. The coating process is continued until a sufficiently thick shell is established.

The dried mould is then de-waxed by inserting it into a steam autoclave in which the wax patterns are melted out, or into a "flash-furnace", in which the wax may be partially burnt out.

After this, the shell is fired in a furnace at a high temperature. This burns out the residual wax and hardens the ceramic, leaving a one piece ceramic shell mould, into which the molten metal is poured to form the casting.

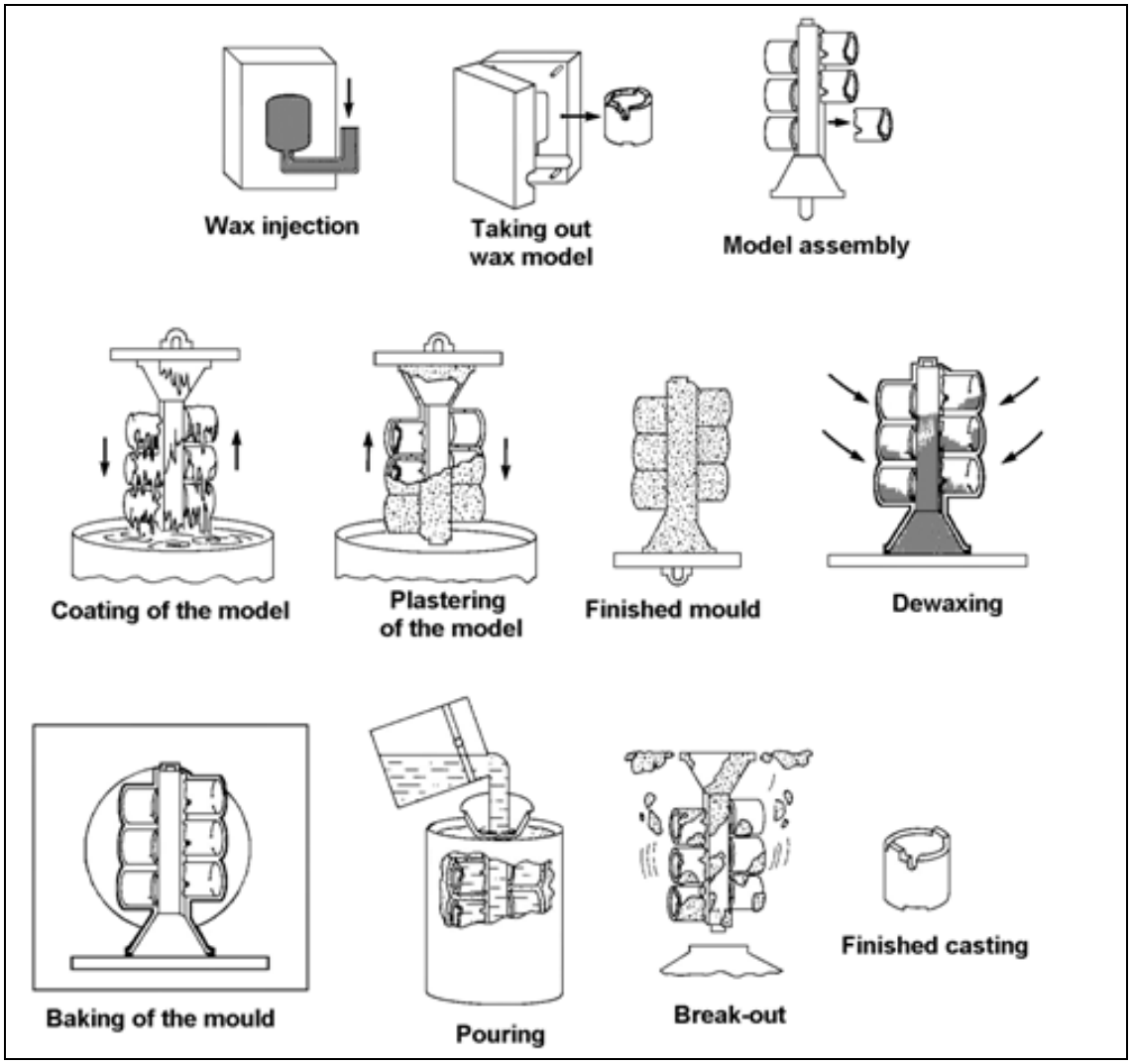


Figure 2.38: Investment casting process
[110, Vito, 2001]

In this process, air pollution may occur during two operations: investing and de-waxing.

Investing:
The liquid ceramic slurry consists of a binder and a very fine refractory powder, reduced to slime by permanent mixing. The binder may be colloidal silica, hydrolysed ethyl silicate or hydrolysed sodium silicate, the choice of the technology applied being determined by technical reasons. When using ethyl silicate, drying is faster, which allows a higher cycle rate, but ethyl alcohol vapours are emitted. These vapours, if present in too large an amount, have to be collected and treated before emission.

De-waxing and firing:
De-waxing by means of a steam autoclave does not produce any significant impact on air. However, this is not the case if the de-waxing is conducted in a firing oven, and during the firing of the shell, where wax residues are burned.

This burning occurs often in a lack of air, which results in the formation of carbon black particles. These particles have to be collected and either destroyed by afterburning or removed. Ceramic filters have been successfully used for this purpose, as they suit the high temperature of the exhaust gases, but this very recent technology has not yet become widespread.

This technique is used e.g. for precision casting and art casting. It is generally not applied in large-scale foundries (>20 tonnes/day capacity), and therefore is mentioned here only for informative reasons.

The ceramic shell process (patented as Replicast®) extends the quality and precision of investment casting to larger components, using a combination of Lost Foam and investment casting principles. The technique uses an inert, fired ceramic mould. To create the mould, an expanded polystyrene replica of the required component is produced, which is dimensionally precise and of a high surface finish. No parting lines or cores are required, nor draft angles, and polystyrene replicas can be glued together to create complex geometries. The polystyrene is burnt out before casting, allowing a wide range of alloys to be cast in the mould - from ultra low carbon stainless steel to nickel based alloys. This is in contrast to the Lost Foam process where liquid metal consumes and replaces the polystyrene pattern, making it unsuitable for the vast majority of steel components (polystyrene is 92 % by weight carbon).
[219, Castings Technology International, 2003]

2.6 Casting

Pouring is the central activity in casting production. The finished mould is filled with the liquid metal under the effects of gravitational or centrifugal forces or pressure. After pouring the casting is cooled to allow solidification and is then removed from the mould for further cooling and treatment.
[32, CAEF, 1997]

2.6.1 Casting in lost moulds

2.6.1.1 Pouring

There are two types of ladle generally used in pouring liquid metal: lip and teapot ladles. A third type (i.e. the bottom ladle) is more specific to steel.

- *Lip pour*: In this type of ladle (Figure 2.39) the metal is charged over the lip, with the flow controlled by tilting the ladle using a geared handwheel. Since the metal flows from the top of the ladle, the metal surface must be slag-free or a skimmer must be used to prevent slag entering the mould. Lip pour ladles are used for pouring small steel castings

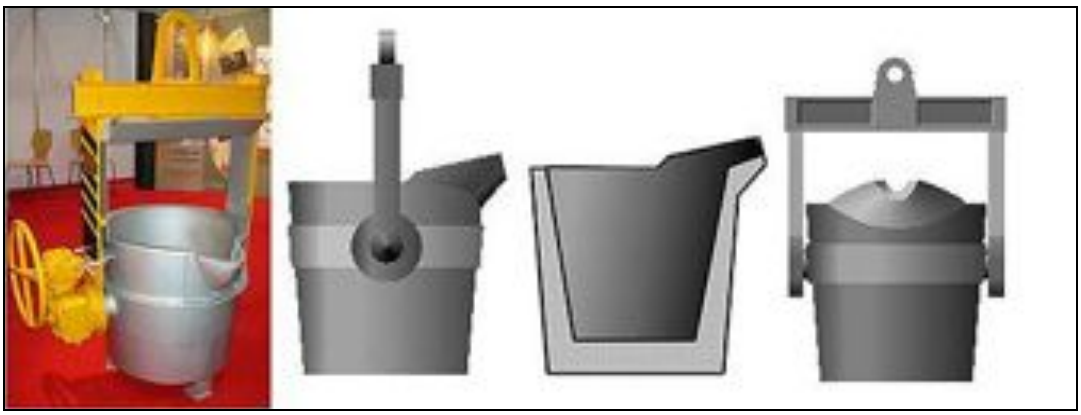


Figure 2.39: Lip pour ladle for molten metal pouring
[237, HUT, 2003]

- *Teapot ladles*: As depicted in Figure 2.40, a refractory dam before the ladle lip ensures that the metal is drawn from the bottom of the ladle, so that the stream is slag free. The molten metal is generally cleaner than from a lip pour ladle. One disadvantage is that the narrow spout may occasionally permit the liquid steel to freeze if the heat is tapped cold or if pouring is prolonged

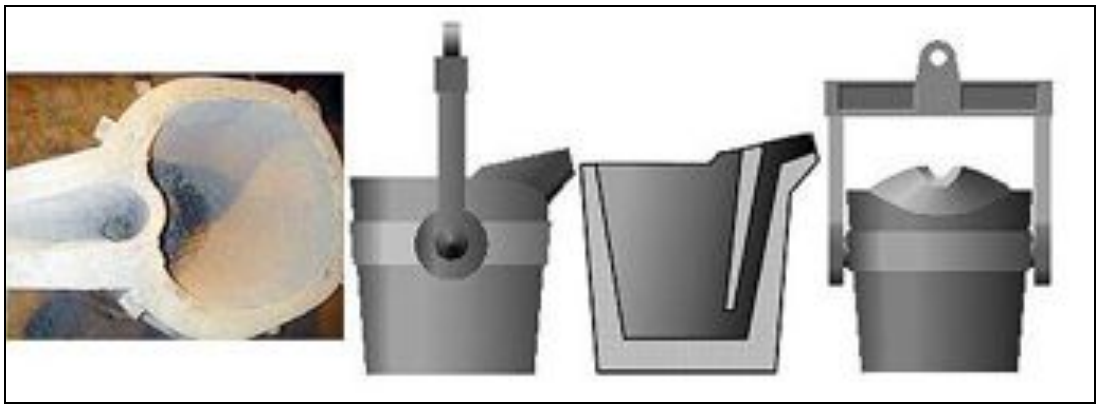


Figure 2.40: Teapot ladle for molten metal pouring
[237, HUT, 2003]

- *Bottom pour ladles*: The ladle is fitted with a pouring nozzle in its base, closed by a refractory stopper rod. The metal is drawn from the bottom and is therefore slag-free and non-metallics, such as deoxidation products, are able to float out of the melt. The metal stream flows downwards, so that there is no movement of the stream during pouring. The disadvantage is that the velocity and the rate of flow change during pouring as the ferrostatic head changes.

Figure 2.41: Bottom pour ladle for molten metal pouring
[237, HUT, 2003]

Automatic casting lines are often equipped with a pouring furnace. The working principle behind one example furnace is depicted in Figure 2.42. The casting line halts when a mould is in the correct position, i.e. under the pouring exit. Metal is poured during a fixed period by elevating a stopper. Because the metal level in the casting recipient is held constant, a fixed volume of molten metal is poured into the mould. The metal level in the furnace is controlled by a floating device, which controls the gas pressure inside the furnace. The casting furnace is refilled with metal from the melting furnace at fixed time intervals.
[110, Vito, 2001], [174, Brown, 2000]

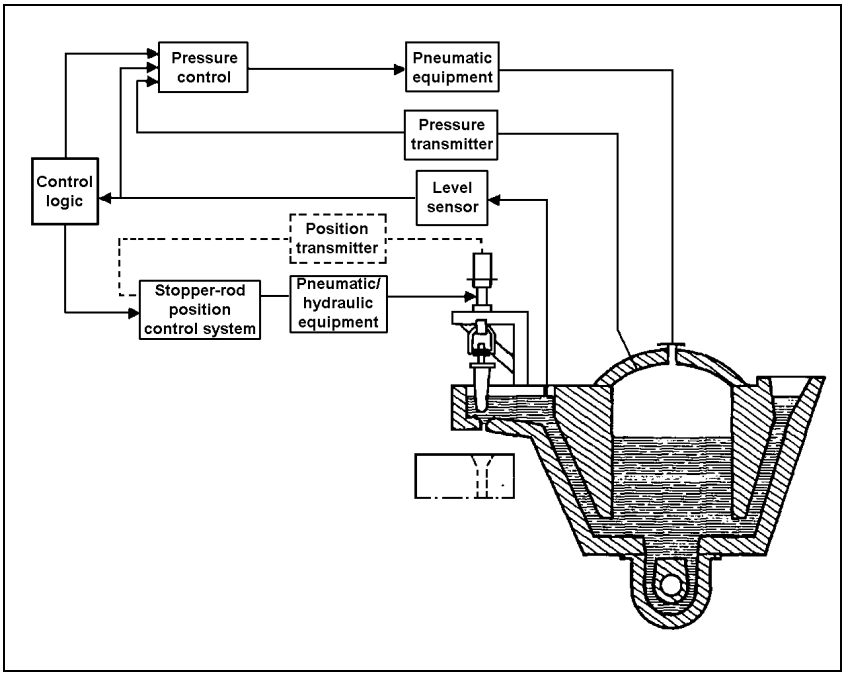


Figure 2.42: Pouring furnace
[110, Vito, 2001]

2.6.1.2 Solidification (1st cooling)

The poured moulds are transported along the moulding line onto the cooling lines. The length of the cooling line determines the final temperature of the casting at the point of shake-out. This temperature must be low enough to provide the casting with sufficient strength during shake-out and further manipulation.

Big moulds are not moved during cooling. The cooling time can be up to several days.
[110, Vito, 2001]

2.6.1.3 Shake-out

In the case of individual moulding, clay or chemically bonded moulds can usually be destroyed by vibration. In most cases this is accomplished by placing the moulding box on a vibrating grate, using a crane to do this. As a result of the vibration, the sand is separated from the casting and the moulding box. The casting and moulding box remain on the grate rods, whereas the sand falls through and is subsequently reprocessed. The casting is usually transported to a cooling area for further cooling in ambient air (second cooling).

A similar shake-out procedure is often carried out in mechanised systems and older low-capacity automated systems (Figure 2.43). Here the moulding boxes are removed from conveyor belts, by means of hoists or other transfer equipment, and placed on vibrators. Finally, the castings are left to cool down or placed in a casting cooling device. In many systems, the sand casting is pressed out of the moulding box and a subsequent controlled cooling of the castings and sand is achieved in combined or separate cooling devices, such as in cooling drums, swing pipes, chain conveyors, fluidised bed coolers, etc.

Figure 2.43: Shake-out at the end of an automated moulding line
[237, HUT, 2003]

Vacuum bonded sand moulds are destroyed by releasing the vacuum. The casting bucket or moulding box, containing the loose sand and the casting, is emptied and then the casting is cooled by one of the described methods.
[32, CAEF, 1997]

2.6.1.4 Casting cooling (2nd cooling)

The controlled cooling of castings and sand is carried out in rotary drums, swing drums or on oscillating conveyor troughs. The casting is cooled in oscillating conveyors or in cable-car baskets. In many cases an airflow, which is often directed in the opposite direction to that of the casting, is used for cooling. In some cases, fine water jets are used in order to increase the cooling effect.

2.6.2 Casting in permanent moulds

2.6.2.1 Gravity and low-pressure die-casting

Gravity and low-pressure die-casting make use of a permanent steel die into which the melt is poured under the influence of gravity or a low-pressure gas. Sand cores can be used to form undercuts and complex interior shapes in the casting. Due to the rapid solidification process,

permanent mould castings have a dense fine-grained structure with good strength characteristics.

The principle of low-pressure die-casting is shown in Figure 2.44. A metal die is mounted above a sealed furnace containing molten metal. A refractory-lined riser tube extends from the bottom of the die into the molten metal. When air is introduced into the furnace under low pressure (15 – 100 kPa) the molten metal rises up the tube to flow into a die cavity with low turbulence, the air in the die escaping through vents and the parting lines of the die. When the metal has solidified, the air pressure is released, allowing the still-molten metal in the riser tube to fall back into the furnace. After a further cooling time, the die is opened and the casting extracted. Due to the absence of feeders and risers, the casting yield is exceptionally high, generally over 90 %. A good dimensional accuracy and surface finish are possible and complex castings can be made using sand cores. This technique is typically used for aluminium castings, e.g. automotive parts such as wheels, cylinder heads, and electric motor housings, and for domestic kitchenware. The die must be coated to optimise the casting release and cooling. In general, a die coating is applied once per shift. The die life is normally around 30000 – 50000 shots. An example of a low-presure die-casting machine is given in Figure 2.45.

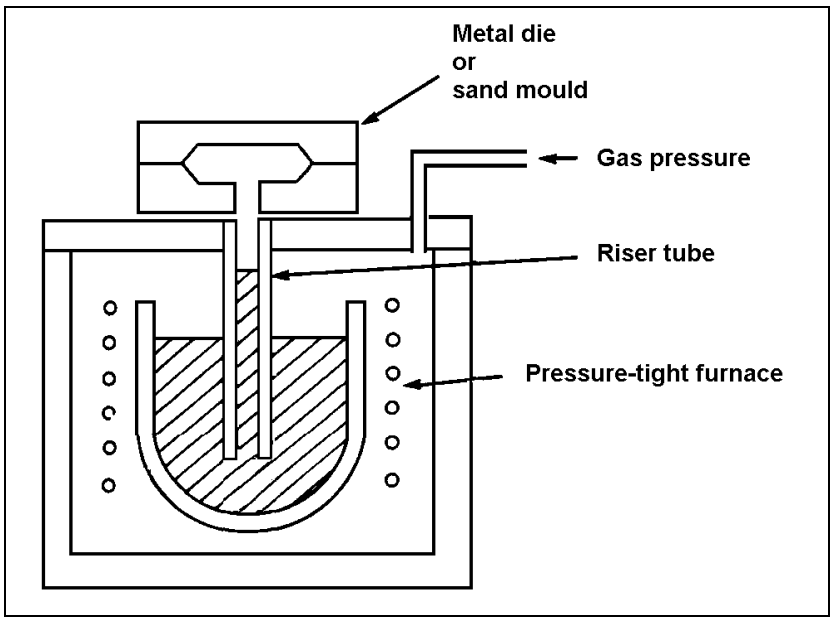


Figure 2.44: The principle of a low-pressure die-casting machine
[175, Brown, 1999]

Figure 2.45: Low-pressure die-casting machine
[237, HUT, 2003]

In gravity die-casting, the molten metal is poured under gravity into a permanent mould or die. Gravity die-casting machines range from simple, hand operated rack and pinion die sets,

manually poured, to carousel machines, which usually have a tilting mechanism for filling the die and which are often operated using a pouring robot. The dies are coated with a refractory-based coating, controll the cooling rate. The time before the casting can be extracted from the die varies from 4 to 10 minutes depending on the type of casting. The process is therefore relatively slow, compared to pressure die-casting. To achieve reasonable output rates, a manual operator will operate 2 – 4 die sets in sequence, allowing an output of 30 – 60 castings an hour. Automatic carousel machines may have 4 – 6 stations with multiple die sets, allowing production rates of around 1 casting per minute to be achieved. The process is most widely used in aluminium casting for series' of 1000 to more than 100000 pieces per year for e.g. manifolds, cylinder heads, water pumps.

Permanent mould coatings are typically formulated using water as a carrier, a high temperature binder (normally sodium silicate) and a refractory filler or blend of fillers. There are two categories of coatings:

- insulating: containing blends of insulating minerals such as talc, mica, kieselguhr, titanium dioxide, alumina, etc.
- lubricating: based on colloidal graphite or boron nitride to aid release of the casting.

Coatings are generally sprayed onto the die. Careful attention to die preparation, coating preparation and application and the type of coating equipment utilised can yield significant quality and productivity benefits.
[175, Brown, 1999]

2.6.2.2 High-pressure die-casting

The term "die-casting" often implies "high-pressure die-casting". The process utilises a permanent die (metal mould) into which molten metal is forced under high pressure. The application of high pressure causes a high and turbulent metal flow, which allows the production of castings with high surface areas and low wall thicknesses. Dies are usually made from two blocks of steel, each containing part of the cavity, which are locked together while the casting is made. Due to the high metal pressure, the maximum size of the casting is limited by the maximum locking force of the casting halves. Retractable and removable cores are used to form internal surfaces. Due to the high metal pressures, only metal cores can be used. This limits the complexity of the casted piece. The metal is held under pressure until it cools and solidifies. The die halves are then opened and the casting is removed, usually by means of an automatic ejection system. Dies are preheated and lubricated before being used, and are either air- or water-cooled to maintain the desired operating temperature. Two basic types of high-pressure die-casting (HPDC) machines are used: hot-chamber or cold-chamber (see Figure 2.46).

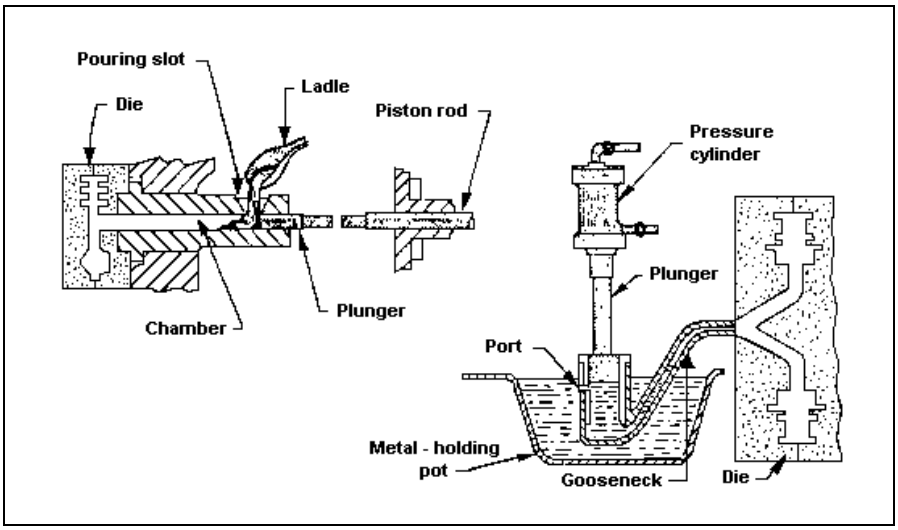


Figure 2.46: Cold-chamber and hot-chamber high-pressure die-casting devices [42, US EPA, 1998]

Hot-chamber HPDC machines comprise a molten metal reservoir, the die, and a metal-transferring device, which automatically withdraws molten metal from the reservoir and forces it under pressure into the die. A steel piston and a cylinder system with a gooseneck is used to create the necessary pressure within the die. A gooseneck machine utilises a cast iron channel to transfer the molten metal from the reservoir to the die. Pressures can range from a few bar to over 350 bar. Hot-chamber techniques are mainly used for zinc alloys and magnesium alloys.

Cold-chamber HPDC machines have molten metal reservoirs separate from the casting machine. Just enough metal for one casting is ladled by hand, or mechanically, into a small chamber, from which it is forced into the die under high pressure. Pressure is produced through a hydraulic system connected to a piston, and is typically in the range of a few hundred bar to 700 bar. In cold chamber machines, the metal is just above the melting point and is in a slush-like state. Since the metal is in contact with the piston and cylinder for only a short period of time, the process is mainly applicable to aluminium alloys, and to a lesser extent magnesium alloys, zinc alloys, and even high melting point alloys such as brasses and bronzes.

Proper lubrication of the dies and plungers is essential for successful high-pressure die-casting. The die lubrication affects the casting quality, density, and surface finish, the ease of cavity fill, and the ease of casting ejection. Proper lubrication can also speed up the casting rate, reduce maintenance requirements, and reduce the build up of material on the die face. Although specific formulations are proprietary, in general, lubricants (also called release agents) are a mixture of a lubricant and a carrier material. Formulations may also include additives to inhibit corrosion, to increase stability during storage, and to resist bacterial degradation. Lubricating materials are typically mineral oils and waxes in water emulsions. Silicone oils and synthetic waxes are finding increased use. Both water-based lubricants and solvent-based lubricants are in use today. Water-based lubricants however dominate the market (95 %). The lubricant is applied to the open die by spraying, between each shot. Dilute solutions of lubricant are used (1:20 – 1:200 release agent:water ratio). Alternative electrostatic powder coatings are currently being developed.

High-pressure die-casting is not applicable to steel and high melting point alloys. The technique finds widespread application for aluminium castings. Dies are expensive but can have a life of 150000 shots. The process is therefore most suitable for long runs of castings. One major advantage of HPDC over other casting methods is that the castings produced can have very complex shapes. The ability to cast complex shapes often makes it possible to manufacture a product from a single casting instead of from an assembly of cast components. This can greatly reduce casting costs, as well as the costs associated with fabrication and machining. Furthermore, HPDC produces castings which have a high degree of dimensional accuracy and surface definition compared to other casting methods, which may help to reduce or eliminate costly machining steps. Finally, castings with relatively thin wall sections can be produced using the HPDC method. This can result in substantial savings in material costs and reductions in component weight.

Relatively little waste is generated in the actual HPDC process compared to other metal casting processes. However, some gaseous and fume emissions occur during metal injection. Metal oxide fumes are generated as some of the metal vaporises and condenses. Gaseous emissions can originate from: the molten metal itself; the evolution of chemicals from the lubricant as it is sprayed onto the hot metal die and as it contacts the molten metal. Emissions to water may occur from any leakage or spillage of hydraulic oil or heating oil and from cooling water.
[42, US EPA, 1998], [128, IHOBE, 1998], [175, Brown, 1999], [225, TWG, 2003]

2.6.2.3 Centrifugal casting

In centrifugal casting, a permanent mould rotates at high speed around its axis as the metal is poured. The speed of rotation and the metal pouring rate vary with the alloy and the size and shape being cast. The rotating axis is generally horizontal or under a small angle (Figure 2.47). Some specific devices apply rotation around a vertical axis. The resulting material has a very dense structure and properties that cannot be obtained with sand casting.

This technique is used to produce cylindrical products in cast iron, steel, and in alloys of aluminium, copper and nickel. Typical parts made by this process are pipes, boilers, pressure vessels, flywheels, cylinder liners and other parts that are axisymmetric.
[179, Hoppenstedt, 2002]

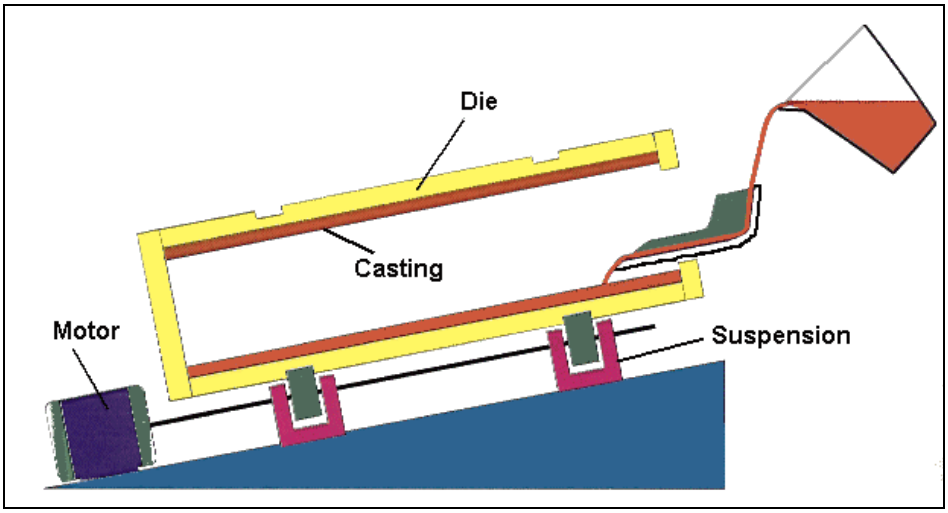


Figure 2.47: Schematic representation of a centrifugal casting machine [179, Hoppenstedt, 2002]

2.6.2.4 Continuous casting

Continuous casting is a high productivity device for the production of bars, tubes and profiles, where through rapid cooling, a fine-grained material with good mechanical properties is obtained. In continuous casting, the molten metal is cast into a water-cooled die, which is open at the bottom or at the side (Figure 2.48). The die gives the desired form to the product. Through intensive cooling, the outside of the metal product solidifies, while it is slowly pulled out of the mould. Through continuous pouring and extraction as the product is pulled out of the mould, the product gets longer. A burner cuts the product whenever the desired product length is reached. This technique is used for both ferrous and non-ferrous casting. The technique is used for the casting of bars, slabs and sheets as a final step in iron, steel and non-ferrous metals production. Its use in this context is described in the BREF for non-ferrous metal industries [155, European IPPC Bureau, 2001] and the BREF on iron and steel production [211, European IPPC Bureau, 2000].

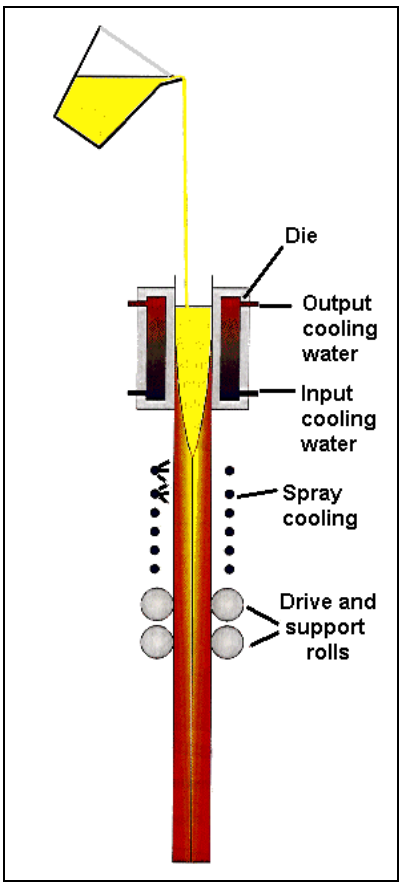


Figure 2.48: Schematic representation of a thread casting machine used for continuous casting [179, Hoppenstedt, 2002]

2.7 Finishing and post casting operations

Finishing of the raw castings encompasses all necessary treatments to yield a finished product. According to the process, various steps may be required, such as:

- removal of the running system
- removal of residual moulding-sand from the surface and core remains in the casting cavities
- removal of pouring burrs
- repair of casting errors
- preparation of the casting for mechanical post-treatment, assembly, thermal treatment, coating, …

In some cases, foundries also perform assembly, surface finishing and coating of the castings. However, these activities are not discussed in this document. Surface finishing and coating techniques are discussed in the BREF documents on Surface Treatment of Metals (STM BREF) and on Surface Treatment Using Solvents (STS BREF).
[110, Vito, 2001], [225, TWG, 2003]

2.7.1 Removal of the running system

In the finishing of the raw castings and to remove the running system (see Figure 2.49), the following operations take place:

- *Beating, pressing*: In the case of brittle materials such as grey cast iron castings and white malleable cast iron, chamfers and feeders can generally be knocked off. Hydraulic equipment is increasingly being used for this task
- *Grinding with grinding wheels:* These can be handheld, semi-automatic or automatic
- *Cutting*: For the removal of massive pieces in carbon steel or low alloy steel, an oxygen-acetylene cutter is used. For cast iron or high alloy steel, oxygen-acetylene-powder or oxygen-LPG-powder cutters are used
- *Sawing*: Materials which are sensitive to heat, such as aluminium alloys, are usually sawed.

Figure 2.49: Casting with running and gating system
[237, HUT, 2003]

Through good design of the connection points, the feeding system may even get broken–off during shake-out. This is mainly possible for grey iron.
[32, CAEF, 1997], [202, TWG, 2002]

2.7.2 Sand removal

Removal of the sand is performed in blasting cabins. The blasting medium is adapted to the material to be treated and varies from blasting grit to glass beads. The cleaning of model plates and permanent moulds is done with glass beads, aluminium beads or CO_2 ice grains. An example of castings before and after blasting is shown in Figure 2.50.

Figure 2.50: Castings before (l., m.) and after (r.) sand removal by blasting
[237, HUT, 2003]

Various blasting techniques exist. The acceleration of the grit is done with compressed air or turbine blades. The treatment is carried out in a closed room, with rubber-sealed doors.

The castings are suspended on a monorail and move batch wise through the blasting cabin. For smaller pieces, a specific moving belt is used. Big pieces are blasted manually, using a lance in an enclosed cabin. In this case, personal safety measures are very important. A helmet with a dust mask and respiratory equipment are required.

The coarse dust (sand and metal flakes) that is generated by blasting of the workpiece, is collected together with the grit. It is dedusted, magnetically separated and sieved. The fine fraction is removed from the exhaust air together with the coarse fraction, using a bag filter. Cleaning of the grit before internal re-use is of major importance as the presence of sand could cause a quick wearing of the throwing shovels.

2.7.3 Removal of burrs

Burrs, which occur at the point where mould and core pieces join, at veins and at other surface irregularities, are removed using grinding wheels and grinding stones. Grinding wheels are handheld, whilst with grinding stones the casting is pressed against a rotating stone.

Other applied techniques include:

- *Slide grinding*: Grinding burrs and small amounts of other excess material on the casting surface can be removed without hand grinding. The parts are revolved in drums or vibrating containers together with abrasive shapes, causing them to be rubbed against each other and against the abrasive wheels. In a typical unit the castings are ground using a bed of pyramidal grinding stones, together with the addition of a water-soap emulsion. The roughness and the size of the grinding stones vary depending on the size of the castings
- *Tumbling*: This technique, also called blast removal, is used to remove thin burrs or small amounts of casting residue. During this process the burrs remove themselves in an airless blast cleaning process as a result of the parts being impacted together in a rotating drum. At the same time the edges are rounded-off. Sometimes the process is assisted by a liquid.

Figure 2.51: Burrs (l.) and their removal using a grinding stone (m.) and slide grinding (r.) [237, HUT, 2003]

Automation of these operations is difficult due to the variability in shape of the burrs and the need to fix the casting easily and quickly. Nevertheless, automatic grinding machines are increasingly being used in serial production. Raw casting parts are inserted into such machines to produce suitably worked parts which do not need any retooling or further manual grinding work.

Furthermore the following techniques are applied in automated lines:

- *Punching*: Due to the use of cutting and forming techniques, serial casting parts are often designed in such a way that the unavoidable burr occurs in predetermined amounts which are easily accessible as far as processing is concerned. If the series is large enough, dedicated punching tools can be designed to quickly remove the burr and to provide the casting with a uniform contour

- *Milling*: With the development of electronic controls for processing machines it has become increasingly easier to compile programs with which to process individual workpieces. Thus it is possible to use milling machines for smaller series instead of the punching machines with their single purpose tools. During such a process, the workpieces are taken up by the device and passed across a number of different milling machines.

Finally, welding may be carried out in order to join castings, as well as to manufacture and repair casting flaws. In most of these cases, arc welding is used. Depending on the requirements and equipment, the work is carried out either with hand operated stick electrodes or with welding wire and with or without inert gas. Scarfing is used on steel castings, which consists in applying grooves for stress relieve. This uses a cutting torch with a copper-coated carbon electrode.
[32, CAEF, 1997], [110, Vito, 2001], [202, TWG, 2002]

2.8 Heat treatment

2.8.1 Introduction

For ferrous castings, there are basically two types of thermal treatments which can be applied: annealing and hardening. In the case of annealing, the tension caused in the workpiece as a result of pouring, and the subsequent cooling down of the casting, is reduced and the structure is evened out. In the case of hardening, the level of heat is raised above the transformation temperature and the workpiece is subsequently rapidly cooled, in a process known as quenching. This causes the material properties to change. Different results may be obtained by the use of water, oil or air quenching. 'Quench and temper' is the name of the procedure in which the workpiece is reheated to the tempering temperature following quenching, and the quenching procedure is repeated.

The malleableising of iron is a thermal treatment which differs from annealing and hardening. Here, the malleable unfinished casting is either transformed to a white or black temperature casting depending on the procedure.

Many non-ferrous castings are used in an 'as-cast' condition, but certain applications require higher mechanical properties than 'as-cast' material. Possible treatments are annealing, controlled cooling, solution heat treatment, artificial ageing and precipitation treatment.
[32, CAEF, 1997], [175, Brown, 1999]

2.8.2 Heat treatment furnaces

2.8.2.1 Chamber furnaces

Chamber furnaces are the most common furnace construction. Their actual design has been adapted in many sub-forms in order to meet the needs of the differing thermal treatments of various types of casting and production. Some examples of chamber furnaces are bogie hearth furnaces, top hat furnaces, hub open-hearth furnaces, etc. Chamber furnaces with continually running conveyance means are called tunnel furnaces. Heating is provided either electrically, or with gas or fuel oil.

For non-ferrous materials, some heat treatments are carried out close to the melting point of the casting, so accurate temperature control is needed. Forced air circulation is used to ensure that the temperature at all parts of the furnace is constant and equal.
[32, CAEF, 1997], [175, Brown, 1999]

2.8.2.2 Shaft furnaces

Pipes, long waves and similar parts are often treated while suspended in a vertical position in shaft furnaces. In shaft furnaces, the heating is provided by electricity, gas or fuel oil.

2.8.2.3 Annealing furnaces

Chamber, top hat or tunnel furnaces are used to temper unfinished castings. The heating of such furnaces is carried out via electricity, gas or fuel oil.

2.8.3 Quenching

In thermal treatment processes, chilling is the cooling down of a workpiece at a greater speed than in calm air. This can be achieved by means of a rapid submersion in water or oil (see Figure 2.52), as well as by forced air-cooling. Care should be taken that the workpieces are cooled at a uniform rate. When submersing in fluids, either the parts must be moved or the fluid must be continually circulated to ensure a full and even cooling of all parts of the workpiece. In a similar principle, in air quenching the blowing procedure must be arranged so that the air covers the entire surface.

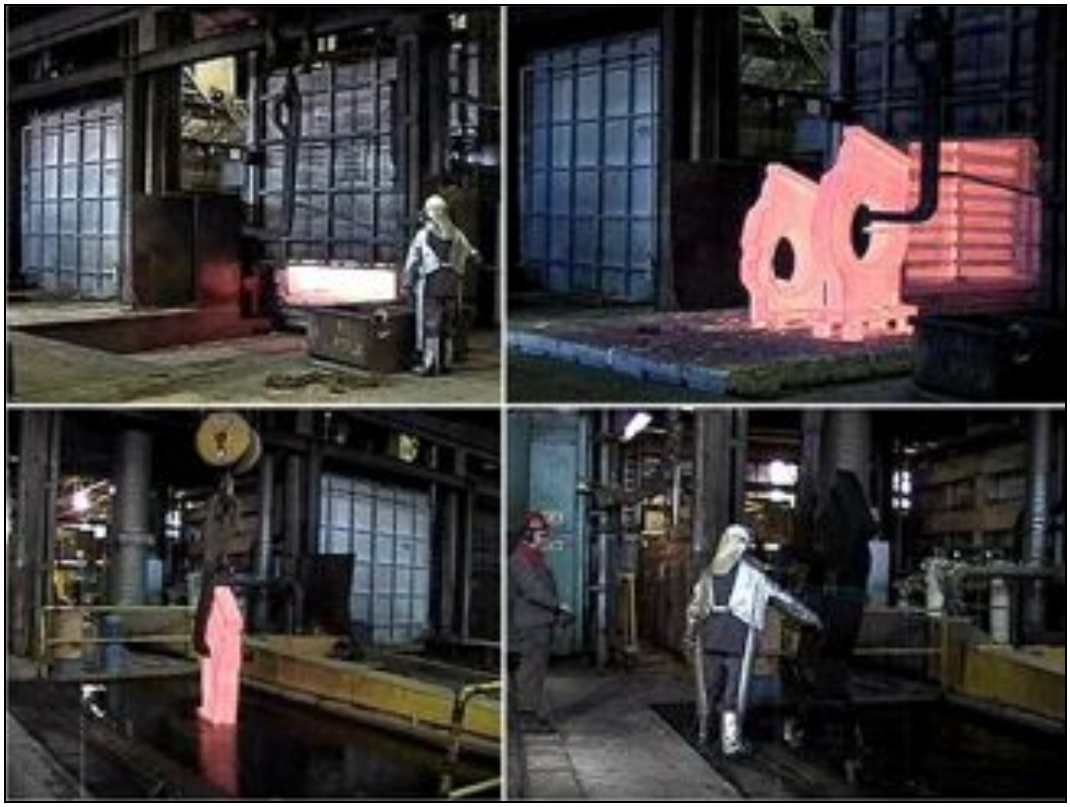


Figure 2.52: Quenching of a hot casting shortly after heat treatment [237, HUT, 2003]

2.8.4 Heat treatment of ductile iron (SG iron)

It is obviously desirable to achieve the required metal properties in the 'as-cast' form to save further treatments being necessary, but this is not always possible because of variations in section thickness, etc. The heat treatment of the castings can eliminate carbides in thin sections, produce more consistent matrix structures and for a given structure, often improve its

mechanical properties, especially by normalising the grain structure. Where tempered martensite structures are needed, heat treatment is essential.
[32, CAEF, 1997], [174, Brown, 2000]

2.8.4.1 Stress relief

Stress relief consists of heating the castings at a rate of 50 – 100 ºC/h to 600 ºC (taking care not to exceed 610 ºC), followed by soaking them for a minimum of one hour, plus an extra hour for every 25 mm of section thickness in the thickest section, and then cooling them at a rate of 50 - 100 ºC/h or less. The castings must be adequately supported in the furnace so that they are not subjected to stress.

2.8.4.2 Breakdown of carbides

Thin section castings may contain carbides in the 'as-cast' structure. These can be eliminated by soaking the castings at 900 – 925 ºC for 3 to 5 hours.

2.8.4.3 Annealing to produce a ferritic matrix

Annealing involves soaking the castings at 900 – 925 ºC for 3 – 5 hours, followed by a slow cooling at around 20 – 35 ºC/h through the critical temperature range (about 800 – 710 ºC), and finally furnace cooling at, say 50 – 100 ºC/h to 200 ºC.

2.8.4.4 Normalising to produce a pearlitic matrix

For normalising, a soaking of the castings above the critical temperature followed by air cooling is necessary. Again a soaking temperature of 900 – 925 ºC is usually used, to ensure that the carbides are broken down. Forced air cooling is used to form pearlite. The type of heat treatment furnace available and the size of the load determines the process cycle that is possible. It may be necessary to adjust the metal composition with tin or copper to help the formation of fully pearlitic structures.

2.8.4.5 Producing hardened and tempered structures

Hardened structures are produced by austenitising the casting at 900 – 920 ºC, followed by oil quenching. Tempering is usually carried out at 600 – 650 ºC.

2.8.4.6 Austempered ductile iron (ADI)

Austempering is an isothermal heat treatment for producing ausferrite structures. It can double the strength of ductile iron whilst allowing it to retain good ductility and toughness. Wear resistance and fatigue properties are excellent, even to such a degree that ADI is comparable with wrought and hardened-tempered steel.

The ADI heat treatment is a two-stage process, as shown in Figure 2.53. Austenitising is carried out at 815 – 930 ºC to fully transform the matrix to austenite. This is done either in a non-oxidising atmosphere furnace or in a high temperature salt bath. Temperatures and times are determined by the chemical composition, the section size and the grade of ADI required; 1 to 1.5 hours is usually adequate. Slow initial heating of the casting is desirable to avoid the risk of cracking the complex shapes. The castings are then quenched to the required isothermal heat treatment temperature, usually between 210 and 400 ºC. This is usually done in a salt bath. The

castings are held at this temperature for 1 – 2 hours to complete the transformation of austenite to ausferrite. Lower temperatures give high hardness, strength and wear resistance, while higher heat temperatures result in higher ductility and toughness. After the isothermal treatment, the castings are cooled to ambient temperature.

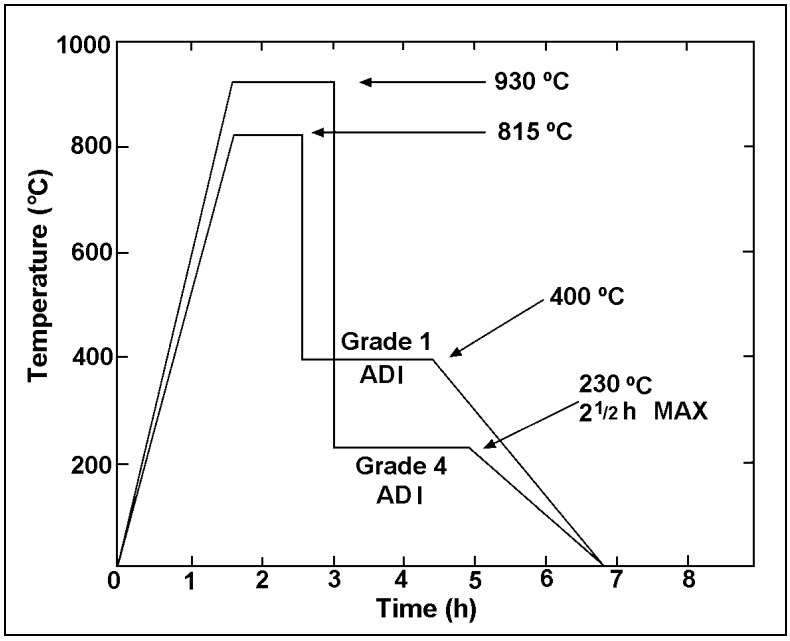


Figure 2.53: Typical austempering heat treatment stages
[174, Brown, 2000]

Unalloyed ductile irons may be austempered in sections of up to about 8 mm thickness. Thicker section castings require the addition of Mo or Ni to increase the hardenability.

Austempered ductile iron is used as a replacement for forged steel components in the agricultural, railway, automotive and general engineering industries; for example, for plough tips, digger teeth, spring brackets, rear axle brackets, gears, etc. ADI production is growing but its use is limited to some extent by the lack of suitable heat-treatment facilities.
[32, CAEF, 1997], [174, Brown, 2000]

2.8.5 Heat treatment of steel

Steel castings are normally subject to a heat treatment before delivery, e.g. normalising, with this heat treatment leading to a structural change. Additionally, potential casting stresses have to be reduced (stress relief annealing). Many steel casting qualities have to be additionally tempered after stress relief anneal (hardening and tempering).

Most steel castings are subjected to a heat treatment to attain the desired mechanical properties and to a stress relief, to obtain the right corrosion resistance and to avoid the difficulties during the finishing operations. The heat treatment is defined according to the steel grade. To remove the chemical and structural segregations, annealing at high temperature is generaly performed. Carbon and low alloy steels undergo:
- normalising and air cooling, or
- austenitising, quenching and tempering.

Austenitic or duplex stanless steels undergo a solution annealing and water quenching heat-treatment. Additionnal heat-treatments such as for stress relief or post weld treatment are also used to eliminate the internal stresses of the material.
[32, CAEF, 1997], [202, TWG, 2002], [225, TWG, 2003]

2.8.6 Heat treatment of aluminium

Aluminium castings are heat treated for: homogenisation, stress relief, improved dimensional stability and machinability, optimised strength, ductility, toughness and corrosion resistance. Most often the heat treatment is a compromise between varying effects, maximising the important properties of one often at the expense of others. The heat treatment of aluminium may involve: annealing, solution heat treatment, quenching, artificial ageing and precipitation treatment. The type of treatment applied is indicated by a suffix to the alloy designation. This is called the temper designation. For sand, gravity and low-pressure die-castings all treatments are possible, though not all are standardised. Pressure die-castings are not solution treated and quenched in the same way as sand, gravity and low-pressure die-castings. Entrapped gas bubbles can expand and cause casting defects. Heat treatment is not a common step for high-pressure die-castings; only about 1 % of this type of castings are subjected to heat treatment. All die-castings may be quenched from the die, precipitation treated and stress relieved without suffering any harmful effects. In the low pressure die casting production of aluminium wheels 90 % of the castings are subjected to heat treatment
[225, TWG, 2003].

2.8.6.1 Stress relieving and annealing

Castings with changes of section, or of a complex shape are likely to develop internal stresses. These can then cause dimensional changes upon machining. To stabilise the casting and to remove internal stresses, castings are heated to a temperature of 200 ºC for 5 hours, followed by slow cooling in the furnace.

2.8.6.2 Solution treatment and quenching

Castings are heated at temperatures just below the melting temperature and held there for a long time to take the alloying constituents into a homogeneous solid solution. The castings are then rapidly cooled by quenching to room temperature to retain the elements in solution. Water or special quenchants are used. The quench tanks are placed close to the furnace to ensure that rapid cooling is possible. Although sensitivity to the quench interval differs between alloys, good practice should limit the interval to 5 – 10 s.

2.8.6.3 Precipitation treatment

The controlled precipitation of alloying constituents is promoted by heating the casting to a temperature of between 150 ºC and 200 ºC. The casting strength and hardness are increased. The process is therefore also referred to as structural hardening. Each alloy has an optimal heat treatment cycle.

2.8.6.4 Artificial ageing

Some casting alloys increase in strength and hardness while left standing at room temperature. The process can take several weeks but can be speeded up by heating above room temperature and then sustaining this heat over time.
[175, Brown, 1999], [202, TWG, 2002], [213, CTIF and CQRDA, 2002], [212, Zalensas, 1993]

2.9 Quality control

During quality control the finished casting is checked for compliance with the product requirements concerning e.g. dimensions, metal structure defects, surface structure. Depending on the type of casting and the size of the series, quality control can be achieved by visual inspection, with the use of measurement tools, or automatically.

In the production of aluminium wheels the castings are controlled via X-ray analysis. A standard image of a good casting is used for verification by a computer program. If there are any differences, the image is studied and assessed by a human operator. Random tests of the alloy are analysed with spectral analysis.

The quality control procedure informs the final decision to reject a casting or to allow its further shipment to the market. Rejected castings are brought back to the raw material input to be remelted.
[225, TWG, 2003]

3 CURRENT EMISSION AND CONSUMPTION LEVELS IN FOUNDRIES

3.1 Mass stream overview

3.1.1 Introduction

The general mass stream overview for the foundry process is given in Figure 3.1. This scheme generally applies for ferrous and non-ferrous foundries. Specific aspects of the various process steps and types will be worked out below.

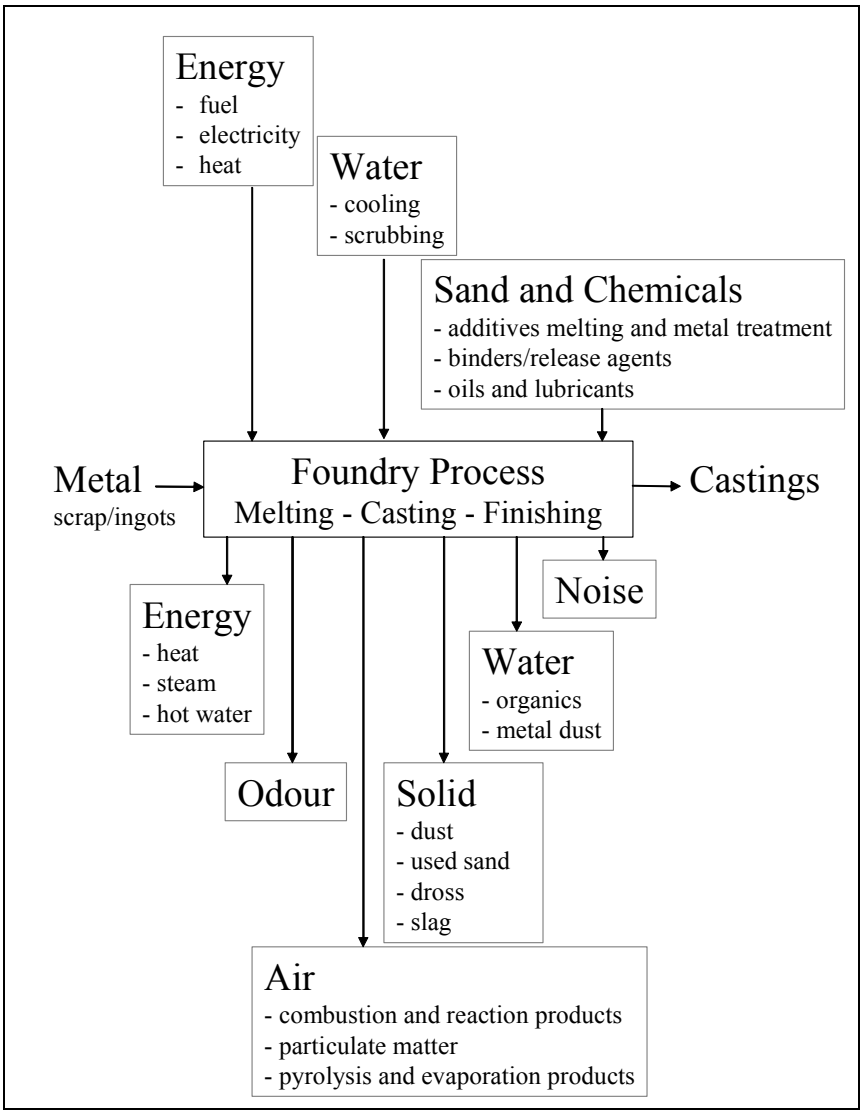


Figure 3.1: Mass stream overview for the foundry process

3.2 Melting and the metal treatment of ferrous metals

3.2.1 Properties of melting furnaces for steel and cast iron

Table 3.1 presents an overview of the typical properties of melting furnaces used for steel and cast iron. The data is then discussed in the sections below.

Process	Steel			Cast Iron					
Type	ELECTRIC ARC FURNACE		INDUCTION F.	INDUCTION F.	CUPOLA FURNACE				ROTARY F.
Subtype	Acid lined	Basic lined	Coreless	Coreless	Cold blast	Hot blast	Hot blast – long campaign	Cokeless - duplex	
Energy source	Electricity	Electricity	Electricity	Electricity	Coke	Coke	Coke	Gas/fuel	Gas/fuel
Thermal efficiency[1](%)	60 – 70	60 – 70	50 – 60	50 – 60	30 – 40	40 – 45	35 – 45	50 – 60	50 – 60
Primary thermal efficiency[2](%)	21 – 25	21 – 25	15 – 20	15 – 20	30 – 40	40 – 45	35 – 45	45 – 50	35 – 45[3]
kWh/tonne metal charge	500 – 700	500 – 700	520 – 800	520 – 800	950 – 1200	800 – 900	810 – 1100	700 – 800	600 – 800
Batch/continuous	Batch	Batch	Batch	Batch	Continuous	Continuous	Continuous	Continuous	Batch
Production rate[4] (tonnes/h)					2 - 10	8 - 70	8 - 70	>5	
Furnace capacity[5] (tonnes)	2 – 50	2 – 50	0.01 – 30	0.01 – 30					1 – 20
Meltdown time (h)	1 – 4	1 – 4	1 – 2	1 – 2					2 – 4
Refining ability	Possible	Possible	No	No	Yes	Yes	Yes	No	No
Capital cost	High	High	High	High	Medium	High	High	Medium	Low
Slag production (kg/tonne metal charge)	10 – 40	20 – 80	10 – 20		40 – 80	40 – 80		40 – 80	20 – 60
Dust production[6] (kg/tonne metal charge)	5 – 8		0.06 – 1		5 – 13	4 – 12		0.8	0.3 – 2.9
Waste gas[7] emission (kg/tonne metal charge)									
CO_2[8]	Depending on power generation		Depending on power generation		400 – 500	350 – 480		100 – 120	120
CO	7.5 – 25 (decarburisation)		n.a.		Possible[9]	0.5 – 2.5		<10	1.0 – 1.5
SO_2	<1		Minor		1 – 2	<1		Fuel dependent	2.5 – 3.0
NO_x	n.a.		n.a.		<1	<1		0.5	0.3 – 0.4

1 Indicated values give an order of magnitude but largely depend on exploitation conditions, such as metal temperature, furnace capacity and production rate
2 Efficiency of electrical power generation assumed to be 35 %
3 Taking into account energy consumption for oxygen production and the raw materials, such as graphite and FeSi, to substitute the oxidised elements during melting
4 For continuous processes only
5 For batch processes only
6 Indicated values are general values found in literature
7 Indicated values are general values found in literature
8 Assuming complete combustion
9 Depending on local exploitation conditions and construction.

Table 3.1: Typical melting furnace properties and emission data
[32, CAEF, 1997], [110, Vito, 2001], [202, TWG, 2002], [225, TWG, 2003] and comments from CTIF

3.2.2 Cupola furnaces

Input	Output
– ferrous material (iron pigs, sponge iron, steel scrap, foundry returns …)	– metal alloy (cast iron)
– alloying metal (ferro-alloys …)	– dust (metal content)
– flux (limestone…)	– CO/CO_2, SO_2, NO_x
– energy (coke, gas, oil, electricity)	– HF
– oxygen	– Dioxins, furans
– cooling water	– organic pollutants
– water	– slag
	– waste refractory

3.2.2.1 Coke and energy consumption

In cold blast operation, the coke consumption between the charges is generally 90 - 120 kg/tonne metal charge, but can be less than 70 kg/tonne metal charge, e.g. in the case of counterweights. Accounting for the amount of coke in the bed gives a total coke consumption of 110 – 140 kg/tonne metal charge. As the calorific value of European cokes is 8.5 kWh/kg, this corresponds to a calorific input of 950 – 1200 kWh/tonne metal charge.

The total coke ratio in a hot blast cupola is generally 110 – 145 kg/tonne metal charge. However, as the average steel percentage is 50 %, and the recarburisation consumes about 1.5 %, the real burned coke ratio is 95 – 130 kg/tonne metal charge, which is 810 to 1100 kWh/tonne metal charge. This corresponds to a thermal efficiency of 35 to 45 %.

Depending on the plant layout, the energy consumed by the fume treatment equipment and the holding furnace, as given in Table 3.2, must be added. German data indicate a specific electricity use for the flue-gas cleaning equipment of c. 20 kWh per tonne of good casting. [202, TWG, 2002]

Energy carrier type	Average consumption kWh/tonne metal charge
Gas for the combustion chamber	40
Electricity for the flue-gas cleaning equipment (fans, etc.)	40
Electricity for the holding furnace	60

Table 3.2: Average energy consumption for off-gas treatment and holding

3.2.2.2 Particulate matter

The emission range of particulate matter is very wide. Particulate emissions depend primarily on the cupola type used, as shown in Table 3.3:

Cupola type	Dust emission (kg/tonne metal charge)	Coke proportion (kg/tonne metal charge)
Cold blast	5 – 13	110 – 140
Hot blast	4 – 10	95 – 130
Liningless hot blast	5 – 12	115 – 135
Cokeless	0.8	0

Table 3.3: Dust emission levels (raw cupola off-gas) from various cupola types [32, CAEF, 1997]

Dust emission levels measured at the stack for three German furnaces are given in Table 3.4.

Flue-gas cleaning	Volume (m^3/h)	Total dust (mg/m^3)	PM_{10} (%)	$PM_{2.5}$ (%)
Above charge hole off-take; bag filter	28500	7	88	47
Cyclone, Venturi, recuperator	16000	68 – 94	96	88
n.d	6000 (Nm^3/h dry)	75	100	45 – 85

Table 3.4: Cupola dust emission levels and PM size distribution [202, TWG, 2002]

In general, particle sizes range from less than 1 µm up to 10 mm, with 50 % less than 100µm. However, 5 to 20 % are smaller than 2 µm, which makes the dust collection more difficult. Cupola dust is primarily made up of coke, silica, rust and limestone, as shown in Table 3.5.

Substance	Composition (%)	
	[32, CAEF, 1997]	[158, Charbonnier, et al., 1998]
Iron oxide	30 – 60	15 – 25
SiO_2	± 25	15 – 30
Coke dust	3 – 15	n.d
MnO	3 – 10	2 – 5
Al_2O_3	1 – 3	2 – 5
MgO	1 – 3	0 – 2
CaO	<1	5 – 10
S	<2	n.d
ZnO, depending on the charge	<3	0 – 30 Zn*
PbO, depending on the charge	<1	0 – 5 Pb*
* In the form of oxides and silicates; applicable for Zn-enriched dusts		

Table 3.5: Typical composition of cupola dust, data in weight per cent [32, CAEF, 1997] and [158, Charbonnier, et al., 1998]

3.2.2.3 Waste gases

Coke fired cupola gas is composed primarily of N_2, CO_2, H_2O, and CO, with smaller amounts of SO_2. On conventional cupolas, where the off-gas is collected above the charging door, a distinction has to be made between the condition of the flue-gases below and above the charging door, since ambient air is entrained through the open charge door. This input significantly changes the total airflow.

If the cupola gases are hot enough, and if there is enough CO present, the gases may burn spontaneously together with drawn-in air ($CO + O_2 \rightarrow 2CO_2$) and temperatures may rise to 900 ºC. Little or no CO will then be left in the exhaust. If no combustion takes place, the air intake will result in a cooling effect, of between 100 and 300 ºC, and the CO/CO_2 balance will remain unchanged. The temperature of the gases just below the charging door is primarily dependent on the charge height; the input of ambient air is determined by the fan capacity or the natural draught available.

The flow of the undiluted cupola top gases is proportional to the coke consumption. Increasing the coke proportion in the charge will decrease the production rate (tonne molten metal/h) if the same blast airflow is maintained. It may then be necessary to increase the blast to maintain the production. The metal temperature will also increase. With reference to the combustion rate ($C + O_2 \rightarrow CO_2$), more coke and blast air will result in an increased flow of exhaust gases.

For a given furnace, the coke and blast air consumption depend on the targeted melting rate and the metal temperature, which can vary on an hourly basis. Typical flowrates reported in

literature vary from 600 to 800 Nm^3/tonne metal charge for cold blast cupolas and 500 to 700 Nm^3/tonne metal charge for hot blast cupolas. The composition of the unburned top gases may be as follows (Table 3.6):

Substance	Volume %
CO_2	10 – 18
CO	5 – 15
H_2	<1
SO_2	<0.05
N_2	Remainder

Table 3.6: Unburned top gas composition for cupola furnace [32, CAEF, 1997]

Above the charging door, the flowrates of the exhaust gases may be two to five times higher, depending on the target temperature (which depends on the kind of dust arrestment system applied) of the diluted gases and, in the case of a recuperative hot blast cupola, the presence of a post combustion chamber. Typical flowrate values are 3000 to 4000 Nm^3/tonne metal charge melted for cold blast cupolas and 900 to 1400 Nm^3/tonne metal charge when post-combustion is performed. The composition of the gases is determined by the rate of dilution (natural draught or fan power), the degree of spontaneous combustion of the CO, or the post combustion itself, which can be executed on the complete or partial flow.[32, CAEF, 1997]

Emission data for the main combustion gas components are given in Table 3.7. Hot blast and cold blast cupolas with varying melting capacities are listed. The table also indicates whether the off-gas is collected under or above the charging door. The hot blast systems show reduced SO_2 emission levels. The disintegrator shows a better dedusting performance than the venturi scrubber. The application of post combustion clearly affects both the CO and NO_x levels, under optimal working conditions. Analysis of the full measurement campaign data shows that sub-optimal operation of a hot blast cupola results in increased CO-emissions: 2000 mg/Nm^3, compared to 5 – 20 mg/Nm^3 in optimised conditions. VOC and PAH emissions rise accordingly. [110, Vito, 2001]

The use of dry dedusting (i.e. using a bag filter) results in dust emission levels ≤20 mg/Nm^3. Inventory data from Italian foundries showed a dust level below 30 mg/Nm^3 (ranging from 0.1 to 32 mg/Nm^3) when a bag filter was applied. Wet scrubbing gives dust emissions up to 80 mg/Nm^3 (ranging from 5.4 to 78 mg/Nm^3) [180, Assofond, 2002]. A value of 68 – 94 mg/m^3 was reported for a German cupola with wet scrubbing (see Table 3.4).

Cupola type	Capa-city tonne/h	Exhaust type	Flow m³/h	FGC equipment	Dust mg/Nm³	SO_2 mg/Nm³	CO mg/Nm³	NO_x mg/Nm³	HF mg/Nm³	O_2 vol %
Hot blast[1)]	19	UC	29000	Venturi[1)]	41	21	17798	21	n.d	11
Hot blast	20	UC	40000	Disintegrator	5	57	712	11	n.d	11
Hot blast	24	UC	46445	Bag filter	1.1 – 1.4	20	14 – 17	70 – 75	7	11
Hot blast	25	UC	35000	Venturi	36	28	21	16	n.d	11
Hot blast	60	UC	75000	Disintegrator	5	58	9	7	n.d	11
Cold blast	3.2	AC	12000	Bag filter	10	401	5084	16	1	11
Cold blast	5	AC	23000	Bag filter	6	434	28558	63	n.d	11
Cold blast	8	AC	20000	Bag filter	20	401	936	36	n.d	11
Cold blast	9	UC	22000	Bag filter	4	105	17286	60	n.d	11

1) Working with an old recuperator
UC: Under charge gas collection; AC: above charge gas collection
All data are continuous monitored daily average values

Table 3.7: Emission data for hot blast and cold blast cupolas working with different set-ups [29, Batz, 1986], [202, TWG, 2002], data recalculated to 11 % O_2

3.2.2.4 Cupola slag

Slags contain oxides that float upon the melt and which arise from impurities in the feed material, wearing of the furnace refractory and from the ash of coke and from the melting loss of the metal charge [225, TWG, 2003]. Slags are bonded through the addition of binders, such as vermiculite. The typical composition of cupola slag is given in Table 3.8. A cupola furnace typically produces 40 – 80 kg slag per tonne of liquid iron.

Compound	%
SiO_2	45 – 55
CaO	25 – 40
Al_2O_3	8 – 20
MgO	1 – 3
MnO	1 – 4
FeO	1 – 6
Sulphides	<1
TiO_2	<1
ZnO	<0.1

Table 3.8: Typical cupola slag composition [172, Neumann, 1994], [156, Godinot, 2001]

Cupola slag consists of 30 % refractory material, 10 % sand (from internal scrap), 40 % CaO (flux), 10 % cokes ashes, and 10 % burn-off material.

An important aspect of cupola slag is its high SiO_2-content. After quenching, the slag has a vitrified structure. This generates an inert non-leaching material.

3.2.2.5 Waste refractory

The cupola furnace has the specific feature that the lining material (quartz-clay mixture) of the furnace at the melting zone only lasts for one melting campaign. The main part of the refractory is converted into slag. The amount to be taken out and disposed of as waste is much smaller than the applied amount.

3.2.3 Electric arc furnace

Input	Output
– ferrous material (steel scrap, foundry returns swarf, pig iron …)	– metal alloy (cast steel)
– alloying metal (ferro-alloys …)	– dust (metal content, refractory)
– flux (limestone …)	– NO_x, CO_2, CO
– energy (electricity, gas, oil)	– organic air pollutants, HC
– oxygen	– metal oxide fumes
– electrodes	– slag (CaO, SiO_2, MgO)
	– waste refractories

3.2.3.1 Input

500 – 600 kWh of electricity is used to melt and raise one tonne of steel to its casting temperature. Furnaces are normally rated at 500 kVA per tonne, giving a melting time of about 1.5 hours.

The electrodes are made of graphite and are consumed during operation through oxidation, volatilisation and breakage, so they must be replaced as necessary. A three tonne furnace typically uses electrodes of 200 mm diameter. Electrode consumption is a significant factor in the cost of arc melting and figures vary from 3 to 10 kg/tonne of steel melted depending on the type of steel produced and the practice used. [174, Brown, 2000]

3.2.3.2 Particulate matter

Particulate emission rates reported in literature vary from 2 to 20 kg per tonne of iron charged with an average of 5 to 8 kg per tonne. The highest emission rates are recorded at the beginning of the melting cycle, during the decarburisation treatment and during back charging [173, Huelsen, 1985]. Particle sizes range from less than 1 µm up to 100 µm, with 50 % being less than 3 to 5 µm. During oxygen treatment, one analysis showed almost 90 % of the particles were smaller than 5 µm.

In terms of the chemical composition of the particulate matter, an even bigger range of measured data can be observed. Table 3.9 gives an overview of the reported figures in the literature.

Substance	Weight per cent (%)
$FeO + Fe_2O_3$	30 – 60
SiO_2	5 – 35
CaO	1 – 15
MgO	0 – 15
ZnO	0 – 16
Cr_2O_3	0 – 8
MnO	2 – 10
Al_2O_3	0 – 5
MoO_3	<1
NiO	<1
Pb	<1
Cd	<0.01
TiO_2	<0.05
V_2O_5	<0.05
Ignition loss	0 – 4

Table 3.9: Chemical composition of EAF dust from steel foundries [32, CAEF, 1997]

The composition of the furnace dust primarily depends on the steel grade being produced. For instance, low alloy steels will not generate emissions containing chromium or nickel, whereas stainless steel will. Another important factor is scrap quality. Melting galvanised steel scrap leads to significant emissions of zinc oxide.

The application of an appropriate hooding of the furnace allows the capture of up to 98 % of the furnace dust. The captured exhaust gas is then cleaned, usually using a bag filter. This reduces dust emission levels to below 10 mg/Nm³.
[29, Batz, 1986]

3.2.3.3 Visible fumes

Visible fumes are emitted during charging of the hot furnace and at the beginning of the melting cycle. The available literature does not report the quantities and the composition of these secondary emissions. Again, the nature of the fumes depends on the cleanliness of the charged material with respect to its oil, grease, paint or other organic matter content.

3.2.3.4 Waste gases

Electric arc furnaces are mainly used for steel melting. They primarily generate dust emissions and gaseous compounds, such as nitrogen oxides, carbon monoxide and organic compounds. The organic compounds depend on the type and amount of impurities in the feed metal. The raw materials used as charge materials in the foundry are selected so that they don't usually contain materials that can produce dioxins. Organic compounds are decomposed into harmless products, so long as no scrap preheating without post-combustion is applied. [29, Batz, 1986]

Emission data for the main combustion gas components are given in Table 3.10. Inventory data from Italian foundries showed a dust level below 10 mg/Nm³ (ranging from 1.2 – 8.3 mg/Nm³) when a bag filter is applied. Wet scrubbing gives dust emissions below 25 mg/Nm³ (ranging from 12 – 24.5 mg/Nm³). [180, Assofond, 2002]

	Capacity tonne/ charge	**Off-gas** collection	**Flow** m³/h	**FGC** equipment	**Dust** mg/Nm³	**SO_2** mg/Nm³	**CO** mg/Nm³	**NO_x** mg/Nm³	**HF** mg/Nm³	**O_2** vol %
EAF	50	FH	265000	Bag filter	2	n.d	n.d	50	n.d	20
EAF	2 x 50	FH	380000	Bag filter	4	n.d	n.d	n.d	n.d	20
EAF	10	PH	160000	Bag filter	1	1	200	5	0.1	20
FH: Full hooding; PH: Partial hooding										

Table 3.10: Typical emission values for EAF furnaces
[29, Batz, 1986]

During melting and refining, CO is generated from the oxidation of the graphite electrodes and the carbon from the metal bath. Estimated quantities are 6 to 20 Nm^3 CO/tonne (or 7.5 to 25 kg CO/tonne) depending on the initial carbon content of the charged material and the required carbon level after treatment. The oxygen injection causes quantities of iron oxide (red smoke) to be emitted from the metal bath. No other significant emissions have been reported. [32, CAEF, 1997]

3.2.3.5 Slags

The chemical composition of EAF slags are given in Table 3.11. The reported values were based on the analyses of 3 samples.

Compound	Average (%)	Range (%)
SiO_2	36.2	28.6 – 41.8
CaO	12.4	7.2 – 17.7
MgO	22.1	18.3 – 27.0
Al_2O_3	8.4	7.4 – 0.1
FeO	0.7	0.5 – 1.0
MnO	14.8	4.0 – 29.6
TiO_2	1.2	0.39 – 2.7
Na_2O	0.3	0.11 – 0.57
K_2O	0.1	0.1 – 0.23

Table 3.11: Chemical composition of EAF slag
[171, The Castings Development Centre, 1999]

3.2.4 Induction furnace

Input	Output
– ferrous material (iron pigs, steel scrap, swarf, foundry returns …)	– metal alloy (cast iron, cast steel)
– alloying metal (ferro-alloys …)	– dust
– carburising agents, flux	– organic and metallic fumes
– energy (electric)	– CO
– cooling water	– slag
	– refractory waste

3.2.4.1 Coreless induction furnace

3.2.4.1.1 Energy input

A coreless induction furnace can melt a tonne of iron and raise the temperature of the liquid metal to 1450 ºC using under 600 kWh of electricity. However, in practice, only a few foundries can achieve this level of specific consumption on a week-by-week basis. The actual energy consumption varies according to the size and working regime of the furnace. Large furnaces, working 24 h a day and using a molten heel can achieve a 600 kWh/tonne value. Surveys of foundries show that consumptions of 520 – 800 kWh/tonne metal charge are common, the variation being due to individual melting practice, such as the rate at which the pouring line will accept the molten metal and whether furnace lids are used effectively. Attention to energy saving measures should allow figures of 550 – 650 kWh/tonne metal charge to be achieved. The typical heat losses from a coreless induction furnace are shown in Figure 3.2.
[47, ETSU, 1992], [174, Brown, 2000], [202, TWG, 2002]

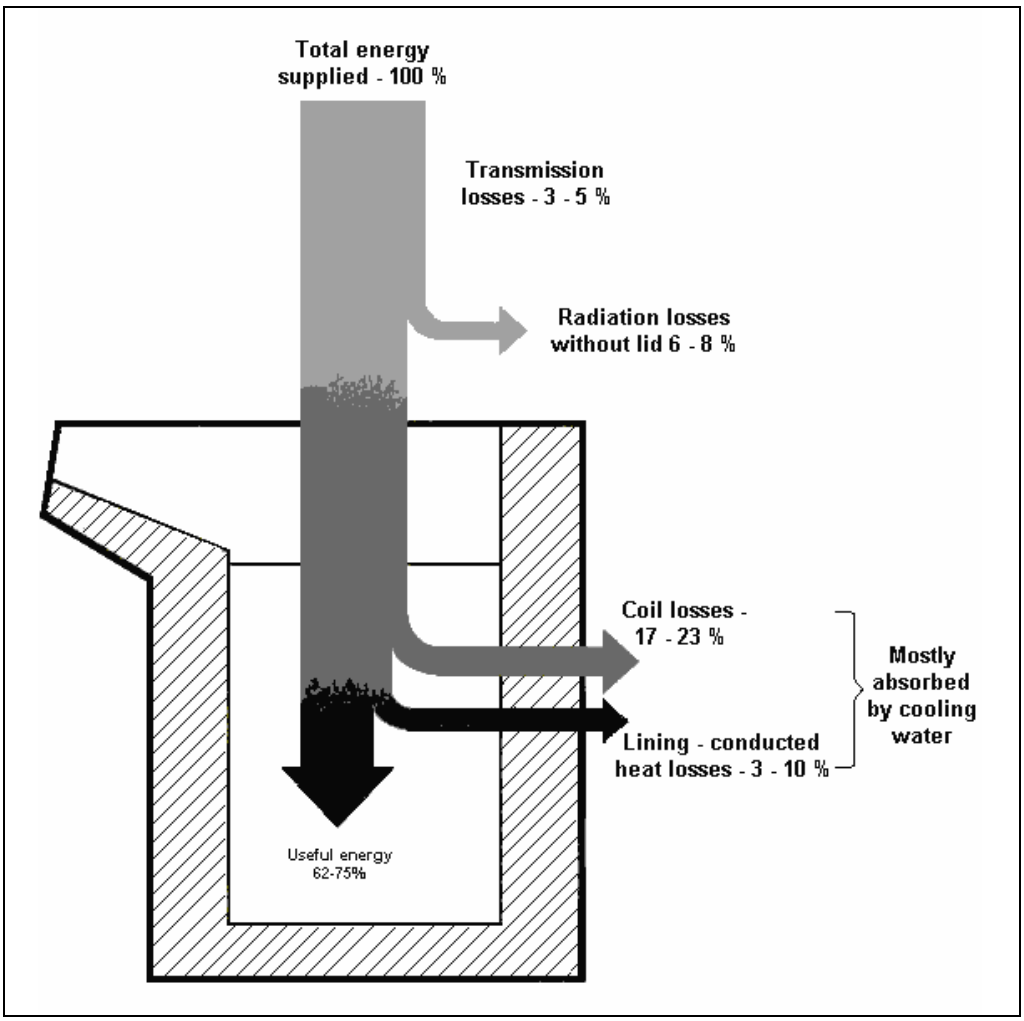


Figure 3.2: Typical energy losses from a mains frequency coreless induction furnace [47, ETSU, 1992]

3.2.4.1.2 Particulate matter

Emission rates of 0.06 to 1 kg/tonne metal charge have been reported in literature, but at present, emission rates of 0.04 to 3 kg/tonne are normal. The highest emission rates occur during charging and at the beginning of the melting cycle. Particle sizes range from 1 – 100 µm, with more than 50 % being smaller than 10 – 20 µm. [32, CAEF, 1997], [202, TWG, 2002]

Dust emission levels and PM distribution from a German IF foundry are given in Table 3.12.

Flue-gas cleaning	Volume (m^3/h)	Total dust (mg/m^3)	PM_{10} (%)	$PM_{2.5}$ (%)
Hood and bag filter	10400	c. 0.4	78	50

Table 3.12: IF dust emission level and PM size distribution [202, TWG, 2002]

As for the chemical composition of the particulate matter, there is no published data regarding the melting of steel, but there is reason to believe that it is close to that of the composition of the dust emitted during the melting of cast iron as shown in Table 3.13. The presence of Zn, Pb or Cd will lead to metallic fumes during the meltdown of the charge.

Substance	Weight per cent (%)
$FeO + Fe_2O_3$	30 – 70
SiO_2 (depending on the lining material)	5 – 25
MnO	<5
Al_2O_3 (depending on the lining material)	3 – 10
CaO	<1
ZnO (depending on the charge material)	<5
Metallic oxides (depending on the charge material)	<0.1
Loss on ignition	0 – 10

Table 3.13: Chemical composition of induction furnace dust in cast iron foundries [32, CAEF, 1997]

3.2.4.1.3 Waste gases

The melting of iron and steel in induction furnaces results in low emissions compared to the cupola furnace. Emissions due to the combustion of fossil fuel are especially prevented. An exhaust capture efficiency of up to 95 % is possible using special capture systems, such as side-draughts, movable hoods and partial covering of the furnace. Filtration of the off-gases is mainly performed using dry systems. Dust emission levels below 5 mg/Nm³ can be obtained [225, TWG, 2003]. Typical emission data are given in Table 3.14.

	Capacity No of furnaces x tonne/charge	Off-gas collection	Flow m³/h	FGC equipment	Dust mg/m³	SO_2 mg/m³	CO mg/m³	NO_x mg/m³	HF mg/m³	O_2 vol %
IF	(2 x 10) + (3 x 3)	Side-draught	54000	Bag filter	5	n.d	n.d	n.d	n.d	21

Table 3.14: Typical emission data for induction furnace melting in a ferrous foundry [29, Batz, 1986]

Charging oily scrap or borings in a cold furnace will lead to the presence of organic vapours in the exhaust gases, which will not be burned since they are created at the beginning of the melting cycle. Adding this kind of scrap to a molten bath (i.e. the molten heel practice) can be very dangerous since small explosions in the metal bath may occur, which can then lead to splashing metal drops and sparks out of the furnace.

Since the scope of the work is limited to the foundry boundaries, no emission data for the generation of electrical energy have been taken into account.

3.2.4.1.4 Slags

The typical properties of induction furnace slags are given in Table 3.15. Induction furnaces produce 10 – 20 kg slag per tonne metal charge. The amount of slag produced depends on the quality of charge material. The lower limit of the given range applies if internal scrap is cleaned (blasted) before re-melting.

Compound	%
SiO_2	40 – 70
FeO	10 – 30
Al_2O_3	2 – 15
MnO	2 – 10
CaO	0 – 3
MgO	0 – 3

Table 3.15: Typical composition of induction furnace slag
[172, Neumann, 1994]

3.2.4.2 Channel induction furnace

In ferrous metal foundries, the channel induction furnace is mainly used as a holding furnace. It is the furnace of choice for duplex operation with the hot blast cupola. In this case, its function is either to hold or to homogenise the chemical composition of the metal, or to serve as a reservoir of the melted metal for the casting. The furnace's role is not to increase the metal temperature, but rather to prevent unwanted cooling.

Figure 3.3 presents the energy consumptions of some representative channel induction furnaces. The consumption depends on process related parameters, such as the holding time. The graph shows that the consumption decreases with increasing annual tonnage. The extreme values are 80 and 20 kWh per tonne transferred.

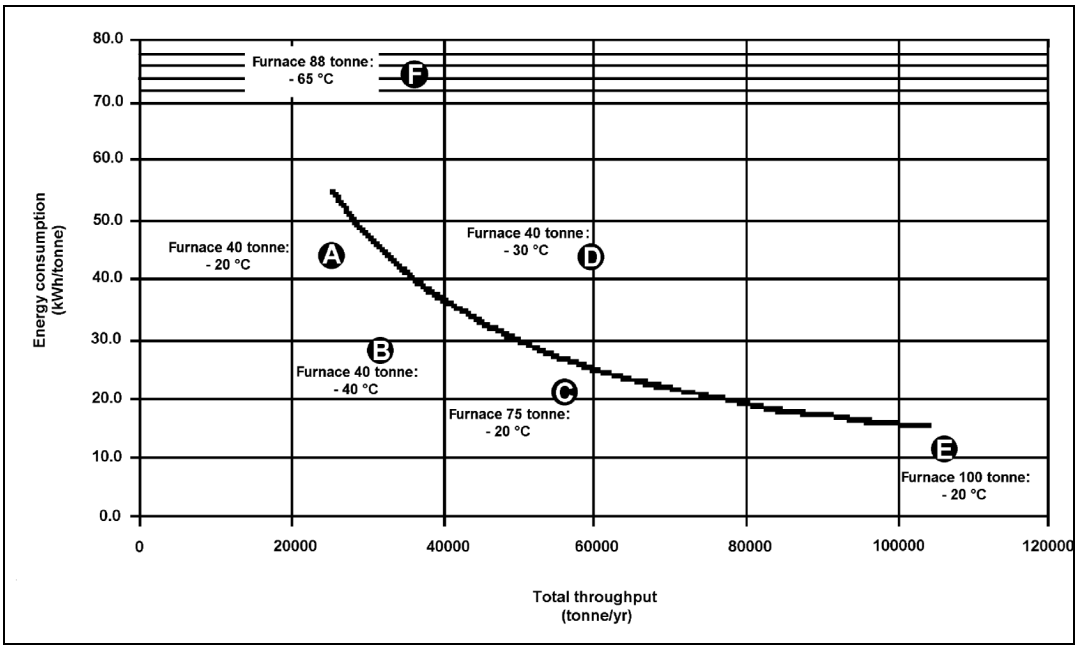


Figure 3.3: Energy consumption (kWh/tonne) as a function of transferred tonnage and loss of temperature for channel induction furnaces
[140, EU Thematic Network Foundry Wastes, 2001]

3.2.5 Rotary furnace

Input	Output
– ferrous material (iron pigs, steel scrap, swarf, foundry returns …)	– metal alloy (cast iron)
– alloying metal (ferro-alloys …)	– dust
– carburising agents, flux	– organic and metallic fumes
– energy (electric, oil, gas)	– slag
– cooling water	– refractory waste

3.2.5.1 Input

As is the case with electric melting, the energy source used in the rotary furnace allows a clean process, especially if natural gas or propane is used. The degree of contamination of the charged scrap is again very important to the nature and the quantities of the emissions that arise. This fact explains why no uniform emission pattern exists, and why the measurement data show wide variations.

3.2.5.2 Particulate Matter

Particulate matter originates from dirt adhering to the charged material, lining wear during charging and melting, and from the burn out of alloying elements and the different additions to the charge. The reported data show overall emission rates of 0.3 to 2.9 kg/tonne metal charge. The grain size is relatively small, from less than 1 µm to 100 µm, with 20 % <1µm, 60 % less than 10 µm and 95 % smaller than 50 µm. [32, CAEF, 1997], [204, Carnicer Alfonso, 2001]

The chemical composition of rotary furnace dust is given in Table 3.16.

Compound	%
Iron oxides	50 – 75
MnO	<1
SiO_2	<1
MgO	1 - 2
Cr_2O_3	<0.5
ZnO	<1
Pb	<0.5
Sn	0.2
Loss on ignition	5 – 10

Table 3.16: Chemical composition of rotary furnace dust in ferrous melting [204, Carnicer Alfonso, 2001]

3.2.5.3 Waste gases

CO_2 production is estimated to be 120 kg/tonne metal charge. The thermal efficiency of the furnace is very high at 50 to 65 % [4], depending on the capacity. This high yield is achieved by using pure oxygen instead of air as a combustion medium. During the reducing flame conditions the combustion of the fuel or gas may be incomplete. CO may be produced under these conditions. However, at this point the exhaust gases leave the furnace at a temperature of 1500 ºC and CO burns spontaneously when in contact with the ambient air, which is used to cool the gases.
If sulphur bearing fuel is used, SO_2 emissions can be significant. However, natural gas or propane does not show any significant SO_2 emission.

NO_x emissions of 50 to 250 ppm in the off-gases have been measured in a 5 tonne furnace. The NO_x originates from the oxidation of atmospheric nitrogen at high flame temperatures (2800 ºC) if ambient air is leaking into the furnace through the burner door. The production of NO_x is significant during the oxidising flame regime but only low during the reducing regime. No reports have been made concerning carbonaceous emissions, probably due to the high flame temperature in the furnace and the relatively high cleanliness of the charged material. [32, CAEF, 1997]

[4] This is if the energy for oxygen production is not taken into account. With oxygen production, the efficiency should be 10 to 15 % less. Furthermore if the energy for the replacement of the burnt out charge elements (C, Si) is discounted the resulting primary efficiency is only about 30 to 35 %.

For ferrous rotary furnaces operating with simple air/fuel burners and an afterburner, dust emissions peak at about 250 mg/m^3 for short periods (between 3 seconds continuously but also intermittently over a period of a minute) during the solid phases of the melt cycle. Thereafter, once the charge starts to become liquid, the dust emissions reduce to less than 30 mg/m^3 during normal running. Emissions may remain as high as 150 – 200 mg/m^3 continually during the solid phase of the melt. 40 % combustible emissions are common. Peak emissions from rotary furnaces consist of at least 80 % unburned fuel and occur during charging operations when the main furnace burner is extinguished and then re-lit. The mentioned emissions only apply if at all times, including during charging, the fumes are ducted via the afterburner, which is kept fully operational [163, UK Environment Agency, 2002]. The following raw gas dust levels have been reported for an oxygas rotary furnace without an afterburner: an average dust load of 400 – 450 mg/Nm³ over the two distinct melting phases. These phases are a solid phase with dust emission levels of 150 mg/Nm³, and a liquid metal phase with peak levels up to 1500 mg/Nm³ at the start of the rotation and 600 – 700 mg/Nm³ during normal operation. [204, Carnicer Alfonso, 2001]

Typical emission data are given in Table 3.17. These were collected from a 1.4 tonne/h cast iron melting furnace, without any flue-gas cleaning equipment. Inventory data from Italian foundries showed a dust level below 15 mg/Nm³ (ranging from 0.6 – 14.6 mg/Nm³) if a bag filter is applied [180, Assofond, 2002].

Parameter	Measured value	Parameter	Measured value
Gas flow (Nm³/h)	9000	Chlorine (mg/Nm³)	0.01
Capacity (tonnes/h)	1.4	Dioxins (ngTEQ/Nm³)	0.018
SO_2 (mg/Nm³)	70 ± 60	PAHs (ng/Nm³)	
NOx (mg/Nm³)	200 ± 200	Naphthalene	548
CO (mg/Nm³)	20 ± 10	Phenanthrene	269
Hydrocarbons (mg/Nm³)	<1	Anthracene	9
HCl (mg/Nm³)	1.64	Fluoranthene	102
HF (mg/Nm³)	0.91	Pyrene	55
Dust (mg/Nm³)	220	Benzo(a)anthracene	10
Mercury (mg/Nm³)	0.35	Chrysene	73
Cadmium (mg/Nm³)	0.001	Benzo(a)fluoranthene	3
Thallium (mg/Nm³)	<0.0015	Benzo(b)+(k)fluoranthene	39
Arsenic (mg/Nm³)	0.0002	Benzo(a)pyrene	12
Nickel (mg/Nm³)	0.015	Benzo(e)pyrene	20
Cobalt (mg/Nm³)	0.0001	Indeno(1,2,3-cd)pyrene	10
Lead (mg/Nm³)	0.38	Dibenzo(a,h)+(a,c)anthracene	3
Chromium (mg/Nm³)	0.022	Benzo(g,h,i)perylene	11
Copper (mg/Nm³)	0.196	Perylene	4
Manganese (mg/Nm³)	0.38	Anthanthrene	3
Antimony (mg/Nm³)	<0.0001		
Vanadium (mg/Nm³)	0.011		
Tin (mg/Nm³)	0.0187		
Selenium (mg/Nm³)	<0.0001		
Platinum (mg/Nm³)	<0.0006		
Palladium (mg/Nm³)	<0.0029		
Rhodium (mg/Nm³)	<0.0016		
Zinc (mg/Nm³)	1.768		
Iron (mg/Nm³)	64.63		
- Data for installation without flue-gas cleaning - Average values for 3 measurements, when the standard deviation is >30 % the value is given			

Table 3.17: Measured emissions for rotary furnace, melting cast iron, without flue-gas cleaning equipment
[110, Vito, 2001]

3.2.6 Argon Oxygen Decarburisation (AOD) converter

Input	Output
- molten steel	- decarburised steel
- alloying metals (ferro-alloys)	- metal oxide dust and fumes (Fe,Mn,Cr,Ni)
- Al, FeSi, lime	- gases (CO_2, CO, inert gases)
- O_2, N_2, Ar	- slag (CaO,SiO_2, AlO_3)

3.2.6.1 Input

The AOD converter is used mainly in the production of low carbon stainless steels and, in special cases, carbon and low alloy steels: to remove impurities such as carbon, sulphur and oxides and also to decarburise high chromium stainless steels. The processed material is liquid steel that has been melted in EAF furnaces or in induction furnaces and afterwards poured off into the vessel through ladles. The technique is most common in the steel industry, but it is also applied in foundries, although to only a limited extent. For decarburisation, oxygen is injected in the converter and oxidises carbon into CO gas, which escapes from the liquid metal. No energy source is used except for the energy from the combustion reaction between oxygen and carbon during oxidation and, afterwards, between oxygen and aluminium (and/or silicon) during reduction.

The consumption of carbon ranges from 0.4 to 1 %, being about 50 – 120 m³ of CO per tonne of steel and 25 – 60 m³ oxygen. To eliminate sulphur it is necessary to use a high basicity slag in a completely reduced liquid steel. Reduction materials, such as aluminium or silicon and lime are charged in the AOD converter. The consumption levels depend on the quality of the steel grade and are given in Table 3.18.

Compound	Consumption (per tonne of steel)
CO	50 – 120 m³
O_2	25 – 60 m³
Al	1 – 2.5 kg
Lime	10 – 20 kg
Si	1 – 2 kg
Ar	1 – 5 m³

Table 3.18: Consumption levels for the AOD treatment of steel [202, TWG, 2002]

3.2.6.2 Output

Dust emissions are comparable to EAF furnaces' dusts, both in quantity and quality. AOD dust emissions have lower levels of residuals (organic) from the scrap charge, but on the other hand have a higher level of metal oxide (Cr, Ni), as it is mainly stainless steel which is processed in AOD vessels.

3.2.6.3 Waste gases

The effluent from the mouth of an AOD consists of carbon monoxide and inert gas. The rate of carbon monoxide evolution depends on the tuyères oxygen injection rate and the oxygen efficiency, or per cent of oxygen which reacts with carbon. This oxygen efficiency, or "carbon removal efficiency", as it is traditionally labelled in AOD operation, varies during the course of an AOD blow, in response to combined variables of the bath carbon level, temperature, bath chemistry, and the mixture of injected gases.

The CO and inert gas mixture leaves the vessel approximately at the bath temperature. The CO mixture exiting the vessel is mixed with excess air in order to fully burn the CO to CO_2 very early in the exhaust duct. This is done to prevent the presence of combustible or explosive mixtures persisting downstream into the duct to the filter equipment.

3.2.6.4 Slags

Slag is particularly "clean" from metal oxides, since, due to the peculiarity of the process, they are usually consumed. The slag composition is given in Table 3.19.

Compound	%
CaO	50 – 70
Al_2O_3	5 – 25
SiO_2	10 – 25
MgO	5 – 15

Table 3.19: AOD slag composition
[202, TWG, 2002]

3.2.7 Vacuum Oxygen Decarburisation Converter (VODC)

The VODC process involves decarburisation under reduced pressure. It is much less used than the AOD process. Vacuum processes (EAF/vacuum) accounted for 5.8 % of the Western World's stainless steel production in 1991. The technique consumes 1 Nm^3 Ar per tonne of steel, shows low chromium oxidation and has a silicon consumption of 3 – 5 kg/tonne. The VODC allows the production of ultra-low-carbon and nitrogen grades. [202, TWG, 2002]

3.2.8 Steel refining and treatment

For deoxidation, aluminium is commonly used in the form of a stick. Additions vary from 0.1 % for medium carbon steel to 0.2 % for low carbon steel. Recovery is between 35 % and 80 %. Mechanical feeding of aluminium wire is also used. [174, Brown, 2000].

3.2.9 Cast iron treatment

3.2.9.1 Nodularisation

The efficiency, the qualitative assessment of flue-gas production and the complexity of the various nodularisation methods are compared in Table 3.20.

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

Table 3.20: Comparison of various nodularisation procedures
[110, Vito, 2001], [225, TWG, 2003]

3.3 Melting and the metal treatment of aluminium

3.3.1 Survey of melting furnaces for aluminium

Table 3.21 shows typical furnace properties, consumption and emission data for various types of aluminium melting furnaces. Due to the wide range of furnace capacities and set-ups, the literature data does not always provide consistent consumption ranges. Consumption levels are highly dependent on the furnace capacity and exploitation conditions, such as metal temperature and charge density.

The use of a pure starting material and mainly electric and gas-fired heating, results in relatively low emission levels from the melting. Due to the limited concern about off-gas quality, information on the flue-gas composition is limited.

In an aluminium melting operation there is no generation of metal fume and the metal is only lost when dross forms. This type of loss is often calle the loss by burning and is an oxidation of the molten metal. It depends on the amount of covering slag and whether combustion occurs. It is brought about by a leakage of air into the furnace or by the malfunction of the burner. The costs for this loss can be high, sometimes even being higher than the energy costs. [148, Eurofine, 2002]

Data for each of the specific furnace types will be discussed and detailed in the subsequent sections.

	Units	Rotary furnace	Hearth type furnace	Shaft furnace	Crucible furnace		
Subtype			One chamber		Fuel heated	Resistance heated	Induction
Energy sources		Fuels (liquid, gaseous)	Fuels (liquid, gaseous)	Fuels (liquid, gaseous)	Fuels (liquid, gaseous)	Electricity	Electricity
Thermal efficiency[1]	%	15 – 40	<30 – 57	35 – 60	15 – 40	65	65 – 70
Primary thermal efficiency[2]	%	15 – 40	<30 – 57	35 – 60	15 – 40	22	22 – 25
Spec. Energy demand[3]	kWh/t Al[4]	600 – 1250	975 – 1150	580 – 900 *610 – 720*	900 – 1200 *610 – 680*	750 *470 – 590*	475 – 640 *440 – 470*
Batch/continuous		Batch	Batch	Continuous	Batch	Batch	Batch
Melting capacity	t	3 – 10	0.5 – 30	0.5 – 4 (-15)	0.1 – 1.2	0.1 – 0.4	0.2 – 25
Holding capacity	t	n.a	n.a	1.5 – 10	0.1 – 1.5	0.1 – 1.5	0.15 – 6
Meltdown time		2 – 4	3 – 4	0.5 – 1	0.5 – 1	4 – 5	0.2 – 0.5
Refining ability		Low	Low	Low	Good	Very good	Low
Loss by burning	%	n.d	n.d	1 – 3	1 – 2	1 – 2	1 – 2
Dust generation	kg/t Al[4]	n.d	<1	<1	<1	Minor	Minor
NO_x [5]	kg/t Al[4]	n.d	<1 – 6	<1 – 6	<1 – 6	n.a	n.a
Investment costs[6]	EUR '000	n.d	n.d	190 – 370	20 – 50	12 – 100	190 – 500
Running costs	EUR '000	n.d	n.d	20 – 100	3 – 20	15 – 45	35 – 150
Abatement techniques		Bag house filter for bigger installations	Bag house filter for bigger installations	Bag house filter for bigger installations	Typically not necessary due to small furnace size	Not necessary	Not necessary

[1] Definition: the relationship between the heat of the molten bath and the fuel heat supplied; indicated values give an order of magnitude but largely depend on the exploitation conditions, such as the metal temperature
[2] Efficiency of electrical power generation (fuels) assumed to be 35 %
[3] Depends on heat recovery measures; only valid for melting; values given by [148, Eurofine, 2002] *in italics*
[4] Units 'per tonne Al' refer to tonne of molten aluminium alloy
[5] Depends on burner design and operational performance
[6] Depends on heat recovery measures; only valid for melting
Sources of information: VDG internal survey; Aluminium Taschenbuch, Band 2, 15. Auflage, Aluminium Verlag GmbH, Düsseldorf, 1996; Aluminium recycling, Aluminium Verlag GmbH, Düsseldorf, 2000; [148, Eurofine, 2002]; comments CTIF

Table 3.21: Typical furnace properties and emission data for aluminium melting [148, Eurofine, 2002] and comments from CTIF and VDG

3.3.2 Shaft furnace

Input	Output
– aluminium ingots, foundry returns	– molten aluminium
– energy	– dust
– deoxidation and gas removal products	– NO_x, CO
	– used refractory

Emission factors have been provided for emissions per tonne of good casting, based on the following assumptions:

- average molten metal yield: 70 % (casting/molten metal)
- average scrap value: 5 % (scrap from finishing/casting)
- global metal yield: 0.7 x 0.95 = 66.5 % (good casting/molten metal)

Consumption and emission data per tonne of good casting for a 3 t/h shaft furnace, melting aluminium are given in Table 3.22. This also gives the flue-gas emission levels of the raw off-gas without cleaning.

Input	**Value per tonne**	**Value per Nm³**
Aluminium ingots	1503 kg/t	
Natural gas	717 kWh/t	
Electric energy	172 kWh/t	
Total energy use	889 kWh/t	
Output		
Slag (with 35 – 40 % Al)	40.3 kg/t	
Used refractories	0.3 kg/t	
Emissions (without flue-gas cleaning)		
Particles	0.12 kg/t	112 mg/Nm³
NO_x	0.18 kg/t	113 mg/Nm³
VOC	0.12 kg/t	
SO_2	0.04 kg/t	
CO		150 mg/Nm³
Pb + Cr + Cu		0.98 mg/Nm³
Cd + Hg		0.01 mg/Nm³
As + Ni		0.03 mg/Nm³
Data are calculated values per tonne of good casting		

Table 3.22: Input and output for aluminium melting in a shaft furnace [177, Silva Ribeiro, 2002]

Table 3.23 gives the consumption levels for a two tonne melting capacity shaft furnace melting aluminium.

	Total measured consumption	**Specific consumption per tonne of charged metal**
Metal charges	115332 kg (54 % ingot, 46 % scrap)	1 tonne
Metal tapped	113983 kg	0.988 kg/tonne
Metal loss	1349 kg	0.012 kg/tonne – 1.2 %
Dross removed	1412 kg	0.012 kg/tonne – 1.2 %
Gas consumption	92786 kWh	804 kWh/tonne

Table 3.23: Results from a 6-day trial melt in a 2 tonne melting capacity shaft furnace for Al [48, ETSU, 1994]

3.3.3 Induction furnace

Input	Output
– aluminium ingots, foundry returns	– molten aluminium
– electrical energy	– dust
– cooling water	– used refractory

Aluminium induction furnaces usually range from 500 kg to 2 tonnes capacity and operate at frequencies of 250 – 1000 Hz.

For example, in one installation, two 1.5 tonne aluminium capacity steel shell tilters are powered by a 1250 kW, 250 Hz power supply with a change-over switch which allows alternate furnaces to be melted. With this system 1.5 tonnes can be melted in 40 minutes.

Induction furnaces are energy efficient melters. The energy consumption for melting is affected by the density of the charge and the melting practice used. Batch melting is less efficient than using a molten heel. A 50 % molten heel is the most efficient. The energy consumption varies from 540 kWh/tonne for a high bulk density charge (small scrap and ingot) to 600 kWh/tonne if a lower density scrap (such as pressure die-casting runners and ingot) is melted. While the energy consumption is low, the costs for melting may be higher than for gas-fired furnaces because of the generally higher cost of electricity as a source of heat. [175, Brown, 1999] [148, Eurofine, 2002]

The induction furnace coil needs a cooling system. Cooling water may run in a closed circuit or in an open evaporative system.

3.3.4 Radiant roof furnace (resistance heated)

These resistant heated furnaces are holding furnaces, mainly used for aluminium alloys. The emission depends on the used metal, the holding-temperature, the surface area and the "metal out" and "metal in" and especially of the holding-time. The emissions are so low that no measurements are available. [202, TWG, 2002]

3.3.5 Hearth type furnace

Hearth type (or reverberatory) furnaces exist in various sizes and shapes. Large hearth type furnaces allow rapid melting and can handle bulky charge material, but the direct contact between the flame and charge material may lead to high metal losses, gas pick-up and to considerable oxide contamination. Temperature control can also be difficult. This type of furnace is used less because of its relatively low thermal efficiency (around 1100 kWh/tonne). The hearth type furnace is also used for copper alloy melting (see Section 3.5.1). [175, Brown, 1999]

Table 3.24 gives the emission data for a 450 kg/h oil-fired hearth type furnace melting aluminium, and working without a flue-gas treatment system.

Compound	Emission level (mg/Nm³)	Mass flow (g/h)	Yearly mass flow (tonne/yr)
O_2	17.6 %		
CO_2	2.2 %		
CO	<4	<24	<0.0438
NO_x	45	270	0.4928
SO_2	13	78	0.1424
dust	1	6	0.011
TOC	5	30	0.0548
Al	0.092	0.552	0.001
Flue-gas flow: 6000 Nm³/h (dry); operational hours: 1825 h/yr			

Table 3.24: Emission data for an oil-fired hearth type furnace melting Al [183, Goovaerts, 2002]

3.3.6 Crucible furnace (fuel and resistance heated)

Input	Output
– aluminium ingots, foundry returns or liquid aluminium if used as a holding furnace – electrical energy or fuel	– molten aluminium – dust

Crucible furnaces are indirectly heated using fuel-fired burners or electrical resistors. For fuel-fired crucibles, the thermal efficiency is not as high as for other melting furnaces, since it is difficult to make use of the heat of the combustion products. They are relatively inexpensive and since the flames are not in contact with the molten metal, metal losses are low and the melt quality is high, and also alloy changes can be readily carried out. [175, Brown, 1999]

For aluminium alloys the amount of particles can roughly be assumed to be around 0.3 kg/tonne of molten metal. [126, Teknologisk, 2000]

Consumption and emission data per tonne of good casting for a 3 t/h crucible furnace, melting aluminium are given in Table 3.25.

Input	
Natural gas	538 kWh/tonne
Electricity	414 kWh/tonne
Total energy input	952 kWh/tonne
Output	
Slag	61 kg/tonne
Refractories	6.87 kg/tonne
Emissions (after bag house)	
NO_x	0.18 kg/tonne
SO_2	0.04 kg/tonne
VOC	0.12 kg/tonne
Dust	0.12 kg/tonne
All data are calculated values per tonne of good casting	

Table 3.25: Consumption and emission data for the crucible melting of aluminium [177, Silva Ribeiro, 2002]

3.3.7 Aluminium melt treatment

For the combination of degassing and cleaning in an impeller station, a mixture of argon or nitrogen with 3 % Cl_2 is generally used. For degassing alone, the gases Ar or N_2 are generally used without Cl_2. The applied flow and degassing time depend on the type of alloy used and the size of the treatment vessel.

The consumption of modification agents, grain refiners and fluxes depends on the type of alloy, but is generally in the order of 100 g – 1 kg per 50 kg of molten metal.

3.4 Melting and casting of magnesium and magnesium alloys

3.4.1 Magnesium melt protection

SF_6 and SO_2 are used as a covering gas to prevent the oxidation (or burning) of molten magnesium. Since SF_6 is more easy to handle than the toxic SO_2, it became the preferred cover gas after its introduction in the mid 1970s. SF_6 has a global warming potential (GWP) of 22200 (for a 100 years time horizon) and an atmospheric lifetime of 3200 years [194, UNEP IPCC, 2002].

The quantities of SF_6 used in various operating conditions are given in Table 3.26 (pressure die-casting) and Table 3.27 (gravity die-casting). These concentrations need to be maintained close to the melt surface [191, IMA, et al.]. The tabled values are the recommended practice for the use of SF_6 from the International Magnesium Association (IMA). In practice, higher concentrations are sometimes used (e.g. 99.4 % CO_2, 0.6 % SF_6) [202, TWG, 2002].

Melt temp. (°C)	Atmosphere over the melt (vol %)	Surface agitation	Residual flux[1)]	Melt protection
650 – 705	Air/0.04 SF_6[2)]	No	No	Excellent
650 – 705	Air/0.2 SF_6	Yes	No	Excellent
650 – 705	75 air/25 CO_2/0.2 SF_6	Yes	Yes	Excellent
705 – 760	50 air/50 CO_2/0.3 SF_6	Yes	No	Excellent
705 – 760	50 air/50 CO_2/0.3 SF_6	Yes	Yes	Very good
1) May be present from prior operations 2) Minimum concentration under controlled conditions Note: Dry air (<0.1 % H_2O) should be used in the mixing				

Table 3.26: The use of SF_6 in pressure die-casting operations under various operating conditions [191, IMA, et al.]

	Quiescent (melting/holding) low gas flowrate		Agitated (alloying/pouring) high gas flowrate	
Crucible diameter (cm)	SF_6 (ml/min)	CO_2 (l/min)	SF_6 (ml/min)	CO_2 (l/min)
30	60	3.5	200	10
50	60	3.5	550	30
75	90	5	900	50
Note: The suggested flowrates are 1.7 % – 2 % SF_6 by volume				

Table 3.27: Use of SF_6 in gravity die-casting operations [191, IMA, et al.]

To date the only flux-free alternative to SF_6 is SO_2. In an undisturbed melt, the use would be typically 1 - 2 % in air or nitrogen at a flowrate of 5 to 10 l/min. [182, Closset, 2002], [218, Harnisch and Schwarz, 2003]

In 2001, the overall EU production of magnesium parts totalled 39100 tonnes, 37 % of which were produced with SO_2 and 63 %, or 24500 tonnes, with SF_6 (see Figure 3.4). This issue is discussed further in Section 4.2.7.1.

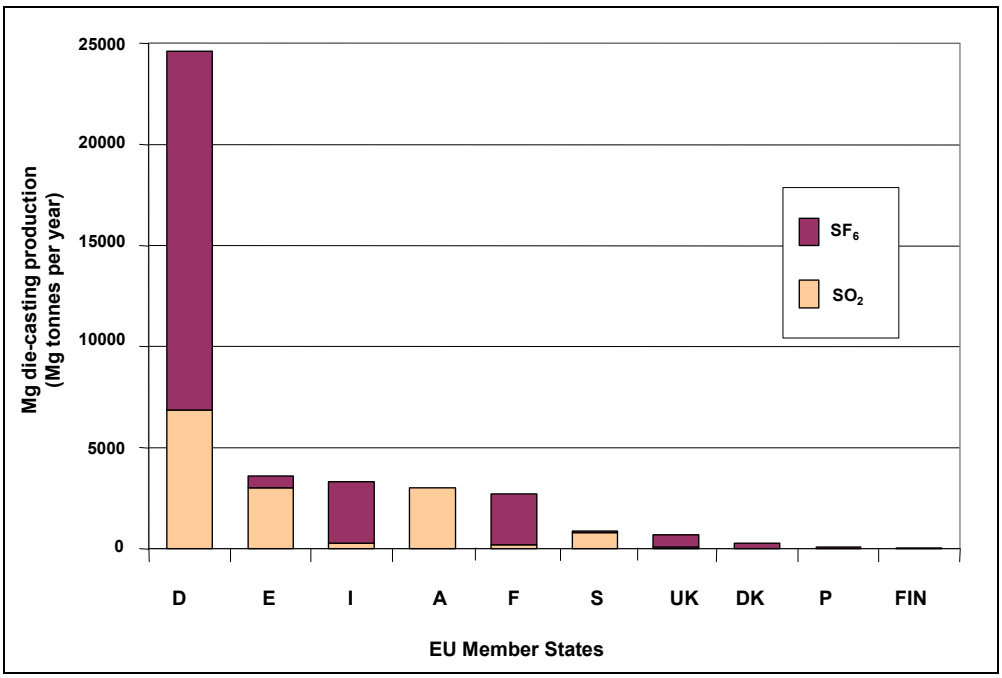


Figure 3.4: Mg die-casting production in tonnes/yr by EU states and by cover gas (SO_2 or SF_6) (data 2001)
[218, Harnisch and Schwarz, 2003]

3.4.2 Magnesium melt treatment

Magnesium alloys containing aluminium are treated with hexachloroethane (HCE) for grain refinement. This treatment applies for alloys for sand and gravity die-casting, which makes up some 10 % of the total magnesium alloys. The required amount of HCE depends on the type of component to be manufactured and existing data based on the experience of the individual foundries. An approximate value of 2 kg of HCE per tonne of aluminium containing magnesium alloy has been reported. [178, Wenk, 1995]

3.4.3 Magnesium scrap

In a Mg die-casting foundry, the amount of return materials (Mg- scrap) is nearly equivalent to the amount of good die-castings. About 80 % of the return material complies with scrap grade class 1 (see Table 3.28).

Class	Description
Class 1	Clean, compact scrap with known composition Feeders: clean Press residues: clean Bad castings: clean, uncoated
Class 2	Scrap castings, painted (partly inserts of Fe, Al, no copper and nickel contamination)
Class 3	Unclean compact metal scrap (oily, wet, contaminated with sand, copper, nickel, ferrosilicon), i.e. mostly post consumer scrap
Class 4	Turnings: clean, dry Turnings: oily, wet Scales, flashings, runners: oily, wet
Class 5	Dross (from metal surface)
Class 6	Crucible slag
Class 7	Flux containing scrap, used salt (black dross)
Class 8	Non–metallic residue
Class 9	intermetallics

Table 3.28: Magnesium scrap grade classes
[206, Ditze and Scharf, 2000]

3.5 Melting and casting of copper and copper alloys

3.5.1 Melting and casting units

Copper and copper alloys are generally melted in crucible furnaces. These furnaces generally operate within the following ranges:

- charge: 30 – 1800 kg
- capacity: 30 – 400 kg
- energy consumption (oil): 0.4 l/kg
- energy consumption (butane): 0.3 Nm^3/kg

Medium frequency induction furnaces are also used with silica or alumina linings.

Table 3.29 gives a typical mass balance for a brass foundry manufacturing taps. Data are given for combined melting and low-pressure die-casting operations (but without finishing and core-making). All data refer to tonnes of good castings sold. The data apply to melting in a gas-fired crucible furnace, with 1 tonne/h capacity.

Input	
Electric energy	1360 kWh
Propane gas	14
Compressed air	48 kWh
Water	85.7 l
Gas removal tablets	0.6 units
Deoxidant	0.9 units
Copper alloy	0.44
Cover flux	0.31
Cores	286
Graphite paint	3.4
Output	
Non-poured sand	101
Poured sand	6.7
Graphite paint	61.4 l
Zinc powder	0.075
Slag	36.3
Brass scrap	57.1
Brass swarf	18.4
Emissions (without flue-gas cleaning)	
Dust	3.9
VOC	3.3
SO_2	0.1
NO_x	0.03
Copper	0.081
Zinc	26.3
All data per tonne of casting sold, data in kg unless stated differently	

Table 3.29: Mass balance data for a brass low-pressure die-casting foundry (melting + die-casting operations)
[177, Silva Ribeiro, 2002]

For copper alloys, the amount of particles emitted greatly depends on the zinc content of the alloys. As a guide the values in Table 3.30 show the relationship between the quantity of particles emitted and the zinc content.

	Zn content (%)	Particle emissions (kg/tonne molten metal)
Bronze	0 – 7	0.3 – 1.5
Brass	20 – 40	0.5 – 16

Table 3.30: Particulate emissions from the crucible melting of copper alloys [126, Teknologisk, 2000]

The production of slags and dross is around 60 kg/tonne of molten metal. This value is similar for melting in induction or hearth type furnaces and for various copper alloys. The composition of the slag depends on the type of alloy melted. In general the copper content is in the 45 – 55 % range. A constant slag quality may be attained by specific mixing of the various slag types from the foundry. This constant quality is needed for external recycling.

The production of refractory waste is 8 – 9 kg/tonne of molten metal for induction melting and 7.5 kg/tonne of molten metal for oil-fired hearth type furnaces.
[34, Binninger, 1994]

3.5.2 Copper and copper alloy melt treatment

When the bubbling of inert gas is used for the degassing of copper, 50 – 70 litres of gas are used for each 100 kg of copper. An alternative is the use of specific tablets or briquettes. Degassing treatment usually takes 3 – 10 minutes depending on the size of the melt. The precise amount of deoxidant needed depends on the melting practice used.
[175, Brown, 1999]

3.6 Melting and casting of zinc and zinc alloys

Table 3.31 gives a typical mass balance for a zinc foundry using pressure die-casting. It applies to the casting of zamac (ZnAl4Cu1 or ZnAl4). Zinc alloy ingots are melted together with rejects and feeders in a gas-fired crucible furnace of the casting machine. A release agent is sprayed on the die before casting. The casted piece is cooled in a water bath and the feeder system is removed. The casting is subsequently degreased and ground. The melting off-gas is collected and dedusted in a dry system. Data on core production and finishing are given in Section 3.9 and 3.11.

Input	
Zinc alloy	1040
Casting rejects	50
Feeders	450
Release agent	20 l
Water	1 m³
Electrical energy	700 kWh
Natural gas	70 Nm³
Output	
Good castings	1000
Swarf	3
Dross	30
Sludge from washing and grinding	2
Off-gas	10000 Nm³
Particulates	1
All data per tonne of good casting, data in kg unless stated different	

Table 3.31: Typical mass and energy data for zinc pressure die-casting

3.7 Melting and casting of lead

Casting processes for lead may be divided into:
- pressure die-casting of lead
- casting for storage batteries
- sand casting for protective screens.

3.8 Waste gas cleaning

3.8.1 Abatement systems

Various waste and exhaust gas cleaning techniques are used in the foundry industry. Their principles are discussed in the BREF document for non-ferrous metal industries. The properties and emission levels of dust abatement systems are given in Table 3.32. A full discussion on the selection of the abatement technique, its applicability in the various foundry processes and the achievable emission levels is given as part of the techniques to be considered in the selection of BAT in Section 4.5.

Technique	Particle Size (µm)	Collection Efficiency at 1 µm (%)	Maximum Operating Temperature (°C)	Range of Achievable Emissions (mg/Nm^3)	Comments
Hot EP	<0.1	>99 Depending on design	450	5 – 15 (Pre abatement >50)	4 or 5 zones. Usual application is pre-abatement
Wet EP	0.01	<99	80	1 – 5 (Visually clear)	EP with 2 zones in series. Mainly mist precipitation
Cyclone	10	40	1100	100 – 300	Coarse particles. Used to assist other methods
Fabric Filter	0.01	>99.5	220	1 – 5	Good performance with suitable dust type
Wet Scrubber	1 – 3	>80 – 99	Inlet 1000 Outlet 80	4 – 50	Good performance with suitable dusts. Acid gas reduction
EP: Electrostatic precipitator					

Table 3.32: Example of current emisions from some dust abatement applications [155, European IPPC Bureau, 2001]

3.8.2 Dioxins

In melting processes, dioxins may be produced if the conditions that give rise to such pollutants are present at the same location and time in the process. These conditions are:
- the presence of chloride ions – these can arise from contaminated scrap, from the use of coal, coke, fuel oil or from certain fluxes
- the presence of organic carbon – this may arise from contaminated scrap and from coal, coke or oil used as a fuel
- temperature conditions between 250 ºC and 450 ºC, with a sufficient gas residence time in this temperature interval
- the presence of a catalyst such as copper
- the presence of oxygen.

In evaluating the risk of dioxin formation, a distinction can be made between non-ferrous and ferrous foundries:

- *Non-ferrous foundries*: In as far as when only ingots and internal scrap are melted, the risk of dioxin formation in the melting stage is very low. The melting of pure non-ferrous metals lacks the presence of both the chlorine and carbon required for dioxin (re)formation. However, the re-melting of external non-ferrous scrap materials for metal production may involve a risk of dioxin formation. This action, however, falls beyond the scope of this document and is considered in [155, European IPPC Bureau, 2001]
- *Ferrous foundries*: Depending on the furnace type and metal load the conditions for dioxin formation could occur. Considering the high temperatures in the melting furnace, dioxin emission (if occurring at all) will mainly generate from *de-novo* synthesis. The above-mentioned conditions can be used to evaluate the risk of dioxin formation.

Dioxin emission data have been gathered from a broad range of sources. Table 3.33 presents data for various metals and furnace types. Blank spaces indicate that the indicated number was not specified. All systems in the survey do not provide specific dioxin capture techniques. A distinction can be made between two groups of techniques where dioxin levels are very low (<0.05 ng/Nm³) or cover a wide range (<0.01 – 3 ng/Nm³). The first group covers aluminium melting, the induction melting of iron and the EAF melting of steel. The second group covers cupola melting and the rotary melting of iron. An analysis of the literature data does not provide a full contribution of the reasons for the differences within the second group. However, it can be seen that the presented HBCs with a wet scrubber system show noticeably lower PCDD/F emission values.

Product type	Furnace	Melting (tonne/h)	Flue-gas (m³/h)	Abatement	O_2 (%)	PCDD/F (ngTEQ/Nm³)
Aluminium	Hearth type	n.d	n.d		n.d	0.002
Aluminium	Hearth type	0.45	9300	None	18.8	0.002
Aluminium	Shaft	1.5	8400	None	18.4	0.01
Cast iron	CBC	3.4	15900	Bag filter	n.d	0.04
Cast iron	CBC	3.7	14300	Bag filter	16	0.09
Cast iron	CBC	4.5	14300	Bag filter	n.d	0.09
Cast iron	CBC	3.4	n.d		n.d	0.33
Cast iron	CBC	5.5	17400	Bag filter	15.9	0.51
Cast iron	CBC	6.5	17500	Bag filter	n.d	0.51
Cast iron	CBC	6	27600	Bag + PC	n.d	3.14
Cast iron	HBC	45.5	55000	Disintegrator	6	0.003
Cast iron	HBC	60	n.d	Disintegrator	n.d	0.003
Cast iron	HBC	40.6	75000	Bag filter	12.5	0.05
Cast iron	HBC	50	75000	Bag filter	n.d	0.07
Cast iron	HBC	15	36400	Bag + PC	n.d	0.05
Cast iron	HBC	13	n.d		n.d	0.10
Cast iron	HBC	18.2	29100	Bag filter	8.6	0.20
Cast iron	HBC	17.1	22500	Bag filter	7.5	0.29
Cast iron	HBC	27	n.d		n.d	1.00
Cast iron	HBC	28	37000	Bag filter	n.d	2.08
Cast iron	HBC	21	32000	Bag + PC	n.d	3.09
Cast iron	IF	19.5	208000	Bag filter	20.2	0.003
Cast iron	IF	n.d	n.d	Bag filter	n.d	0.01
Cast iron	RF	8	n.d		n.d	0.004
Cast iron	RF	1.4	9000	None	n.d	0.02
Cast iron	RF	2.1	18600	Bag filter	19.9	0.45
Cast iron	RF	3.5	n.d	Bag filter	n.d	0.61
Steel	EAF	5.4	54150	Bag filter	20.9	0.003
Steel	EAF	9	5000	Wet scrubber	n.d	0.02
CBC: Cold blast cupola; HBC: hot blast cupola; RF: rotary furnace; IF: induction furnace; EAF: electric arc furnace;						

Table 3.33: Dioxin emission data for various foundry types
[21, Strauß, 1994], [23, Brettschneider and Vennebusch, 1992], [27, Kran, et al., 1995], [43, Batz, 1996], [110, Vito, 2001], [202, TWG, 2002], [225, TWG, 2003], personal communications

The dioxin emission data for the various ferrous metal melting furnaces are discussed below.

- *Cupola furnaces*: In cupola furnaces, a massive surplus of chlorine is always present from coke. Enough carbon is present from coke too, but an additional input of carbon may be needed the event of caused by poor scrap qualities. Under specific operational conditions, the conditions for dioxin formation could occur. Since *de novo* synthesis mainly occurs during cooling of the flue-gas, this applies to both hot blast and cold blast cupolas. In Table 3.34, the result of a statistical analysis of all the measurement data from Table 3.33 for CBC and HBC is given. Whereas Table 3.33 presents average values per plant, for Table 3.34 individual measurements were used to perform an overall analysis.

	Units	Cold blast	Hot blast
Average	ngTEQ/Nm³	0.54	0.75
St. dev.	ngTEQ/Nm³	1.08	1.3
Median	ngTEQ/Nm³	0.18	0.09
Minimum	ngTEQ/Nm³	0.001	0.001
Maximum	ngTEQ/Nm³	5.1	4.4
Number of measurements		35	18
Number of furnaces		11	11

Table 3.34: Cupola furnace dioxin emissions
[21, Strauß, 1994], [23, Brettschneider and Vennebusch, 1992], [27, Kran, et al., 1995], [43, Batz, 1996], [110, Vito, 2001], [202, TWG, 2002], [225, TWG, 2003], personal communications

Data from a German survey (6 installations, 18 measurements) showed a range of 0.006 - 0.22 ng TEQ/Nm³, with an average of 0.0724 ng TEQ/Nm³ (0.0608 i-TEQ/Nm³). The data set of the survey partially overlaps with the data set presented above, but it did not give sufficient information to expand it. [224, Helber, et al., 2000]

The data show that the average, the standard deviation and the range of values are similar for both cold blast and hot blast furnaces. The median value for hot blast is lower than for cold blast furnaces. This confirms the statement from [224, Helber, et al., 2000] that there is no statistical difference between dioxin emissions for hot and cold blast cupola furnaces. The high standard deviation shows that the data should be interpreted on a plant-by-plant basis rather than on an averaged basis.

For wet dedusting with a disintegrator, the off-gas passes through the critical temperature window (250 – 450 ºC) after dedusting, i.e. with a low dust content. Additionally, chlorides have been washed out. This strongly reduces the risk of *de novo* synthesis.

- *Rotary furnaces*: Due to the limited possibility of alloying, the rotary furnace charge generally consists of clean material. Due to the high flame temperature, the hot gases leave the furnace at temperatures of between 1000 and 1300 ºC. Post combustion occurs inside the furnace volume. *De novo* synthesis is possible if flue-gases cool slowly. Reported data range from 0.004 – 0.61 ngTEQ/Nm³.

- *Induction furnaces*: Due to the limited possibility of alloying, the induction furnace charge generally consists of clean material. Furthermore the furnace does not produce a ducted high temperature flue-gas stream that cools down slowly.

- *Electric arc furnaces*: EAF furnaces allow melt treatment and alloying if operated in basic lining practice. This enables the use of dirty scrap as a raw material for melting. If scrap containing organic and/or chlorinated compounds is charged, dioxins may be formed during cooling of the flue-gas stream. This may be the case when using scrap from e.g. electronic equipment, transformers, and shredded vehicles. The EAF in acid lining practice does not allow metal treatment and therefore the possibility for feeding contaminated scrap is reduced. This also reduces the risk of dioxin formation.

[161, UK Environment Agency, 2002]

3.9 Mould and core production

3.9.1 Introduction

Mould and core production involves mixing sand with various chemicals, in some cases followed by a heating step. Gaseous or volatile reaction-products and excess reagents are emitted. Table 3.35 presents a survey of the emissions and other environmental impacts during the mixing, setting and storage of the moulds and cores. A further discussion of the emission and consumption levels for each of the binder types is given in the subsequent sections.

System name and binder constituents	Setting method and relative energy requirement	Emissions to air during mixing and setting	Other environmental impacts
GREEN SAND Clay Coal dust or substitute Water	Pressure – low	Particulate matter – no significant emission to the environment	Sand spillage around conveyors needs to be avoided to reduce the likelihood of fugitive emissions. Abatement from the mixing process is not essential (the process is usually self-contained with displaced air vented to the foundry)
SHELL SAND Phenol - formaldehyde (Novalak) Resin	Heat - high	Formaldehyde* Ammonia* Phenol* Aromatics HCN	Odour can be an issue as the shell machines are normally extracted to air
ALKALINE PHENOLIC Resol - Alkaline phenol-formaldehyde resin 1. Gas hardened (alkaline phenolic cold-box) 2. Self-setting (alkaline phenolic no bake)	Gas hardened with methyl formate vapour – low Cold-set with esters - low	Formaldehyde* Phenol* Methyl formate Formaldehyde* Phenol* Esters	
PHENOLIC URETHANE 1. Gas hardened: Cold-box 2. Self-setting (phenolic urethane no bake)	Amine vapour – low Self-set with substituted pyridine – low	Isocyanate (MDI) Amine* Formaldehyde* Phenol Isocyanates (MDI) Formaldehyde* Phenol	Odour is frequently a problem – where DMEA is used odours arise and abatement is essential. This may be incineration or gas scrubbing (using sulphuric or phosphoric acids) – the latter gives rise to liquors, which are a special waste. Where TEA is used scrubbing is only required if odour problems arise
FURAN Combination resins of: Phenol Urea Furfuryl alcohol Formaldehyde	Cold-set with acids – low	Formaldehyde* Phenol* Furfuryl alcohol* Hydrogen sulphide Acid mists	Resins and acids must be kept apart (unless sand is present) as they are vigorously exothermic when in contact
HOT-BOX Combination resins of: Phenol Urea Furfuryl alcohol Formaldehyde	Heat – high	Formaldehyde* Acids Furfuryl alcohol* Phenol* Ammonia Isocyanic acid Methyl isocyanate	Odour can be an issue as the shell machines are normally extracted to air

System name and binder constituents	Setting method and relative energy requirement	Emissions to air during mixing and setting	Other environmental impacts
OIL SAND Linseed oil and starch	Heat – high	Acrolein* Complex organics	Odour can be an issue as the core ovens are often extracted to air
CO_2 PROCESS Sodium silicate	Gas hardened with CO_2 gas – low	None	
SILICATE ESTER Sodium silicate	Cold-set with esters – low	Esters	
Note 1: All the above processes give rise to spent sand (including broken cores, spillage and mixer residues) that may go to landfill Note 2: Substances marked with * are those most likely to give rise to odour from the process referred to Note 3: Any resin binder component would be regarded as special waste for disposal purposes and if spilled could give rise to a risk of contamination of water systems Note 4: Amines and methyl formates used for gas hardening are highly flammable and odorous. The avoidance of leaks in storage is essential			

Table 3.35: Environmental impact from binder systems
[126, Teknologisk, 2000], [160, UK Environment Agency, 2002], [225, TWG, 2003], [229, Lilja, et al., 2000]

Quantitative data for dust emissions from moulding shops have been gathered in an Italian foundry survey. The results are given in Table 3.36. All exhaust cleaning systems attain a level <15 mg/Nm³.

	Concentration (mg/Nm³)			Emission factor (g/tonne)*		
	Average	Minimum	Maximum	Average	Minimum	Maximum
Bag filter	3.2	0.4	12.1	24.4	0.5	108.3
Wet scrubber	5.2	3.6	6.7	6.2	4.0	8.0
Wet Venturi system	9.6	8.5	10.9	34.2	30.1	39.9
Units: g/tonne of good casting Number of data points: bag filter: 33; wet scrubber: 4; wet venturi system: 3						

Table 3.36: Emission values and emission factors for dust emissions from moulding shops after exhaust cleaning
[180, Assofond, 2002]

The emissions given in Table 3.35 refer to the stages of mixing, setting and storage of the moulds and cores. Most emissions persist during the metal pouring and casting cooling stages, but now with the addition of pyrolysis products. These will be discussed in Section 3.10.1.

Table 3.37 gives dust emission data from a German measurement campaign. The dust was analysed into PM_{10}, $PM_{2.5}$ and PM_1 fractions.

Activity	Off-gas volume (Nm³/h)	Gas cleaning equipment	Total dust (mg/m²)	PM_{10} (%)	$PM_{2.5}$ (%)	PM_1 (%)
Sand preparation	25600	Bag filter	0.3			
Green sand preparation	24400	Fume hood, bag filter	0.7	88	38	
Sand preparation	70400	ESP	22 – 28.3	79	18	
Core shop	4670 (dry)	Amine washer	0.7	98	47 – 62	
Moulding shop	52300 (dry)	Bag filter	0.7	95 – 97	50 – 60	2 – 5
Finishing	22000 (dry)	Bag filter	5.3	100	45 – 48	9

Table 3.37: Example dust emissions and particle size for mould and core-making
[202, TWG, 2002]

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

Input	Output
– sand – bonding clay (e.g. bentonite) – coal dust, dextrin – water (to prepare moulding mix)	– green sand moulds – dust (silica fines, partially burnt-out clay, unburned coal dust and ash)

The composition of the bentonite added to the sand depends on the specific properties of both the sand and the bentonite, as well as on the desired strength and gas permeability of the finished mould. Table 3.38 gives some parameters of clay-bonded sand, as obtained from a selection of 105 sand samples taken from iron foundries.

Parameter	Units	Average	% of samples in range of average ± 10 %		Maximum value	Minimum value
			Range	%		
Water content	%	4.1	3.4 – 4.5	48	6.9	2.4
Bentonite content	%	8.3	7.5 – 9.1	45	11.9	5.6
Density	g/cm³	0.940	1.00 – 0.85	75	1.06	0.73
Loss on ignition	%	5.0	4.5 – 5.5	20	15.0	1.0
Compressive strength	N/cm²	18.6	16.7 – 20.5	54	24.5	13.2

Table 3.38: Typical properties of green sand, measured on 105 sand samples from 105 iron foundries
[36, Winterhalter, et al., 1992]

Further additives are mixed in the green sand mixture:

- *Coal dust*: Used mainly in iron foundries, but also to a lesser degree in some non-ferrous foundries. Coal dust levels in green sand vary from 2 or 3 % for small castings, to 7 or 8 % for heavy section castings. Too much coal dust can give rise to holes in the castings or in misruns. Various coal dust replacement products exist. They are generally added in a slightly altered concentration compared to the coal dust
- *Cereal binders*: Starch and dextrin are used mainly in steel foundries to avoid defects caused by silica expansion and to control moisture excess in the sand mix. Effective additions of cereal binders to new green sand facing mixes are between 0.5 and 0.75 %. In unit type green sands, part of the cereal is destroyed during the casting process. The recommended addition on each recycle is 0.1 to 0.25 %, depending on the amount of cereal burn-out and on the dilution by cores and new sand.

[174, Brown, 2000], [225, TWG, 2003]

3.9.3 Moulding with unbonded sand (V-process)

Input	Output
– dry sand – PE sheets – energy (produce and maintain vacuum)	– moulds – dust

The thermal shock induced by the contact of the molten metal breaks up the sand grains, generating dust that is mostly emitted during shake-out. The remaining dust in the sand has to be removed in order to allow the re-use of the sand for moulding. Using this method, only a small amount of dust should occur during the filling of the moulding boxes.

This process is of interest because of its very low environmental impact. However, as its process cycle involves many steps, the moulding rate is low and the gap between starting times for each new different casting is lengthy. Moreover investment costs are very high. As a consequence, this process has found only limited application.

3.9.4 Moulding and core-making with chemically-bonded sand

Input	Output
– sand	– sand moulds and cores
– resin	– excess reagents
– catalyst, hardener, additives	– reaction products
	– dust

3.9.4.1 Chemicals consumption levels

The consumption levels of the various types of binders, hardeners, catalysts and additives are given in Table 3.39.

Hardening type	Resin type	Resin addition % on sand weight	Catalyst/ hardener type	Catalyst/ hardener addition % on resin weight	Additive type	Additive Addition % on sand weight
Cold-setting	Furan	0.8 – 1.5	Sulphonic acid	25 – 60	Silane	0.1 – 0.2
	Phenolic	1 – 2	Sulphonic acid	25 – 50	n.a	n.a
	Polyurethane	0.8 – 1.5	Pyridine derivate	2 – 6	n.a	n.a
	Resol	1.0 – 1.5	Ester	22 – 25	n.a	n.a
	Alkyd oil	1.0 – 2.0	Isocyanate	18 – 20	Catalyst	0.002 – 0.2
	Ester silicate	2.0 – 4.5	Ester	10 – 15	n.a	n.a
Hardening type	**Resin type**	**Resin addition % on sand weight**	**Catalyst type**	**Catalyst addition % on sand weight**	**Additive type**	**Additive Addition % on sand weight**
Gas hardening	Phenolic/Furan	0.8 – 1.2	SO_2	0.3 – 3	Peroxide	0.1 – 0.5
	Polyurethane Cold-box	1.0 – 1.8	Amine	0.05 – 0.15	n.a	n.a
	Resol	1.2 – 1.8	Methyl fomate	0.3 – 0.5	n.a	n.a
	Resol	2 – 2.5	CO_2	0.7 – 1.25	n.a	n.a
	Acryl/Epoxy	1.2 – 1.6	SO_2	0.02 – 0.05	Peroxide	0.05 – 0.06
	Silicate	2 – 4	CO_2	1 – 2	n.a	n.a
Hardening type	**Resin type**	**Resin addition % on sand weight**	**Catalyst type**	**Catalyst addition % on resin weight**	**Additive type**	**Additive Addition % on sand weight**
Thermosetting	Oil	0.8 – 4			n.a	n.a
	Warm-box furfuryl alcohol-based	1.0 – 1.5	Cu salts of sulphonic acids	10 – 30	n.a	n.a
	Hot-box phenolic or furan based	1.2 – 3.0	Ammonium salts	10 – 25	n.a	n.a
	Croning phenolic	1.5 – 5	Hexamethylene-tetramine	15	n.a	n.a

Table 3.39: Consumption levels of various resins, catalysts, hardeners and additives for chemically-bonded sand preparation
[174, Brown, 2000], [225, TWG, 2003]

3.9.4.2 Emission factors

The use of chemical binders results in the production of various compounds during mixing, mould- and core-making, storage, pouring and cooling, as indicated in Table 3.35. Some indicative emission factors for several processes are given in Table 3.40 and Table 3.41.

	Furan sand	Phenolic sand
Organic solvents	1.4	1.25
Phenol	0.02	0.18
Formaldehyde	0.08	0.15
All data in kg/tonne molten metal		

Table 3.40: Emission factors for mould making
[110, Vito, 2001]

	Cold-box	Hot-box	Shell
Dust	n.a	0.003	0.003
Furfuryl alcohol	0.1	n.a	n.a
Formaldehyde	0.01	n.a	0.003
Organic solvents	n.a	0.03	n.a
Aromatic solvents	0.12	n.a	n.a
Amines	0.13	n.a	n.a
All data in kg/tonne molten metal n.a: not applicabble			

Table 3.41: Emission factors for core-making
[110, Vito, 2001]

3.9.4.3 Cold-setting processes emissions

Emissions for the cold-setting processes can be described as follows:

- *Phenolic*: Vapours of formaldehyde and phenol may be emitted because of the vapour pressure of these constituents. But, as the polymerisation occurs at ambient temperature, these vapour pressures are low and given the consumption rates, the emissions are insignificant
- *Furan*: Vapours of formaldehyde, phenol, furfuryl alcohol and alcohols may be emitted because of the vapour pressure of these constituents. But, as the polymerisation occurs at ambient temperature, these vapour pressures are low and given the consumption rates, the emissions are insignificant
- *Polyurethane*: Vapours of formaldehyde, phenol, isocyanate and aromatic solvents may be emitted because of the vapour pressure of these constituents. As the polymerisation occurs at ambient temperature, the vapour pressures of the components are low and given the consumption rates, the emissions are insignificant. Obnoxious odours may be generated in the moulding area but are not likely to cause external nuisance
- *Resol-ester:* The resin contains unreacted phenol and formaldehyde, but their emissions are extremely low and environmentally insignificant
- *Alkyd-oil:* During production of the moulds and cores, there are no emission problems, unless they are cured by heat, in which case odour problems may occur
- *Ester silicate*: This process does not generate any emission problems.

[32, CAEF, 1997]

3.9.4.4 Gas-hardened processes emissions

Emissions for the gas-hardened processes can be described as follows:

- *Cold-box*: Vapours of formaldehyde, phenol, isocyanate and aromatic solvents are emitted in low quantities, in spite of their low vapour pressures. Aromatic solvent emissions are highest during purging. The most significant emission is that of amines, which have low odour detection thresholds and can create an external nuisance. Amines are hazardous, with a relatively low exposure value limit, and possess a strong characteristic smell at very low concentrations
- *Resol-ester*: The resin contains unreacted phenol and formaldehyde, but their emission levels, even during the gassing and purging periods, are very low. Methyl formate is not toxic, does not have an unpleasant smell and its exposure value limit is relatively high
- *Resol-CO_2*: The resin has low contents of unreacted phenol and formaldehyde, and their emission levels, even during the gassing and purging periods, are very low
- *SO_2 hardened phenolic and furan resin*: The resins and the prepared sands generate formaldehyde emissions. The major emission problem is caused by sulphur dioxide, which is very hazardous
- *SO_2 hardened epoxy/acrylic*: Minimal emissions are generated during the core-making process
- *CO_2 silicate*: This process does not generate any emission problems during moulding or core-making.

[32, CAEF, 1997]

3.9.4.5 Hot curing processes emissions

Emissions for the hot curing processes can be described as follows:

- *Hot-box emissions*: The patterns are generally heated by open air gas burners, producing combustion gas emissions. The off-gas may contain phenol, ammonia, formaldehyde and monoisocyanates (if the resin contains nitrogen)
- *Warm-box emissions*: Compared to the hot-box process, the emissions are significantly lower. The emissions do not contain phenol or ammonia, and also formaldehyde emissions are diminished by a factor of 4. As the pattern temperature is also lower compared to the one used for the hot-box process, the working conditions are also improved. The environmental impact is considered to be relatively low
- *Shell emissions*: Compared to the hot-box process, cured sand consumption is very low. However, the pre-coated sand contains 2 to 3 times more resin, but as the pattern temperatures are approximately the same, the resulting impact on working conditions is similar.
- *Linseed oil emissions*: As the oils are often in solution in organic solvents such as naphtha or kerosene, a large amount of VOC is generated by curing, which may result in an external odour nuisance. This problem is even more persistent during pouring. These problems, as well as poor productivity, are some of the reasons for the reduction in interest in the use of this process.

[32, CAEF, 1997]

A mass balance for a hot-box core shop is given in Table 3.42. Data were collected from a core shop of a low-pressure die-casting brass foundry [177, Silva Ribeiro, 2002].

Input	
New sand	371
Electric energy	352.9 kWh
Propane gas	7
Compressed air	187.1 kWh
Resin	8.3
Conservative	0.51
Catalyst	0.76
Coating	1.7
Output	
Cores	287.7
Sand not poured	84.3
Resin	1.4 l
Metallic and plastic containers	
Emissions (after bag filter)	
Particulate emissions	0.11
VOCs	0.83
All data are per tonne of castings sold, values in kg unless stated differently	

Table 3.42: Mass balance data for brass foundry core using a hot-box process [177, Silva Ribeiro, 2002]

3.9.5 Coating of chemically-bonded sand moulds and cores

Input	Output
– coatings ready to use or mass to be diluted with water or alcohol – heat for solvent evaporation	– VOC (alcohol-based)

3.9.6 Expendable pattern casting (Lost Foam/full mould casting)

3.9.6.1 Unbonded sand – Lost Foam

Input	Output
– EPS granulate	– sand moulds
– EPS glue	– EPS residues
– refractory coating	– products of pyrolysis and combustion
– sand	– dust

In producing aluminium castings, around 15 kg/tonne good casting of EPS granulate is consumed. Refractory coating consumption is around 20 kg/tonne good casting.

Table 3.43 shows a comparative analysis of a green sand and a Lost Foam aluminium foundry, both producing 5490 tonnes of good castings per year. It should be noted that the values do not take into account the internal regeneration. In practice, both types of foundry will apply regeneration, thus reducing the amount of residue effectively left for disposal.

Residue type	Lost Foam foundry	Green sand foundry
Foundry sand (without internal regeneration)	1.04	2.95
Filter dust (without internal regeneration)	0.056	0.22
Filter dust (with internal regeneration)	0.056	0.61
EPS residue	0.0027	-
All values in kg/tonne good casting		

Table 3.43: Comparative data for residue production from Lost Foam and green sand aluminium casting [96, Spillner, 1997]

Emission data for organic compounds are given in Table 3.44. These apply to an aluminium Lost Foam foundry producing 1.5 tonne/h compared to a green sand foundry producing 1.2 tonne/h and using 1.9 tonne/h cold-box cores. The Lost Foam foundry was equipped with a bag house and a post combustion unit. The green sand data apply to a unit with bag house filtration. The data show that the Lost Foam foundry, with the application of more intense flue-gas cleaning, emits higher levels of BTEX and formaldehyde, but a clearly lower level of organic carbon. Post combustion of the casting off-gases is needed to decompose the products from EPS pyrolysis upon pouring.

Compound	Lost Foam foundry	Green sand foundry
Benzene	35.33	8.5
Toluene, xylene, ethylbenzene, styrene	354.67	18.58
Unknown organic compounds	96.67	655.0
Total organic carbon	857.33	1283.33
PAH	1.45	1.43
Formaldehyde	18.00	2.08
Phenol	18.00	69.83
All values in g/tonne molten aluminium		

Table 3.44: Stack emission data for Lost Foam and green sand aluminium foundries [96, Spillner, 1997]

3.9.6.2 Chemically-bonded sand – full mould

Input	Output
– EPS granulate	– sand moulds
– EPS glue	– EPS residues
– refractory coating	– products of pyrolysis and combustion
– sand	– dust
– binders	

The mass flow of emissions from full mould and hollow mould casting processes are to be considered as similar. This can be seen from Figure 3.5 which shows the mass flow of organic carbon as a function of time upon pouring. Time '0:00' corresponds to the starting of the pouring. The data were collected using furan-bonded sands, both for full and hollow mould making.

The full mould process shows a high emission upon pouring and an initial peak emission immediately after pouring which levels off within 1 hour. The hollow mould process shows a lower initial emission, but the levelling off goes slower and takes up to 2 hours. Therefore, the total organic carbon emission over the whole cooling step is equal for both processes. Additional measurements showed that the same profile applies for benzene, ethyl benzene, phenol and furfuryl alcohol. The maximum emission for styrene and toluene occurs after 15 – 30 minutes. This is due to an initial condensation of the molecules on the colder parts of the mould. [215, Müller, 1996]

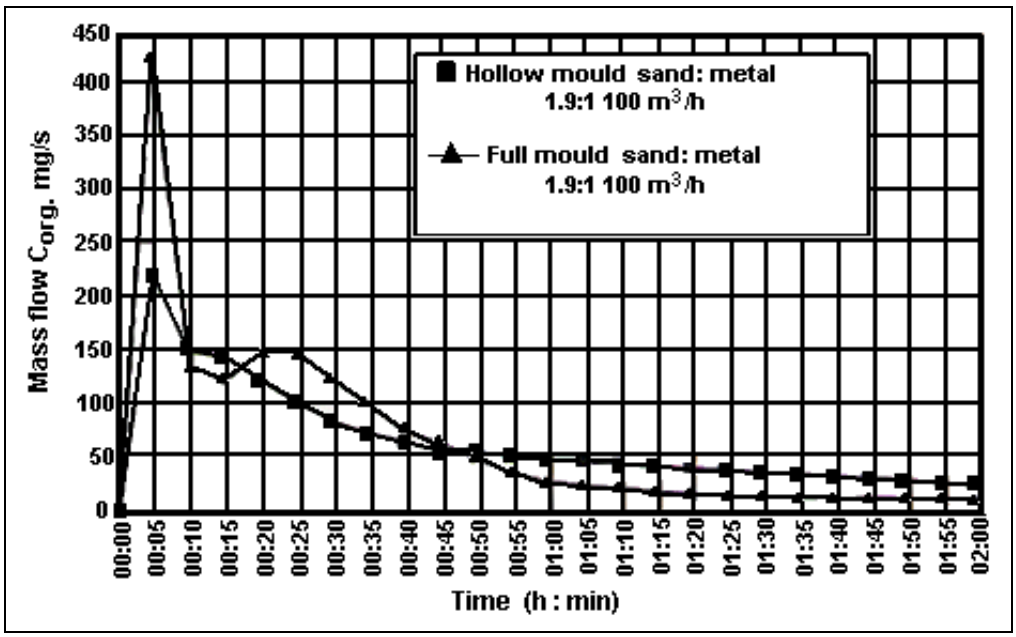


Figure 3.5: Waste gas load upon pouring in full and hollow moulds
cast alloy: lamellar iron; mould: furan bonded sand; 1.9 tonne sand: 1 tonne Fe
[215, Müller, 1996]

3.10 Casting

3.10.1 Casting, cooling and shake-out, using lost moulds

3.10.1.1 Emission levels

Input	Output
– finished moulds – molten metal	– castings – used sand – combustion products (from preheating of pouring ladles) – organic pollutants from pyrolysis and thermal degradation of binder, blackening moulds, etc. (phenol, formaldehyde, amine, hydrogen cyanide, PAH, benzene, VOC) – odour – waste from exhaust air cleaning (dry/sludge) – dust from shake-out

Whilst **preheating** ladles, combustion gases are generated as a result of using natural gas as the common energy source.

The following emission types can occur during **pouring**:
- thermally degradable components, such as exothermic sleeves, react releasing fumes and/or vapours
- chemical compounds from the binder and some blacking systems which can be released as a result of thermal degradation and/or volatilisation, e.g. combustion gases, water vapour, and volatile organic compounds. Some of the degradation products can be odorous.

Experience shows that the maximum emissions (related to total-C) only occur 10 minutes or more after pouring. CO is the main component, with the level of CO being indicative of the release of other compounds. [110, Vito, 2001]

During **cooling and shake-out,** the thermal decomposition processes proceed and volatile compounds are generated, mainly controlled by diffusion and evaporation rates.
The removal (shake-out) of the sand moulds and cores from castings is a dust-intensive procedure, as the moulds, at least partially, have to be crushed.

The **second cooling step** releases nothing except water vapour from those plants, where water spray is used as a cooling aid. [32, CAEF, 1997]

The type of emissions during casting are dependent on the binder type used. Emissions are comparable to those during the mixing stage, with the addition of pyrolysis products occurring upon contact with the hot metal. Table 3.45 gives the results from a qualitative survey of the emissions associated with the various binder types.

System name and binder constituents	Emissions to air during casting	Comments
GREEN SAND Clay Coal dust or substitute Water	Particulate matter- soot from coal burning Carbon monoxide and carbon dioxide Benzene Toluene Xylene	Potential odour (may be associated with the sulphur content of the coal)
SHELL SAND Phenol - Formaldehyde (Novalak) Resin	Particulate matter – soot from the incomplete combustion of carbon based resins Carbon oxides Phenol*, cresols* and xylenols* Ammonia Aldehydes Benzene PAH	Odour problems more prevalent – treatment may be necessary although dispersion may suffice
ALKALINE PHENOLIC Resol - Alkaline phenol Formaldehyde resin 1. Gas hardened 2. Self-setting	Particulate matter – soot from the incomplete combustion of carbon based resins Carbon oxides Formaldehyde Phenol, cresols and xylenols Aromatics	Odour may be a problem
PHENOLIC URETHANE 1. Gas hardened e.g. Cold-box 2. Self-setting (phenolic urethane no bake)	Particulate matter – soot from the incomplete combustion of the carbon based resins Carbon oxides Nitrogen oxides Monoisocyanates Formaldehyde Phenol, cresols and xylenols Aromatics (inc. polycyclics) Anilines Naphthalenes Ammonia	Odour may be a problem

System name and binder constituents	Emissions to air during casting	Comments
FURAN Combination resins of: Phenol Urea Furfuryl alcohol Formaldehyde	Particulate matter – soot from the incomplete combustion of the carbon based resins Carbon oxides Phenol, cresols and xylenols Formaldehyde Aromatics (inc. polycyclics) Sulphur dioxide Ammonia Aniline Isocyanic acid* Methyl isocyanate*	Odour may occasionally be a problem
HOT-BOX Combination resins of: Phenol Urea Furfuryl alcohol Formaldehyde	Particulate matter – soot from the incomplete combustion of carbon based resins Carbon oxides Nitrogen oxides Formaldehyde Phenol, cresols and xylenols Aromatics (inc. polycyclics) Aniline Ammonia Isocyanic acid* Methyl isocyanate*	
OIL SAND Linseed oil and starch	Particulate matter – soot from the incomplete combustion of carbon based resins Carbon oxides Butadiene Ketones Acrolein	Odour may be a problem
CO_2 PROCESS Sodium silicate	Carbon oxides	
SILICATE ESTER Sodium silicate	Carbon oxides Alkanes Acetone Acetic acid Acrolein	
* For resin containing nitrogen (urea)		

Table 3.45: Environmental impact from binder systems upon pouring, shake-out and cooling [160, UK Environment Agency, 2002]

Emission factors for iron casting in cold-setting sand moulds as used in Belgium are given in Table 3.46.

Compound	Average kg/tonne melted
CO	1.1
Aliphatic heterocyclic hydrocarbons	0.22
Aromatic hydrocarbons	0.05
HCN	0.03
Formaldehyde	0.02
Sulphur compounds (when using paratoluene sulphonic acid)	0.10
Volatile organophosphorous compounds (when using phosphoric acid)	0.11

Table 3.46: Emission factors for iron casting in cold-setting resin-bonded sand moulds [110, Vito, 2001]

The emission factors during pouring, cooling and shake-out for a mixed sand system, have been determined through an intensive measurement programme in two automotive foundries in Mexico. The foundries under study produced iron castings, using green sand moulds and chemically-bonded sand cores. The emission factors are very process-specific and vary according to changes in the mould or core composition, or changes in the process parameters such as cooling time, or in the techniques applied, such as the type of shake-out device applied. Nevertheless, the emission factors obtained provide useful information on the type of emissions and on the relative importance of the various process steps. The emission factors for the most important detected air pollutants are presented in Figure 3.6. The data show that the highest emissions occur during shake-out and only minor emission occur during pouring. Naphthalene and monomethylated naphthalenes mainly contribute to the PAH emission. Further analysis of this category revealed that many of the carcinogenic PAHs, such as benzo(a)pyrene were not detected.

The major metal emissions include manganese, lead, nickel, copper and chromium, with lead and manganese being greatest. [141, CERP, 1999]

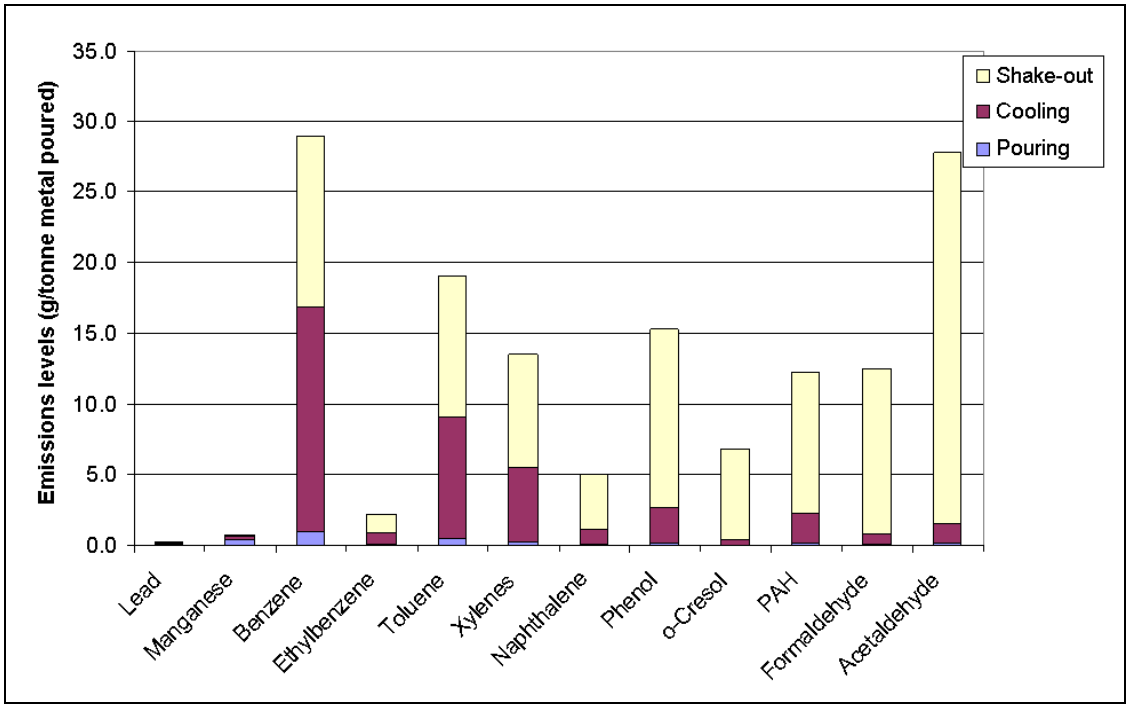


Figure 3.6: Emission levels of pollutants upon pouring, cooling and shake-out for a green sand iron foundry
[141, CERP, 1999]

Emission factors for particulate matter are displayed in Figure 3.7. These are based on measurements of total dust, PM_{10} (particles less than or equal to 10µm) and $PM_{2.5}$ (particles less than or equal to 2.5µm). Note that by definition PM_{10} includes $PM_{2.5}$. [141, CERP, 1999]

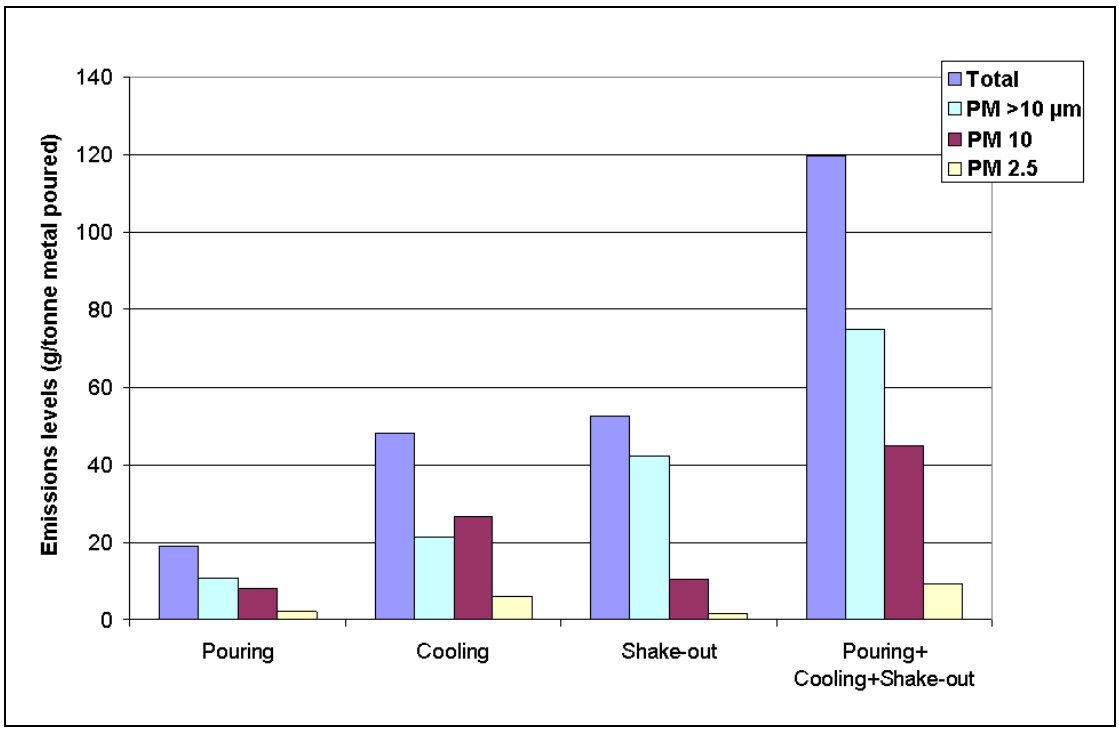


Figure 3.7: Emission levels for particulate matter upon pouring, cooling and shake-out for a green sand iron foundry
(Total = PM_{10} + $PM_{>10}$)
[141, CERP, 1999]

Data in the above figures apply to raw gas. In an Italian sector survey, emission data for cleaned exhaust flows were collected and are given in Table 3.47 [180, Assofond, 2002]. All exhaust cleaning types reach a dust emission level of <20 mg/Nm³. Wet scrubbers show the best performance, though it should be noted that the data are based on only three measurements.

Flue-gas cleaning equipment	Concentration (mg/Nm³)			Emission factor (g/tonne)*		
	Average	Minimum	Maximum	Average	Minimum	Maximum
Bag filter	5.8	1.0	16.8	68.5	7.8	206.9
Wet scrubber	2.3	1.8	2.8	16.3	13.3	18.0
Wet multicyclone	18.6	14.6	21.9	202.2	163.6	224.4
Wet Venturi system	11.7	6.2	16.9	116.3	38.2	187.7
* Emission factor in g/tonne of good casting						

Table 3.47: Emission values and emission factors for dust emission from shake-out after flue-gas cleaning
[180, Assofond, 2002]

3.10.1.2 Sand-to-liquid metal ratios

Excessive amounts of sand in the moulding system results in unnecessary capital and operating costs. A lower sand-to-liquid metal ratio will reduce the total volume of sand in the system and, therefore, reduce the consumption of new materials.

The distribution of sand-to-liquid metal ratios for green sand in the iron sector is shown in Figure 3.8. Data were collected from a survey of the UK foundry sector. While the average sand-to-liquid metal ratio in this sector is 9:1, some foundries are operating either considerably above or below this figure. The lower ratios are generally associated with certain types of metal moulds or single-product foundries where box size/casting combinations are more easily optimised. The higher ratios are generally caused either by jobbing or short-run situations. Here, many widely varying casting configurations (and thus pattern configurations) will have been

involved or the original product/product mix will have changed significantly since the plant was designed.

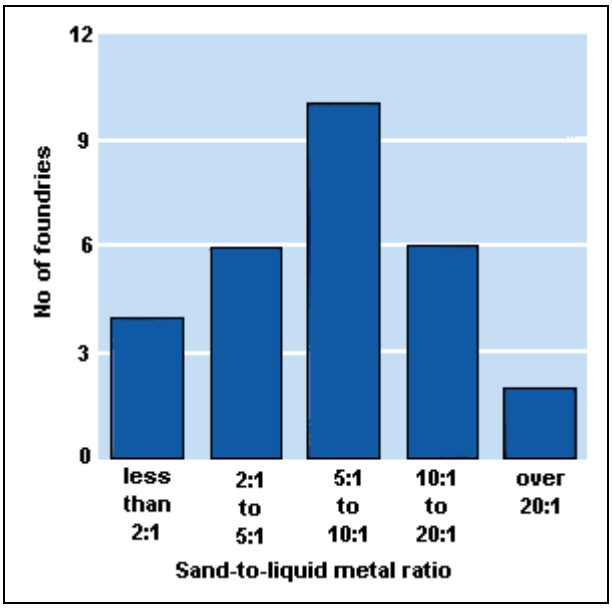


Figure 3.8: Green sand-to-liquid metal ratios in iron foundries [73, ETSU, 1995]

Figure 3.9 shows the distribution of total mixed sand-to-liquid metal ratios for green sand in the copper sector, where the average sand-to-liquid metal ratio was about 4:1. The reason this value is lower than that for the iron sector is largely because most copper foundries are product orientated with an optimised box size.

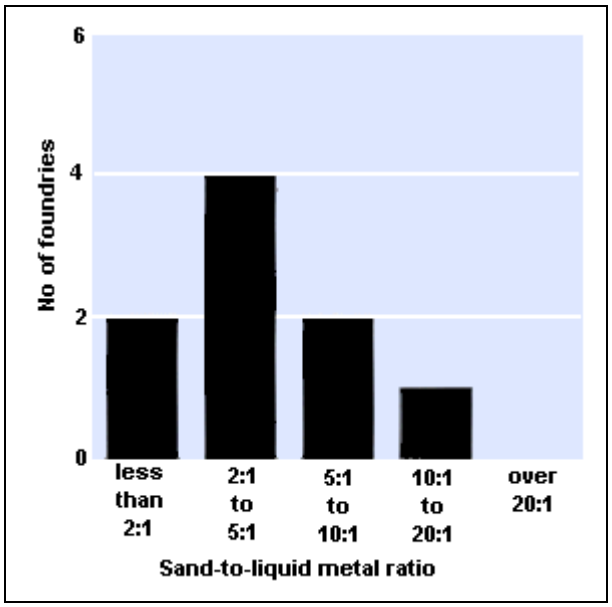


Figure 3.9: Green sand-to-liquid metal ratios in copper foundries [73, ETSU, 1995]

Data for chemically-bonded sand-to-liquid metal ratios for various metal types are given in Figure 3.10.

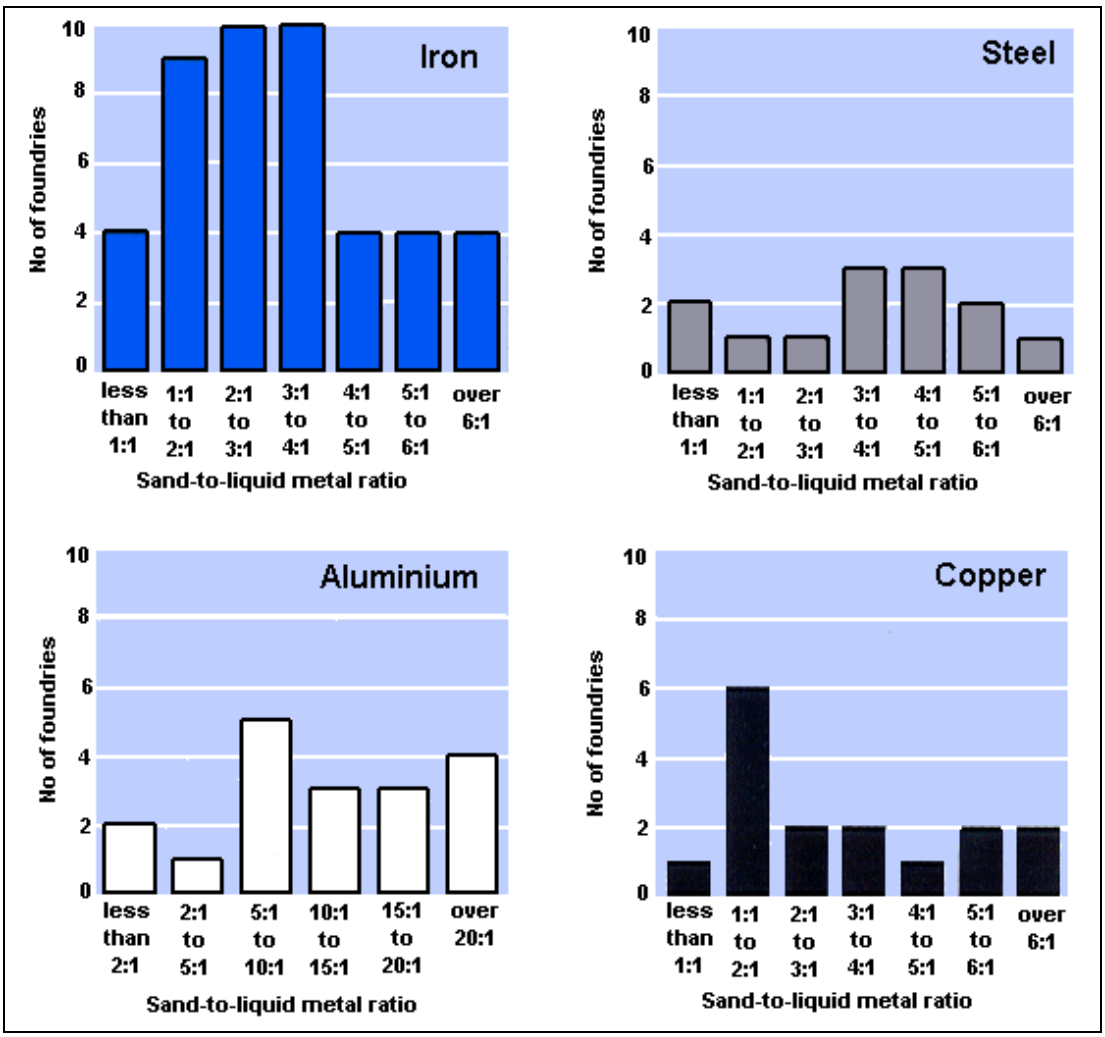


Figure 3.10: Total mixed sand-to-liquid metal ratios in UK foundries [72, ETSU, 1995]

3.10.1.3 Metal yield

The metal yield is the ratio of the amount of metal melted to the weight of the finished good castings. Five main factors affect metal yield, i.e.:

- quality requirement
- choice of mould-box size
- the extent of runner and feeder systems
- metal shrinkage
- scrap casting rate.

Metal yield does not have a direct effect on sand use. However, an increase in yield may result in fewer moulds being produced, which means that less sand is consumed overall. Lower metal yields are generally associated with higher integrity products, where superior quality standards may be required, necessitating a more extensive feeding system. Lower yields, however, may also be indicative of higher scrap rates and excessive feeding systems. In these circumstances, foundries need to review their process control and mould production methods. The average metal yields for the main alloy sectors are given in Table 3.48.

Sector	Average metal yield (%)	Range of yields reported (%)
Lamellar iron	68	40 – 90
Nodular iron	63	40 – 90
Aluminium	57	40 – 80
Copper	58	30 – 90
Steel	45	n.d

Table 3.48: Metal yield in the main alloy sectors [73, ETSU, 1995], [225, TWG, 2003]

Data were collected through a survey in the UK foundry sector and from the Portuguese foundry association (the latter for steel). A significant number of survey respondents declined to supply yield data, particularly in the aluminium and copper sectors. However, some general comments on metal yield can be made:

- the range of yields reported for lamellar iron and nodular iron was from 40 % to over 90 %
- metal yields reported by aluminium foundries were fairly evenly distributed between 40 % and 80 %. Over 50 % of aluminium foundries, however, chose not to supply data
- half the small number of copper foundries that supplied data are achieving yields of between 50 % and 60 %, though the reported range is 30 % to over 90 %.

[73, ETSU, 1995]

3.10.1.4 Used foundry sand

A review and study of foundry waste sand quality and composition was performed in Finland. Data were collected from literature and from own experiments [169, Orkas, 2001].

In several studies, chemical analyses on used foundry sands from various sources were performed. A summary of the most significant results is presented in Table 3.49. The data show that the contents of metallic and organic harmful compounds in used foundry sand are normally low. Generally, the contents of organic and metallic harmful compounds are higher in green sands compared to chemically-bonded sands. Inorganic sands are basically very clean.

Compound	Green sand (mg/kg)	Organic sand (mg/kg)	Inorganic sand (mg/kg)
Ba	35 – 118	2.4 –5.5	n.d
Cr	1.7 –13.5	1.2 –7.2	<5
Fe	2950 – 21000	640 – 16300	530 – 1700
Zn	1.5 – 1450	1.6 – 49	<10 – 30.0
Cd	0.03 – 6.7	0.01 – 0.03	0.02
Pb	1.6 – 390	0.4 – 2.1	1.3
Cu	4.7 – 5.0	2.7 – 4.4	<1.5 – 6.0
Ni	<2.5 – 20.0	0.3 – 8.5	2.5 – 8.3
Mn	76 – 78	22 – 79	25 – 34
As	0.2 – 2.1	0.2 – 1.8	<0.5 – 0.51
Phenol	1.1 – 29.6	0.1 – 14	0.03
Total PAH	1.0 – 206.6	0.1 – 8.8	<1.75

Table 3.49: Results from analyses of used foundry sands from several sources [169, Orkas, 2001]

The Castings Development Centre (CDC) analysed the PAH-values (total PAH, naphthalene and carcinogenic PAH) and phenol contents from different used foundry sands. The results are shown in Table 3.50. For a given sand production line, the variations in the PAH and phenol contents in used sand are relatively low.

	Polycyclic aromatic hydrocarbons, (mg/kg)			Phenol	
Sand system	**Naphthalene**	**Carcinogenic PAH**	**Total PAH**	**Total (mg/kg)**	**Leachable (µg/l)**
Green sand	<1.0 – 7.4	0.03 – <1.0	<10 – 11	1.4 – 63	26 – 1600
Alkaline phenolic	1.1 – 4.8	0.026 – 0.096	2.3 – 8.1	1.4 – 210	0.025 – 4400
Furan	0.87 – <1.0	0.014 – 1.5	1.0 – <10	0.18 – 15	1.2 – 19
Resin shell	0.11 – 7.1	0.01 – 0.67	0.75 – 9.3	3.7 – 3300	0.025 – 3200

Table 3.50: PAH and phenol contents of used foundry sands
[169, Orkas, 2001]

Leaching tests showed that the leaching of metals is generally low and that the leaching of chromium caused by the presence of chromite sand is negligible [169, Orkas, 2001].

3.10.2 Casting in permanent moulds

Input	**Output**
- water-based release agent - cooling water - molten metal - cores	– casting – oily mist from release agent spraying – organic pollutants from thermal degradation of core binder – metal oxide containing dusts from holding furnace – dust from shake-out of cores – waste water

Mass balance data for three different foundries using pressure die-casting of molten aluminium are given in Table 3.51.

	Foundry A	Foundry B	Foundry C
Input			
Water	802 l/tonne	935 l/tonne	1709 l/tonne
Release agent	16 l/tonne	8.26 l/tonne	1.12 l/tonne
Electricity	1103 kWh/tonne	1380 kWh/tonne	652 kWh/tonne
Output			
Waste water[1] COD pH SS Oil and grease BOD5 Al	 18000 mg/l 7.5 1300 mg/l 3000 mg/l 2000 mg/l 5 mg/l	122 l/tonne	 126 mg/l 7.5 1 mg/l 1 mg/l (total hydrocarbons) 78 mg/l 0.6 mg/l
Exhaust gas NOx VOC Dust		 0.006 kg/tonne 0.28 kg/tonne 1.8 kg/tonne	 0.14 – 0.27 kg/tonne 0.030 – 0.16 kg/tonne
All values per tonne of good casting or in mg/l effluent [1] For foundry C, waste water quality after treatment consisting in a distilling plant and cooling-evaporation towers			

Table 3.51: Mass balance data, exhaust and effluent composition for aluminium presure die-casting units
[177, Silva Ribeiro, 2002], [202, TWG, 2002]

In current die-casting practice, water-based release agents are sprayed on the open die, after dilution to a 1:50 – 1:200 ratio. Besides die coating, this spraying is used for die cooling. This

explains the difference in water use displayed in the table. This practice causes a loss and spillage of water, and up to 40 % of water/agent leakage into the foundry waste water system.

Emission and consumption levels for permanent moulding processes depend on the type of alloy used, the surface area of the melt, the quantity of the sand cores which are inserted in the mould, and the surface/volume rate of the casting. The sand cores are the main sources of emissions. There is no important difference between the different casting techniques. Due to the wide variety of processes and applications, it is not possible to give average data. [202, TWG, 2002]

Electricity consumption depends on process aspects, such as the closing force of the die, which are chosen on technical grounds.

Emission factors for the casting of bronze, brass and zamac as used in Belgium are given in Table 3.52.

Alloy	CuO	SnO	PbO	ZnO	Al_2O_3	MnO
Bronze	0.06	0.04	2 – 20	625 – 6250	n.a	n.a
Brass	0.01	n.a	0.007 – 1	125 – 21500	n.a	n.a
Zamac	n.a	n.a	n.a	0.004	0.2	0.01
All data in g/tonne molten metal						

Table 3.52: Indicative emission factors for casting of bronze, brass and zamac [110, Vito, 2001]

3.11 Finishing/post-casting operations

Input	Output
- unfinished castings - abrasives - water, soap - electricity	– finished castings – dust (*sand, metal particles*) from mechanical operations – volatised metals, combustion products from thermal operations – waste water

3.11.1 Slide grinding

Table 3.53 shows input-output data for the slide grinding of aluminium castings. The effluent water goes to a water treatment system and is re-circulated into the slide grinding equipment. Abrasive rocks are used and come out unaltered, besides for some minimal wearing.

Input	
Electricity	20.7 kWh
Cleansing agent	0.5 l
Water	490 l
Output	
Liquid effluent	400 l
All values per tonne of good casting	

Table 3.53: Input-output balance for the slide grinding of aluminium castings [177, Silva Ribeiro, 2002]

3.11.2 Shot blasting

Emission levels from the exhaust gas of shot blasting have been collected in an Italian foundry survey. The results are displayed in Table 3.54. All techniques reach maximum dust emission levels below 30 mg/Nm³. The average value is below 15 mg/Nm³. The wet Venturi system is the

least effective system, leaving an emission factor well above those for the other techniques. On the other hand, it also acts as is a safety device to prevent an aluminium-dust-explosion [225, TWG, 2003].

	Concentration (mg/Nm³)			Emission factor (g/tonne)		
	Average	Minimum	Maximum	Average	Minimum	Maximum
Bag filter	5.3	0.4	19.3	53.1	0.3	327.3
Wet filtration	12.0	4.2	16.4	21.9	7.9	30.1
Wet multi-cyclone	8.2	4.2	14.8	54.9	18.5	135.4
Wet Venturi system	12.8	1.1	22.3	149.0	2.3	523.5
Emission factor data in g/tonne of good casting and for cleaned gas						

Table 3.54: Emission data for the exhaust gas from shot blasting, using various dedusting techniques
[180, Assofond, 2002]

3.11.3 Fettling

Emission levels from the exhaust gas of fettling have been collected in an Italian foundry survey. The results are displayed in Table 3.55. All techniques achieve dust emission levels below 30 mg/Nm³. The bag filter and Venturi allow maximum levels below 10 mg/Nm³. The wet multi-cyclone is the least effective system, leaving an emission factor well above those for other techniques. The emission factor is largely dependent on the amount of finishing needed and thus the type of castings made.

	Concentration (mg/Nm³)			Emission factor (g/tonne)		
	Average	Minimum	Maximum	Average	Minimum	Maximum
Bag filter	3.0	0.4	7.5	17.0	2.3	85.6
Wet multi-cyclone	14.8	7.6	23.3	275.6	96.2	497.2
Wet Venturi system	2.5	1.1	5.9	45.5	35.5	63.4
Emission factor data in g/tonne of good casting and for cleaned gas						

Table 3.55: Emission data for the exhaust gas from fettling, using various dedusting techniques,
[180, Assofond, 2002]

3.11.4 Finishing operations in steel foundries

Concerning steel foundries, specific cutting, scarfing and welding processes are used. Average dust emission values are given in Table 3.56. These apply for the use of the following techniques:

- *Cutting* (of runner system): Tetrene-acetylene-iron oxide for stainless cutting
- *Scarfing*: Carbon electrode covered with copper
- *Welding*: Using electrodes or wire.

Finishing technique	Dust emission (kg/tonne)
Tetrene cutting	11 - 13
Scarfing	9 - 11
Electrode/Wire	3 - 3.5
All values in kg per tonne of good casting	

Table 3.56: Average dust emission from steel finishing
[202, TWG, 2002]

3.12 Heat treatment

Input	Output
– finished castings	– finished casting (heat treated)
– energy (electric, gas or fuel oil)	– combustion products from firing
– quenching: water, oil, air	– water vapour, fume, oil mist
	– NO_x, SO_2

The emissions from heat treatment furnaces mainly comprise combustion gases, particularly from gas- and oil-fired furnaces. The composition of the combustion gases depends on the fuel-type used. Oil-fired furnaces will generate SO_2-emission, which are not present for natural gas burners. Where quenching processes are carried out, emissions of fume, water vapour, or oil mist will also occur, depending on the quenching media.

Heat treatment furnaces are known to be continuous sources of well known non-air components. Emission levels are closely related to energy consumption, burner design and maintenance. Emission collection is trivial in annealing furnaces. The capture of the emissions in the different furnaces does not differ considerably, and emissions are expelled via the waste gas pipe. In general, no further waste gas treatment is applied.

Generally, quenching is a batch process. For this reason emission levels alternate substantially. Emissions from the quenching baths are regarded mostly to be irrelevant for the environment, although they may become more relevant with large scale production. Data about source strength (emission rates) and chemical compounds have not been found.
[32, CAEF, 1997]

3.13 Waste water

3.13.1 Sources of waste water

The amount of process water used in foundries is small and mainly depends on the selection of techniques for dedusting. Waste water is generated mainly in dust removal and waste gas treatment systems, which are applied in the melting shop, moulding material preparation and reclamation and in the cleaning shop. Waste water is also generated in core production, if wet scrubbers are used (depending of the core-making technique and bonding agents used). In a minority of plants (2 plants reported in Europe), water is used for wet sand regeneration. Furthermore, water is generally used for cupola shell cooling and for the cooling baths for (die) castings.

Possible sources of waste water are:
- scrap storage area and site-drainage
- sand preparation
- wet scrubbers used for dedusting in various areas of the foundry
- cooling of pressure die casting machines and tools
- vibratory finishing (slide grinding)
- cooling baths used for heat treatment.

The production-specific waste water quantity averages **0.5 m^3/t good castings**.

[160, UK Environment Agency, 2002], [195, UBA, 2003]

3.13.2 Waste water from scrap storage

Scrap may have adhering soil, and external scrap typically exhibits production-specific impurities. The adhering impurities may be washed off when it rains and may then enter the soil and groundwater. An overview of the possible impurities is given in Table 3.57:

Scrap type	Adhering impurities
Swarf	Cutting oils, emulsions (may contain chlorine)
Punching scrap	Punching oils (may contain chlorine)
Broken machine castings, not conforming to specifications	Hydraulic oils, gear oils
Scrap from cold forming and smitheries	Phosphates, zinc soaps, graphite, forming oils

Table 3.57: Possible impurities for specified scrap types [195, UBA, 2003]

If the adhering impurities are substances constituting a hazard to water (oils, emulsions), then requirements on the storage of substances constituting a hazard to water must be complied with.

3.13.3 Waste water from wet scrubbers used in cupola melting

Wet scrubbers are in use in melting shops to clean the cupola off-gas. Wet scrubbers use water to remove dust particles (average loading: 10 – 15 g/Nm^3) and gases such as sulphur dioxide from cupola off-gas. In the settling tank, a large part of the solid particles are captured and thereby almost completely removed from the scrubbing water.

The partly acid gases washed out of the cupola off-gas, such as sulphur dioxide, accumulate in the scrubbing water, causing its salt concentration to increase (e.g. the formation of e.g. sodium sulphate) and its pH to decrease. This salt accumulation is supported by evaporation losses, so it is necessary to draw the water off from time to time.

Waste water from wet dedusting systems in melting shops mainly contains:
- solids such as oxides of silicon, iron and aluminium, calcium carbonates and cyanides
- heavy metals, although with the exception of zinc, these are present only in very low concentrations
- organic pollutants, which can enter waste water via soiled scrap.

AOX (absorbable organic halides) levels in water used for the scrubbing of cupola off-gas can amount to several milligrams. Possible causes of AOX are scrap coatings and adhering chlorinated organic compounds entering the water during the gas scrubbing process. Chlorinated organic compounds can also reach the water via auxiliaries, such as commercial-grade hydrochloric acid or iron and aluminium chlorides, which are used as flocculants.

Table 3.58 gives an overview of the pollutant concentrations in filter effluent from the dewatering of sludge from the wet scrubbers of cupola furnaces.

Analyte	Units	Value
pH value		7.2 - 9.9
El. conductivity	µS/cm	1400 - 18400
Lead	mg/l	<0.01 - 2.5
Cadmium	mg/l	<0.01 - 0.03
Chromium	mg/l	<0.01 - 0.13
Copper	mg/l	0.02 - 0.89
Nickel	mg/l	0.04 - 0.23
Mercury	mg/l	< 0.001
Zinc	mg/l	1.8 - 27.9
Sulphate	mg/l	430 - 1550
Chloride	mg/l	1330 - 3947
COD	mg/l	154 - 7580

Table 3.58: Pollutant concentrations in filter effluent from dewatering the sludge from the wet scrubbers of cupola furnaces
[195, UBA, 2003]

3.13.4 Waste water from the casting, cooling and shake-out area and from mould production/sand preparation

In the casting, cooling and shake-out area and in mould production/sand preparation, insoluble fines from the moulding material are captured during dedusting, along with small organic proportions from the bonding agent used. If wet dedusting is applied, these compounds are found in the waste water flow. The inorganic solids are iron oxides and clays, which are in part finely dispersed and difficult to remove.

3.13.5 Waste water from core-making

In core-making shops, chemical scrubbers are in use. They use either acid (cold-box process) or basic (SO_2-process and Croning). The quantity of waste water discharged is dependent upon the accumulation of pollutants and salts in the circulating water. If pollution levels are too high, part of the polluted water must be drawn off.

Scrubbing solutions from cold-box and hot-box core-making contain readily biodegradable amines and phenols.

The treatment of amine-containing scrubbing solutions requires a nitrification/denitrification stage. These treatment steps can also be carried out in an external biological waste water treatment plant. An alternative to discharge is the recovery of the amines.

Following oxidation, scrubbing solutions from the SO_2 process mainly contain sodium sulphate. Since high sulphate concentrations (>600 mg/l) can lead to damage to sewerage systems, a limit value is set by the respective competent authority according to local conditions (e.g. the presence of sulphate-resistant piping and dilution with other waste water).
[195, UBA, 2003]

4 TECHNIQUES TO CONSIDER IN THE DETERMINATION OF BAT FOR FOUNDRIES

In this section, techniques for environmental protection and energy saving measures are given for individual processing steps. The various techniques are structured into generic topics, which allows a thematic approach to be taken for assessing the various different foundry processes and steps.

The techniques all aim to either optimise the process or to reduce the environmental effects by, e.g.:

- careful selection and optimisation of each unit operation i.e. in: storage, melting and metal treatment, mould and core production, casting
- the reduction of emissions to air and water
- the increase in the efficient use of energy
- the minimisation and re-use of residues.

In line with the thematic approach, information has been organised in the following sections:

4.1. Raw material storage and handling
4.2. Metal melting and molten metal treatment
4.3. Mould- and core-making, including sand preparation
4.4. Metal casting
4.5. Fume, flue-gas and exhaust air capture and treatment
4.6. Waste water treatment
4.7. Energy efficiency
4.8. Sand: regeneration, recycling, re-use, disposal
4.9. Dust and solid residues: treatment and re-use
4.10. Noise reduction
4.11. Decommissioning
4.12. Environmental management tools.

In order to allow the selection of best available techniques, all techniques to be considered in the BAT decision are presented according to a standard structure. The items of this structure are explained in Table 4.1.

Name of the type of information	Type of information included
Description	Technical description of the technique
Achieved environmental benefits	The main environmental impacts addressed by the technique.
Operational data	Data on consumption and emission levels from operational plants using the technique. Any other information on how to operate, maintain and control the technique
Cross-media effects	Any side effects and disadvantages to other media, caused by implementation. Environmental effects of the technique in comparison with others
Applicability	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 (i.e.furnace type, moulding technique, …) and type of product (ferrous, non-ferrous)
Economics	Information on costs (both investment and operational) and possible savings, including details on how these costs have been calculated
Driving force for implementation	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)
Example plants	Reference to plants in which the technique is applied and from which information has been collected
Reference literature	Literature which was used in writing the section and which contains more details

Table 4.1: Information contained in the discussion of each technique included in Chapter 4

This chapter presents the information for each technique. The later balancing and selection of techniques will be dealt with in Chapter 5, but based on the information of Chapter 4.

4.1 Raw material storage and handling

4.1.1 Introduction

The storage and handling of solid materials, gases and liquids is discussed in the Storage BREF [205, European IPPC Bureau, 2003]. The document discusses available techniques for e.g. heaps, silos, tanks and packaged materials (e.g. dangerous and flammable substances). These are applicable for foundry raw materials such as sand, scrap, coke, fuels (gas, oil), chemicals, additives and for residues such as used foundry sand, filter dust and slags. In this section, we will only discuss foundry-specific issues which are not covered by the storage BREF.

4.1.2 Covered storage and impermeable scrap yard

Description
The scrap storage area can be structured and managed in such a way that the following factors are taken into account:
- the composition of the furnace charge necessitates knowledge of the feed material. Applying separate storage for various metal types or grades allows control of the charge composition. This can be achieved using compartments or boxes in the storage area or bunker
- the introduction of mineral and oxide materials such as rust, soil or dirt causes increased refractory wear. The use of a cemented scrap yard prevents the entrainment of soil, dirt or water
- a roof constructed over the storage area can help keep rainwater out and can help contain dust emissions.
- a water collection and treatment system can be used to prevent pollution to soil or water.

Achieved environmental benefits
The use of a roof and a reinforced yard allows the collection of run-off water and therefore prevents uncontrolled emissions to water and soil. Direct emissions to soil are also minimised since mixing of the material with soil is prevented.

Cross-media effects
No cross-media effects apply.

Applicability
The use of an impermeable scrap yard can be applied in the storage of scrap in all new and existing foundries. Scrap is stored under a roof or with the provision of a water collection and treatment system to prevent water and soil pollution.

Driving force for implementation
Control of the charge composition improves control of the furnace operation and hence the metal composition. Also allows the minimisation of refractory wear.

Example plants
This technique is applied in the majority of the foundries.

Reference literature
[202, TWG, 2002]

4.1.3 Storage measures for binder chemicals

Description
Binder chemicals carry specific manufacturer's recommendations for storage. Failure to comply with these recommendations will result in unusable or sub-standard products that either require disposal as special waste or lead to poor casting quality due to sub-standard moulds/cores. Table 4.2 summarises the quality problems arising from the incorrect storage of liquid binder chemicals. Correct storage takes account of these problems.

Problem	Effect on product	Implications	Effect on castings
Exposure to excessive cold	Aqueous-based products may freeze	Product segregation may occur, causing mould failure. Affected products require disposal	Casting production may not be possible
Exposure to excessive heat and sunlight	Premature ageing, cross-linking of resin and increased viscosity	Poor mixing properties, low mould strengths and poor resistance to high temperatures	Fining defects
Prolonged storage or cold storage	Increased viscosity	Dispersion onto sand grains difficult. Sand mixture flows less well and is difficult to compact. Low-strength moulds	Erosion, exogenous (sandy) inclusions finning and dimensional faults
Contamination by moisture	Products containing isocyanates will deteriorate due to reaction with water	Binder performance is poor and product may need disposal	Increased risk of gas defects (pinholes)
Sediment disposal in bulk silicate storage tanks	Pumped liquid may become inconsistent	Low-strength moulds	Oversize castings and shrinkage effects

Table 4.2: Problems arising from an incorrect storage of liquid binder chemicals [71, ETSU, 1998]

Some basic measures include:
- roofed and ventilated area
- collection of spilled liquid
- locked storage area.

Depending on the climate, exposure to excessive cold or heat, and sunlight can be accounted for. Additional precautions are necessary for the storage of highly flammable liquids such as methyl formate, triethylamine (TEA), dimethylethylamine (DMEA) and mould coatings containing isopropyl alcohol.

Achieved environmental benefits
Reduction of the amount of waste chemicals arising, which are unsuitable for use.

Most binder chemicals are hazardous, and are characterised by one or more of the following properties: toxic, corrosive, flammable. These properties mean that even small spills can pose a danger to worker's health and safety, while larger releases can result in a serious incident. A major spill that is allowed to enter a surface water drain can cause serious pollution of watercourses.

Cross-media effects
No cross-media effects apply.

Applicability
This technique applies to all new and existing installations.

Driving force for implementation
Safety measures and optimisation of foundry operations.

Example plants
This technique is applied in the majority of the foundries.

Reference literature
[75, ETSU, 1996]

4.1.4 Use of clean scrap for melting and removal of sand from the return material

Description
Melting clean scrap prevents the risk of non-metal compounds being taken up by the slag and/or attacking the furnace lining. These compounds are typically lime, iron oxides, manganese oxides, and basic oxides (e.g. MgO from nodular iron returns) in combination with silicon refractory (acid). If the amount of contamination is limited, this will reduce the amount of slag formed and will allow a longer lifetime of the furnace and ladle lining. For nodular iron production using a furnace with acid refractory, the adhering silica sand may have a beneficial effect, since it neutralises the MgO coming from foundry returns.

The presence of contaminants and oxides in the furnace load, will consume part of the melting energy. Furthermore, the removal of slags necessitates a higher bath temperature to keep the slags in a liquid state.

Internally recycled scrap consists of feeders systems and rejected casting. Feeder systems are knocked off after shake-out. In general they do not retain adhering sand, due to their geometry. Rejected castings are excluded upon quality control, which is carried out after the castings are cleaned using sand blasting or shot blasting to remove all adhering sand. The use of sand-free return material therefore, in general, necessitates no extra treatment.

Achieved environmental benefits
This technique reduces the amount of slags and dust that need disposal and limits VOC-emissions. The energy consumption is reduced (by 10 to 15 %) due to the reduced amount of slag. Additionally the extracted airflow may be reduced.

Shot blasting of the scrap can be recommended for scrap where its contamination would lead to the production of excessive amounts of slag. The use of only shot-blasted scrap would actually require slag-forming additives to create the slag.

Cross-media effects
If foundries only accept clean scrap, the overall recycling rate for dirty scrap will reduce. This will generate a need for additional cleaning operations and increase the disposal of scrap.

The use of cleaning techniques to remove sand from return material consumes energy. This is balanced however by the energy gained in the melting stage.

Operational data
An energy consumption to clean 30 - 40 kg of sand from 1 tonne of casting of 12 - 15 kWh has been reported for an operational foundry. The consumption level is dependent on the size and type of casting.

For a steel foundry using EAF melting, an increase in molten metal recovery (poured metal/charged metal) of 2 to 3 % has been reported.
A typical metal charge for EAF is: 55 % foundry steel scrap; 40 % internal returns; 5 % metal correction additions.

Applicability
The removal of sand from internal scrap can be applied in all new and existing foundries. The use of clean scrap for melting can be applied in all foundry types, but the choice of the scrap grade should be related to the techniques installed for melting and gas cleaning. If the whole sector shifts to clean scrap, this will generate a problem for the recycling of dirty scrap.

The use of clean ferrous scrap (both steel and pig iron) will lead to increased purchase costs and will require investment in new cleaning equipment. There are no difficulties caused by scrap surface oxidation nor by using pig iron ingots during melting in cupola furnaces (reduction process). Electric furnaces will have difficulties only with contaminated scrap which does not comply with the parameters for steel scrap used in foundries.

Cupola furnaces can easily melt scrap which is not clean. There is little coke overconsumption and little environmental consequence, if the gases are correctly treated.

Limiting the slag is very important for good operation of the coreless induction furnace. The operation is more affected by the scrap cleanliness than the other furnace types.

The use of dirty scrap has no adverse effects on rotary furnace operation but is the main determining factor for dust emissions. There is little environmental consequence if the gases are correctly treated.

Economics
The price for clean scrap (i.e. class 1) is 20 to 30 % higher than that for contaminated (i.e. class 2) scrap. Furthermore, disposal costs for slags and dust are reduced by applying this technique.

Driving force for implementation
High disposal fees for residues and high prices for the refractory.

Example plants
This technique is commonly applied in foundries.

Reference literature
[103, Vereniging van Nederlandse Gemeenten, 1998], [110, Vito, 2001], [202, TWG, 2002]

4.1.5 Internal recycling of scrap ferrous metal

Description
Internal scrap is produced from the knock-off of feeders and runners, in quality control and in finishing operations. The relative amount of internal scrap produced can be calculated from the metal yield as defined and described in Section 3.10.1.3. In order to minimise residue production, internal scrap is returned to the scrap metal feed of the furnace.
For steel foundries, a 100 % use of return metal is uncommon, due to the amount of dissolved gas. Operators consider 60 % to be the maximum amount of return metal (feeders, scrap castings,...) in the charge metal. Swarf and turnings may cause excessive molten metal oxidation.

Internal scrap recycling may also be limited in the case of nodular base iron melting, as a high amount of silicon (about 1 % in most cases) is added in the liquid iron during the metal treatment. In some cases re-melting the whole internal scrap is not possible because the final silicon would be too high (typically 2.5 – 3 % in the castings).

In the case of grey or nodular iron, lead or bismuth are very noxious for the properties of the metal after solidification. If there has been a pollution incident the returns (internal scrap) must not be recycled.

Achieved environmental benefits
Minimisation of residues through recycling of raw materials.

Cross-media effects
No cross-media effects apply.

Applicability
This technique applies to all new and existing installations.

Economics
The technique does not involve any additional costs.

Driving force for implementation
Minimisation of residues, optimal use of metal.

Example plants
The technique is applied in all European foundries.

Reference literature
[202, TWG, 2002]

4.1.6 Internal recycling of magnesium scrap

Description
"In cell" recycling:
Clean feeders can be directly melted in the melting furnaces. Because of oxides and other inclusions, the possible amount of recycling is limited. Specialised equipment for exact analytical and metallographical control is necessary.

"In house recycling":
Here the scrap is treated and recycled at a separate recycling-plant on-site at the foundry. Two techniques may be applied:
- *Fluxless re-melting:* Re-melting of Mg scrap under a covering gas in a hearth type furnace; applicable only to class 1 scrap. Advantages are the low additional investment and low energy consumption
- *Salt re-melting:* Re-melting of Mg scrap under a salt cover. Is applicable to the processing of all scrap classes except used fluxes and sludge (not treated). If only class 1 – 2 scrap is used, HP (high purity) magnesium alloys may be produced.

Both techniques can be used to produce Mg-ingots or molten metal for liquid charging.
Both in fluxless and salt-covered re-melting, dross (the floatings on the melt) and sludge (the sinkings in the melt) are generated, as well as residues retaining a residual metal content (70 - 80 % Mg for sludge, 60 – 90 % Mg for dross). For recovery of the metal content, three options exist:
- salt re-melting (in the same or a separate furnace)
- re-melting in the aluminium industry
- utilisation in the desulphurisation of iron or steel.

If the scrap is re-melted in a fluxless melting furnace, the salt re-melting of dross and sludge involves the operation of a separate furnace.

The re-melting of mixed class scraps is performed using salt re-melting. The mixed scrap needs pretreatment. Table 4.3 gives a survey of the input-outputs of a pretreatment installation.

Inputs	Equipment	Outputs	End-of-pipe technology
- oily or wet Mg-turnings (>2 % oil/water) - electricity	**Centrifuge**	- Mg-turnings (<2 % oil/water) - oil/water-emulsion	
- centrifuged and all other turnings - electricity	**Turning–press (T = 400 °C)**	- pressed turning - exhaust air	Particle separator for the vaporised oil
- feeders, bad castings - dross (without salt, from the foundry process) - electricity	**Shredder (if necessary)**	- shredded material - dust	

Table 4.3: Inputs and outputs for a magnesium scrap treatment plant [202, TWG, 2002]

The recovery of metal from the re-melting salt residue is done using dry crushing and screening with magnetic separation or by using a wet washing system. The wet system produces a magnesium fraction and a sludge, which, after dewatering, may be used in fertiliser industry.

Achieved environmental benefits
The main benefit is the optimised recycling of magnesium. Internal recycling has the added benefit of eliminating transport to an external recycling plant. The metal efficiency of the recycling is increased by type-specific melting.

Cross-media effects
Fluxless re-melting involves the use of sulphur containing protective gases, which contribute to global warming (SF_6) or are poisonous (SO_2). This issue is discussed in 4.2.7.1.

Operational data
Experimental mass flow diagrams for the re-melting of class 1 scrap are given in Figure 4.1 and Figure 4.2. These include the internal re-melting of sludge and dross.

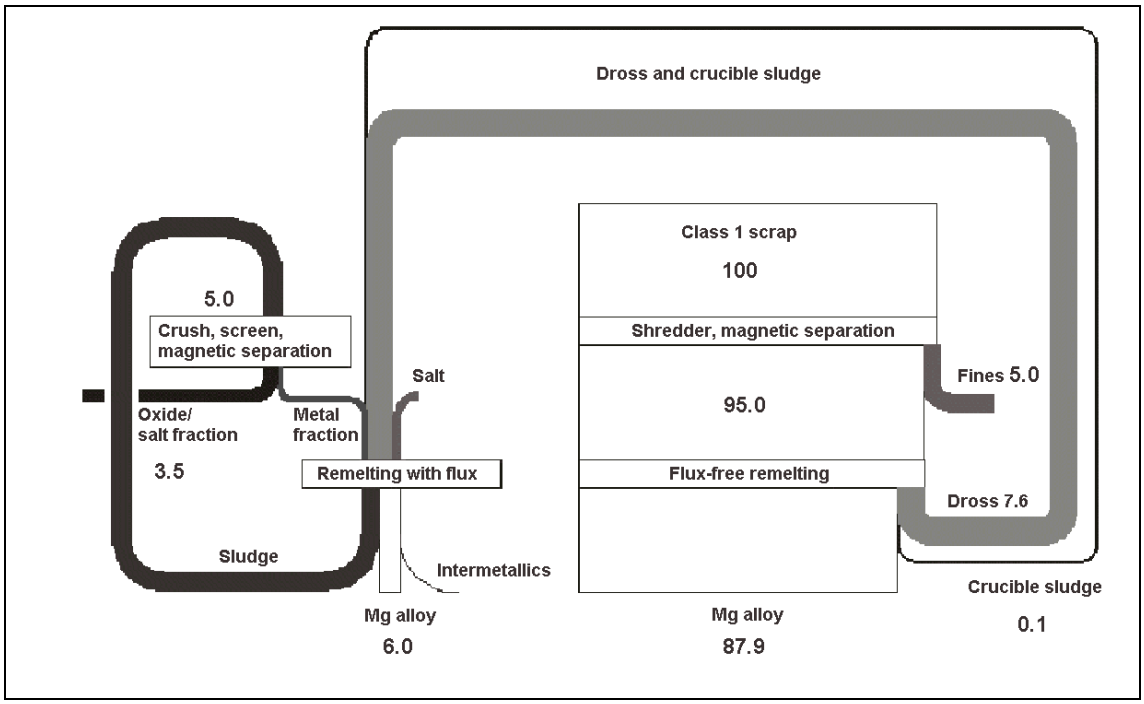


Figure 4.1: Mass flow diagram for the fluxless re-melting of magnesium class 1 scrap [206, Ditze and Scharf, 2000]

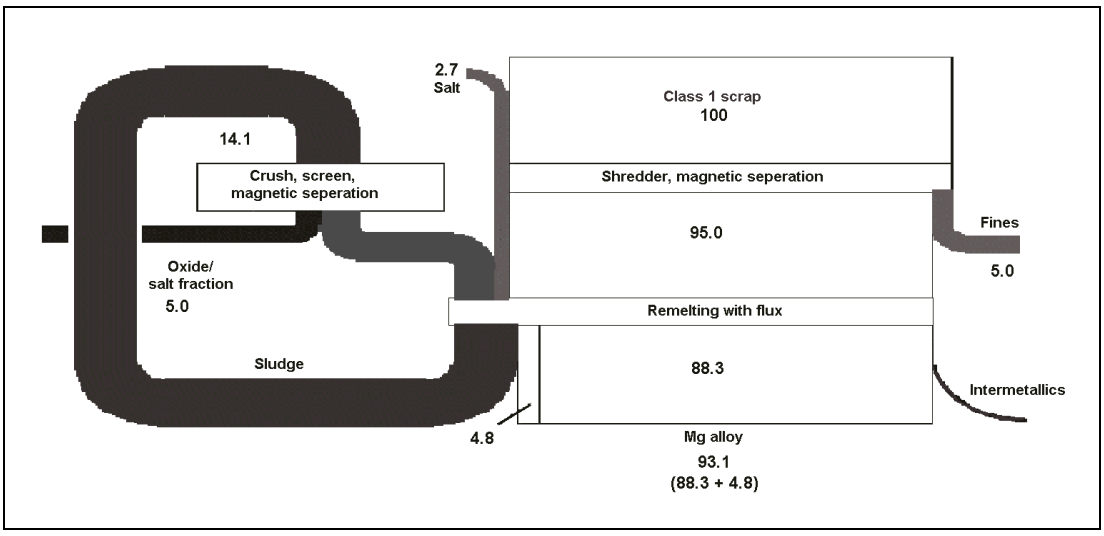


Figure 4.2: Mass flow diagram for the salt re-melting of class 1 magnesium scrap [206, Ditze and Scharf, 2000]

Operational data from a 2000 tonne/yr salt re-melting plant for mixed treated scrap (3 furnaces with a capacity of 600 kg each) give consumption levels of salt: of 3.4 kg/tonne scrap and natural gas: of 26.5 Nm^3/tonne scrap.

The wet treatment of the salt fraction produces a magnesium fraction (43 %) and a sludge (57 %). The sludge is dewatered using a membrane filter press and the water is re-circulated into the process.

Applicability
This technique is applicable for new and existing magnesium foundry installations.

Economics
Costs for external recycling are estimated to be approximately EUR 1200/tonne, depending on the type of transport used, the transport distance and the local market. The costs for in-house recycling are EUR 500/tonne, a difference of EUR 700/tonne. For a single plant with 1500 tonnes/yr recycling material this means a potential saving of more than one million euros per year.

The given data are general and have to be adapted individually for each enterprise. Depending on the products and the processes used, the expenses needed for separation of the waste have to be taken into account. The waste has to be collected specifically for every alloy and every procedure.

Further factors of major influence are:

- depreciation (approximately 10 % in a depreciation period of 5 years)
- personnel costs (35 – 40%)
- cost for new material (approximately 30%) to substitute the material loss (estimated 7%)
- costs for energy, maintenance, spare parts, salt, disposal (20 – 25%).

The amortisation of a flux-based facility with two furnaces is in the range of 8 to 11 months. The amortisation of a continuous facility with 500 kg magnesium per hour will likely take a few months more.

Driving force for implementation
Optimisation of magnesium use, with a reduction of the amount of magnesium sent for disposal.

Example plants
TCG Unitech, Kirchdorf/Krems (A): uses an in-house recycling facility.
No fluxless re-melting plants have been reported in Europe, although the melting technology is available on the market.

Reference literature
[202, TWG, 2002], [206, Ditze and Scharf, 2000], [223, Rauch, et al., 2003]

4.1.7 Recycling of used containers

Description
Suppliers of chemicals and additives may take back their empty containers (plastic, wood, metal) for recycling. The use of the largest size container possible may be considered.

Achieved environmental benefits
Prevents waste and further stimulates recycling.

Cross-media effects
If containers are returned without further cleaning, no cross-media effects apply.

Applicability
This technique is applicable in all new and existing installations.

Economics
Economic data differ from site to site and depend on the conditions agreed with the supplier.

Driving force for implementation
Prevention and recycling schemes for waste and packaging waste regulations.

Example plants
This technique is commonly applied in European foundries.

Reference literature
[110, Vito, 2001]

4.2 Metal melting and molten metal treatment

4.2.1 Cupola furnaces

In this section, techniques concerning melting practices and furnace operation will be discussed. These techniques may apply either to cold or hot blast operation, or to both. Flue-gas related techniques, such as post combustion and flue-gas cleaning, are discussed in Section 4.5.2. That section also discusses the conversion of cold blast to hot blast cupola furnaces.

4.2.1.1 Optimisation of furnace operation

Description
The amount of dust and exhaust gases resulting are directly related to the amount of coke charged per tonne of iron. Therefore, all measures that improve the thermal efficiency of the cupola will also reduce the emissions from the furnace.

Possible good melting practice measures include:

- *Operating the furnace in its optimum regime as much as possible*: For any given cupola, the influence of the blast rate and the coke charge on the tapping temperature of the metal and the melting rate, can be expressed in the form of a net diagram or Jungblüth diagram. A net diagram is only valid quantitatively for the cupola for which it was obtained. It displays how the metal temperature and melting rate behave upon changes in the blast rate and coke charge, and allows determination of the point (or line) of optimal thermal efficiency
- *Avoiding excess temperatures* of the melt and reducing the superheating temperatures by taking measures during the handling of tapped metal
- *Uniform charging*: taking care during charging to get a uniform distribution of metal and coke
- *Improving the control* of the charge weight, the blast airflow and the metal temperature
- *Minimising air losses*: The correct supply of air is essential for efficient cupola operation. This is often hampered by air losses. Therefore, it is important to pay close attention to the prevention of all leaks to ensure efficient operation. Slag holes on intermittently tapped cupolas are often left open and are frequently oversized, resulting in considerable air losses. Air losses are particularly common for hot blast cupolas. They take place in the heat-exchanger. The consequence is that oxygen must be injected in the tuyères instead of the air which is lost
- *Avoiding "bridging" in the cupola*: Bridging and scaffolding are the hanging or non-descent of cupola charges in the cupola shaft. This causes a loss of melting efficiency, and in severe instances melting can be completely stopped
- *Utilising good lining practice*: As melting proceeds, the diameter and the area of the melting zone increase due to lining erosion and wear. This affects the operation, moving it away from the optimum. Minimising the lining attack is therefore an energy saving measure. For satisfactory and economic cupola operation the melting zone needs to be efficiently repaired after each melt.

Achieved environmental benefits
Increased energy efficiency, reduction of cokes consumption, reduction of residues.

Cross-media effects
No cross-media effects are reported

Applicability
This technique applies to all new and exisiting cupola furnaces.

Driving force for implementation
Optimisation of furnace operation.

Example plants
Good melting practice measures are applied in all cupola foundries.

Reference literature
[32, CAEF, 1997], [44, ETSU, 1993], [202, TWG, 2002]

4.2.1.2 Quality control of coke input

Description
The quality of the coke used has a direct bearing on the efficiency of cupola operations. It particularly affects the initial temperature carbon pick-up and the sulphur content of the iron. Specifying the foundry coke involves testing the following contents:

- *Fixed carbon*: The higher the carbon content, the higher the calorific value
- *Ash content*: A high ash content is undesirable since it lowers the calorific value of the coke and generates a greater volume of slag in the cupola
- *Volatile matter*: Volatile matter is undesirable since it reduces the fixed-carbon content, and thus the calorific value of the coke
- *Sulphur*: Sulphur is well known as an unwanted element in any type of cast iron and leads to SO_2 emissions. The lower the sulphur content of the feedstock coke, the better. The sulphur content of the coke depends on the sulphur content of the feedstock coal. Unfortunately there is no known method to remove sulphur from coal
- *Moisture*: Moisture in the coke when dispatched from the coke oven is undesirable, since it reduces the amount of carbon available by weight. However, it is necessary for the coke to contain some moisture, to avoid fires on conveyer belts and in lorries and wagons
- *Size*: The size of the foundry coke directly affects the coke consumption per tonne of iron melted and also the melting rate. To achieve optimum performance the coke size dispatched from the coke oven generally needs to be sized such that the furnace coke has a mean size diameter greater than 90 mm, with no more than 4 % smaller than 50 mm. The content of fines will influence emissions of dust during (un)loading and handling.

Achieved environmental benefits
Optimising the coke input results in a higher process efficiency.

Cross-media effects
No cross-media effects apply.

Operational data
Typical properties of foundry coke are given in Table 4.4:

Property	Typical value (%)	Limit value (%)
Ash	5.8 – 5.9	6.5 max.
Volatile matter	0.3 – 0.4	0.8 max.
Sulphur	0.68 – 0.70	0.75 max.
Moisture	1.5 – 2.5	3.0 max.
Strength M80 Micus index M10 Micus index	 81 – 82 8 – 8.5	 78.0 max. 9.0 max.
Fixed carbon	93.7 – 93.8	93.0 min.
Higher calorific value	32200 kJ/kg	31800 kJ/kg

Table 4.4: Typical properties of foundry cokes
[197, Nalonchem, 2002]

The data in Table 4.4 are taken from supplier specifications. Local standards may use higher limit values.

Applicability
The technique is applicable to all new and existing cupola installations.

Economics
In general, low sulphur feedstocks are more expensive.

Driving force for implementation
To improve the efficiency of the foundry process.

Example plants
This technique is commonly applied in European foundries using cupola furnaces.

Reference literature
[44, ETSU, 1993], [225, TWG, 2003]

4.2.1.3 Operation with acidic or basic slag

Description
A flux is used to render the slag fluid enough to separate from the iron and to allow it to flow freely from the cupola. The most commonly used flux is limestone (calcium carbonate), which calcines in the cupola shaft to form lime, a basic oxide, which then combines with the other slag-forming constituents (mainly acidic in character) to provide a fluid slag.

The basicity of a slag is given by the following ratio: (CaO % + MgO %)/SiO_2 %

Most cupolas operate with an acidic or slightly basic slag (basicity <1.2). Basic cupolas (basicity up to 2) offer 3 advantages:
- higher carbon
- lower sulphur
- possibility of charging lower quality scrap.

But they present the following disadvantages:
- silicon losses are high
- refractory costs are high, unless operating with a liningless cupola
- fluxing material costs are higher
- metal analysis is more difficult to control than acid cupola melting.

Achieved environmental benefits
For acidic cupolas, dry filters can be used. The slag of basic cupolas has a higher melting point. So a flux based on CaF_2 is generally used to make it fluid. In this type of cupola, there are emissions of fluor-containing components. This necessitates the application of wet scrubbers for efficient capture of these components.

Applicability
This technique applies to all new and existing cupola installations. If basic slag is used, a wet dedusting is necessary.

Example plants
This technique is commonly applied in European foundries using cupola furnaces.

Reference literature
[44, ETSU, 1993], [202, TWG, 2002], [225, TWG, 2003]

4.2.1.4 Increasing shaft height of CBC

Description
The required shaft height for cupolas at various melting rates is given in Table 4.5. These shaft heights optimise the preheat for the descending burden. However, if the gas is to be burned at the charge-hole, a shorter shaft height may be considered. In general, the shorter the shaft, the hotter the top gas and the greater the ease of combustion – either spontaneous or assisted by an afterburner.

Melting rate of Cupola (tonne/h)	Height from tuyères to charging door sill (m)
Up to 5	4.9
5 – 8	5.8
>8	6.7

Table 4.5: Shaft height requirements

The thermal efficiency of the cold blast cupola furnace can be improved by increasing the shaft height. In general, the higher the furnace shaft, the longer the combustion gases remain in contact with the charge, and the more heat is transferred to the charge.

Achieved environmental benefits
Depending on the installation type, the height must be optimised to allow burn-out of the gases and efficient heating of the charge.

Cross-media effects
No cross-media effects apply.

Operational data
Operational data are given in Table 4.6. The modification involves a doubling of the upper zone volume. This results in a reduction of coke consumption from 140 to 115 kg/tonne, which is a relative reduction of 18 %. It should be noted that in general an optimal shaft height follows the rule-of-thumb: 'height = 5 x diameter at tuyères'. The initial situation in the example furnace was therefore sub-optimal.

	Cupola before modification	Cupola after modification
Diameter		
- melting zone (m)	1.4	1.4
- upper zone (m)	1.4	1.7
Heigth over tuyères (m)	5	6.5
Coke ratio (kg/tonne)	140	115

Table 4.6: Example data for the change in coke consumption upon shaft height increases [202, TWG, 2002]

Applicability
Optimisation of the furnace height needs to be performed at the design stage of the furnace, otherwise height increases will usually only be performed during major re-building works of the furnace.

Driving force for implementation
To increase the efficiency of the furnace operation.

Example plants
Operational data are taken from an example plant in France.

Reference literature
[32, CAEF, 1997], [44, ETSU, 1993], [202, TWG, 2002]

4.2.1.5 Installation of secondary row of tuyères for a cold blast cupola (CBC)

Description
The thermal efficiency of the cold blast cupola furnace can be improved by the installation of a secondary row of tuyères. These provide extra oxygen above the combustion zone, which induces the oxidation of the CO in the combustion gases, the CO being formed by the endothermic reduction of CO_2 by C (coke). This technique liberates the "latent" heat of the combustion gases, thus improving the thermal efficiency of the cupola.

The divided blast cupola is equipped with two rows of tuyères, each supplied with a measured and controlled quantity of blast air. Compared with a normal cupola, fitted with a single row of tuyères, the divided blast cupola enables:

- a higher metal tipping temperature and higher carbon pick-up to be obtained for a given charge-coke consumption
- the charge coke consumption to be reduced and, if required, the melting rate to be increased, whilst maintaining a given metal tapping temperature.

To obtain the maximum benefit from divided blast operation, the blast should be divided 25 - 50 % top and 75 – 50 % bottom. The 2 rows should be spaced about 1m apart (cold blast) to 0.5 m (hot blast). Each row of tuyères needs to be provided with its own blast supply system.

Achieved environmental benefits
A reduction in coke consumption and an increase in thermal efficiency.

Cross-media effects
No cross-media effects apply.

Operational data
By the use of two rows of correctly-spaced tuyères with the blast equally divided between them, the metal tapping temperature can be increased by approximately 45 – 50 ºC for a given coke consumption. Alternatively, the coke consumption can be reduced by 20 – 32 % and the melting rate increased by 11 – 23 %. When operating with a divided blast but without reducing the coke charge, so that a higher melting temperature is obtained, the carbon pick-up tends to increase slightly (by approx. 0.06 %), and the melting loss of silicon tends to also increase, by approximately 0.18 %.

With divided blast operation, the lining burn-out extends further into the furnace shaft. At the start of a melt it is therefore necessary to measure and adjust the coke bed height. On melts of short duration, i.e. those less than about 2 – 3 hours, the saving in coke charge does not usually compensate for the additional requirements of bed coke. Nevertheless, even on short melts, the higher tapping temperature and the higher carbon pick-up obtainable with divided blast operation can be an advantage to many foundries.

Other reported advantages are:
- the exit gas temperature is only 250 ºC, compared to the conventional cupola, where the temperature is 450 ºC
- it can take 100 % bigger chunks of re-melting scrap
- it is possible to increase the steel scrap ratio in the metal charge.

Additional operational data are given in Annex 1.

Applicability
The second row of tuyères is applied as a standard technique for new cold blast cupola installations and may be applied to existing installations during reconstruction. This technique is not normally applied for hot blast operation

Economics
The divided blast cupola has been well proven in practice as a means of obtaining economic operation for a modest investment cost.

The capital cost of converting existing cupolas to divided-blast operation is low compared to the savings obtained. BCIRA quoted one British foundry where the payback period was only fourteen weeks. A large Canadian foundry saved CAD 170000 in one year for a conversion cost of only CAD 18000. An additional benefit from a lower coke use per tonne of iron is the lower sulphur content, this saves on the desulphurisation plant and gives a higher quality iron.

Additional economic data are given in Annex 1.

Driving force for implementation
To increase the efficiency of the melting operation.

Example plants
In France, all the recent cold blast cupolas use 2 rows of tuyères: STAUB (Merville), FONTE ARDENNAISE (Vivier au court), BERNARD HUET (Vivier au court). There is also 1 hot blast with 2 rows: FIDAY GESTION (Chassey les Scey)

Reference literature
[32, CAEF, 1997], [196, Unido, 2002], [202, TWG, 2002], [225, TWG, 2003]

4.2.1.6 Oxygen enrichment of blast supply

Description
The thermal efficiency of the cold blast cupola furnace can be improved by oxygen enrichment of the combustion air. This gives rise to a higher combustion temperature of the coke. In this way coke consumption can be decreased or higher temperatures of the tapped metal can be obtained.

Compared with normal operation, the continuous use of oxygen enables one of the following improvements to be made:
- a higher metal temperature, higher carbon pick-up and lower melting loss of silicon for the same coke consumption, or
- a lower coke consumption for a given metal temperature, with no increase in carbon pick-up or reduction in the melting loss of silicon, or
- an increased output from an existing cupola, as a result of the increased melting rate.

Oxygen injection provides the possibility of reacting quickly to process drifts, and then compensating for small changes in process conditions. Thus, oxygen injection is often used intermittently, usually whenever the process requires adjustment.

The effectiveness of the oxygen depends on the method by which it is introduced into the cupola. Three processes have been developed:
- *Direct enrichment of the blast supply*: Oxygen is fed into the main blast, this technique is applied in the majority of the cold blast cupolas
- *Injection into the well*: Oxygen is injected into the coke bed from a ring-main which supplies water-cooled injectors, whose number depends on the cupola size. Oxygen used in this way is at least twice as effective as when it is used to enrich the blast supply directly. However, this type of injection is confined to continuously-tapped cupolas, since with intermittent tapping there is a risk that slag and or metal may rise to the level of the injectors. The technique was developed in the UK but it has not found widespread application
- *Injection at the tuyères*: Oxygen is introduced into the cupola through injectors inserted into each tuyère or into alternate tuyères. The effectiveness of this method lies between direct blast injection and well injection methods. This technique is used in 20 – 30 % of cases, but more in hot blast operation.

The principles of oxygen injection are depicted in Figure 4.3.

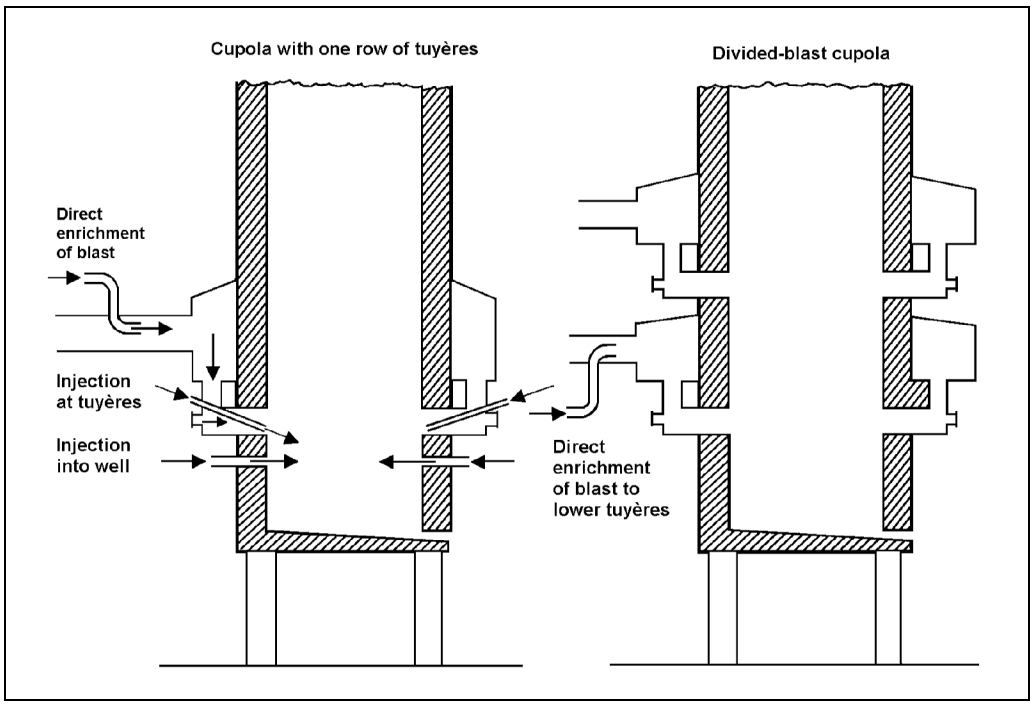


Figure 4.3: Various methods of oxygen injection
[44, ETSU, 1993]

Achieved environmental benefits
The application of oxygen results in a reduced coke consumption and a better process control. Additionally, a reduction in the emission of dioxins and furans from cold blast cupolas have been reported (see Section 4.5.1.4).

Cross-media effects
The technique requires oxygen which is produced off-site and involves a consumption of electric energy.

Operational data
Compared to conventional cold blast operation with one row of tuyères, the increase in tapping temperature obtained for a given charge of coke, can be expected to be as follows:
- blast enrichment + 15 ºC
- well injection + 85 ºC
- tuyère injection + 40 ºC

Divided blast operation with a direct enrichment of blast air, results in an increase in the tapping temperature of 85 ºC compared to cold blast operation. In divided blast operation, neither well injection nor tuyère injection give any greater benefit than the simple method of direct injection.

An important application of oxygen has been to increase the melting rate of an existing cupola, well beyond its usual optimum melting capacity. In divided blast cupolas, the melting rate increases by around 6.8 % and the tapping temperature by about 20 ºC for each 1 % of direct oxygen enrichment in the blast air. If an increase in temperature is not required and the coke charge is reduced, an even greater increase in the melting rate can be obtained for the same blast rate and oxygen enrichment.

Additional operational data are given in Annex 1.

Applicability
Today, almost all European hot blast cupolas inject oxygen through the tuyères. For cold blast furnaces, the use of oxygen enrichment can be considered as the standard technique. In this

case, enrichment of the blast supply is usually applied. The oxygen level of the oxidising air mixture is usually between 22 and 25 % (i.e. an enrichment of 1 % to 4 %).

Economics
The effect that using oxygen has on melting costs greatly depends on the price of oxygen, which in turn is related to the amount used. Foundries with larger outputs can generally buy oxygen more cheaply. The economic case for using oxygen has to be established on a case-by-case basis.

The substantial increase in outputs obtainable has enabled foundries to increase outputs without high capital investments in new plant, and to reduce costs and overtime payments, so much so that the overall reduction in costs amply justify the cost of oxygen. Such improvements must take into account the related core and mould making capacity.

Driving force for implementation
To optimise the efficiency and control of the melting process.

Example plants
This technique is commonly applied in European foundries using cupola furnaces.

Reference literature
[32, CAEF, 1997], [156, Godinot, 2001]

4.2.1.7 Superheating of HBC blast air

Description
An alternative technique for increasing the flame temperature is to superheat the blast air to 800 – 900 ºC. For this, injection of an air plasma, or heating in tubular resistance heaters is applied. Experience has shown that increasing the blast temperature by 200 ºC, from 550 ºC to 750 ºC, which takes 60 kWh per tonne of iron, saves 10 kg of coke per tonne melted. The main benefit, more important even than saving coke, is the flexibility: the hourly output can be increased by 30 % without modifying the melting bed. Additionally, the application of (plasma) superheating allows a change in raw material from clean cast iron to steel, with a subsequent positive economic effect.

Achieved environmental benefits
Reduced coke consumption and increased efficiency of the process.

Cross-media effects
Electrical heating causes an increase in electricity consumption (58 kWh/tonne).

Operational data
Operational data are given in Annex 1. The heating of the blast air produces a lower flue-gas volume as compared to hot blast long campaign operation. As compared to oxygen injection, the flue-gas volume and electricity consumption is larger.

Applicability
The technique applies to new and existing HBC furnaces.

The technique (both with electrical and plasma heating) achieves a similar effect as injection of oxygen through the lances, but can be applied in a more complex installation and produces a larger flue-gas volume. Additionally, oxygen injection allows make-up for leaks in the air circuit.

Economics
Economic data are given in Annex 1.

Driving force for implementation
To optimise the efficiency and to control the melting process.

Example plants
PSA, Sept-Fons, France
Three foundries in France apply tubular resistance heating.

Reference literature
[156, Godinot, 2001]

4.2.1.8 Minimal blast shut-off periods for HBC

Description
A cupola blown just intermittently will not operate efficiently, and will result in a reduced metal tapping temperature, as shown in Figure 4.4.

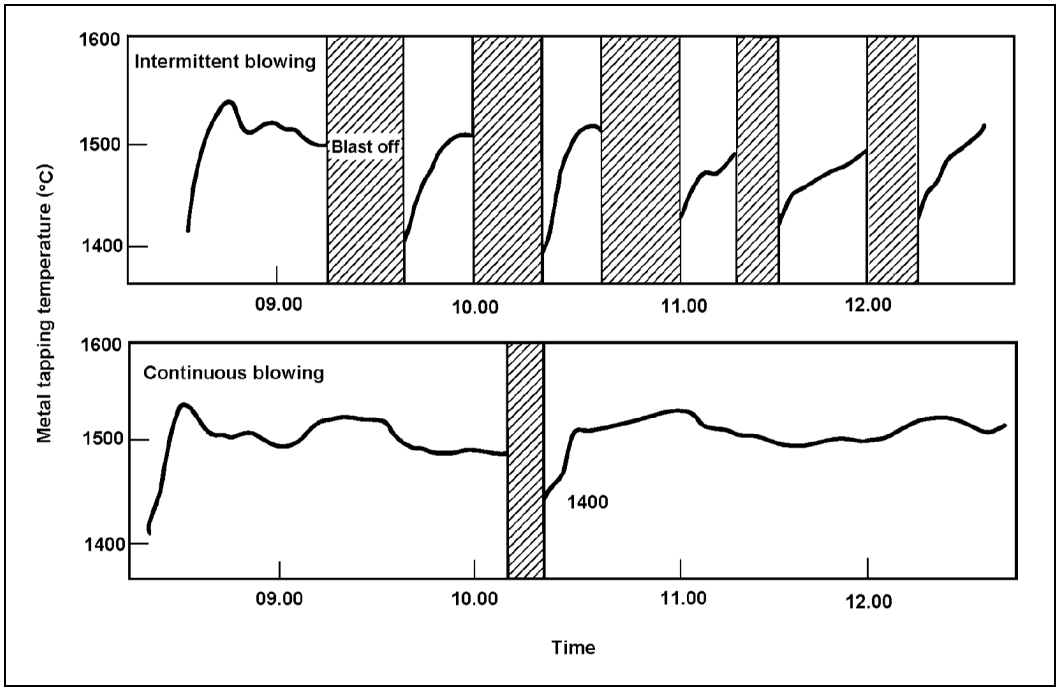


Figure 4.4: Effect of blast shut-off periods on tapping temperature in a post-blast cupola [44, ETSU, 1993]

Frequently shutting off the blast due to only intermittent demands for metal:
- reduces the average tapping and pouring temperatures and increases the extent of their variations, with a consequent risk of producing defective castings
- increases the variation in metal composition, particularly the carbon and silicon content, with a danger of then producing 'off-grade' metal
- increases the coke consumption, through the operators' attempt to improve the tapping temperature
- affects the degree of nucleation in the iron and increases its shrinkage tendencies.

Moulding and casting schedules are therefore programmed to produce a reasonably constant demand for metal, thereby minimising or even eliminating the need for blast shut-off periods or for large variations in the blast rate.

Where large fluctuations in demand are unavoidable, the installation of an electric holding furnace might be considered. This can provide a large buffer reservoir for metal, to take up

variations in demand, so that the cupola can be operated continuously at a reasonably consistent blast rate. It can also be used to help even out variations in temperatures and composition.

Achieved environmental benefits
Reduction of cokes consumption. Higher process energy efficiency.

Cross-media effects
Operating the electric holding furnace incurs a higher energy consumption.

Applicability
This technique is applicable to all new and existing cupola furnaces.

Economics
The economics of installing a holding furnace must be very carefully considered, particularly in foundries with relatively low production rates.

Driving force for implementation
To increase the efficiency of the foundry process.

Example plants
The applicable blasting regime is part of the operational considerations in all European foundries using cupola furnaces.

Reference literature
[44, ETSU, 1993]

4.2.1.9 Cokeless cupola furnace

Description
In the cokeless cupola, the metal charge is heated by the combustion of natural gas. Instead of the traditional coke bed, a bed of refractory spheres on a water-cooled grid supports the metal charge. The molten metal droplets run through this bed and are collected in the well at the bottom of the furnace. The life of the spheres exposed to the superheating temperatures of the metal is limited. A cokeless cupola is therefore run at a reduced temperature (1400 ºC instead of 1500 ºC) and superheating of the liquid metal is done in an attached gas-fired or induction furnace (duplex operation).

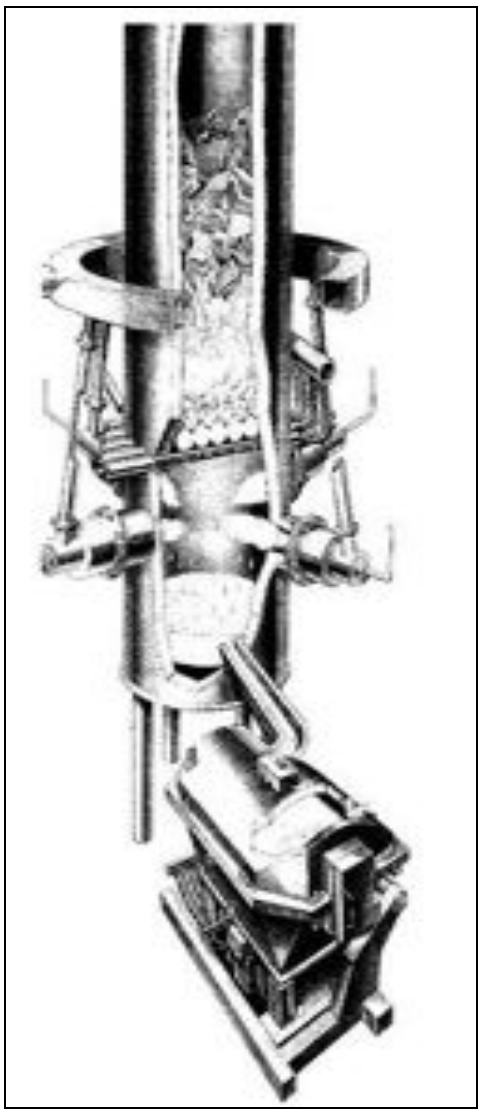


Figure 4.5: Cokeless cupola furnace in duplex operation
[110, Vito, 2001]

An important operational factor is that the cokeless cupola has to be run continuously. There is a high risk of clogging and blocking on the cooled grate bars. In case there is a need to stop the metal flow (e.g. due to problems in the moulding shop), the power of the burners can be reduced to 35 – 40 %, in order to compensate for wall heat-losses. The need for continuity needs to be balanced with the usage of refractory in the melting zone. Therefore, melting campaigns of one week are typically used.

The oxidising atmosphere and relatively low flame temperature cause increased oxidation losses. This limits the possibility to feed in steel. A maximum amount of 35 % of steel is used in the production of nodular iron, though 20 % can be considered general practice. The quality of the feed needs to be well controlled since the cokeless cupola is more susceptible to bridging than the coke-fired cupola.

In the production of nodular iron, an important advantage of the cokeless cupola is that there is no resulphurisation, so the melt may be used immediately after recarburisation.

Achieved environmental benefits
Besides a higher thermal efficiency, this furnace has other environmental advantages. The combustion of natural gas instead of cokes has the following consequences for the flue-gas:

- less dust (0.8 kg/t metal charge instead of 10 to 15 kg/t metal charge for cold blast cupola)
- no CO or SO_2 and less CO_2 (120 kg/t metal charge instead of 450 kg CO_2/t metal charge for cold blast cupola)
- the flue-gas rate is smaller (495 m³/t metal charge instead of 770 m³/t metal charge for cold blast cupola without water-cooled refractory), and hence the dedusting installation can be designed much smaller.

Cross-media effects
The use of cokeless cupola melting necessitates duplex operation, in order to allow superheating of the iron. For superheating in an induction furnace, there is an increased need for electrical power compared to the hot blast operation.

Operational data
Operational data are given in Table 4.7. The furnace is generally operated at an air factor of $\lambda = 1.15$. The capacity of the furnace may be high (often in the range 10 – 12 t/m².h). The amount of spheres is 1 – 1.4 % of the metal charge. The energy efficiency of the cupola, without taking the coupled induction furnace into account, is in the range of 70 %.

	Units	Consumption (per tonne of molten metal)
Natural gas consumption		
Preheating of the furnace	m³	600
Melting	m³	48.0
Electrical energy consumption		
a) Superheater		
Superheating	kWh	64.0
Holding	kWh	15.0
b) Auxiliary equipment	kWh	25.0
Consumption of lining material		
Furnace shaft	kg	5 – 8
Syphon	kg	0.7
Superheater	kg	0.5
Water consumption	m³	0.4
Oxygen consumption	m³	19.7
Metallic charge	**Components**	Part (%/t)
	steel	25 – 35
	pig iron	20 – 30
	returns/cast iron scrap	35 – 55
Alloying and additives	**Components**	Part (%/t)
	Carburiser	1.1
	Briquettes – Si	0.8
	Ceramic balls	0.95
	Slag forming constituent	0.3

Table 4.7: Typical operational data for a cokeless cupola furnace [202, TWG, 2002]

Due to the absence of cokes (and CO), no latent heat is lost from the cokeless furnace system. Full heat recuperation from the flue-gas occurs in the shaft. In duplex configurations (for example in conjunction with an induction furnace), efficiencies in the range of 40 to 60 % may be obtained. Thermal efficiencies for coke fired cupolas vary between 25 % (cold blast) and 45 % (hot blast, long campaign).

Emission data for cokeless and hot blast cupola furnaces are compared in Table 4.8. These apply for the following configurations:

- cokeless cupola: below-charge exhaust capture; oxidising atmosphere (λ = 1.15); no post combustion; dry filtration
- hot blast cupola: below-charge exhaust capture; post combustion in separate chamber, followed by recuperation and dry filtration.

	Cokeless				Hot blast cupola			
	Working conditions		**Nm³/t**	**kg/t**	**Working conditions**		**Nm³/t**	**kg/t**
Gas	50 Nm³/tonne							
Energy	500 kWh/Nm³							
λ	1.15							
Coke					12 %			
Steel					50 %			
Recarburi-sation					1.9 %			
Total combustible carbon					9 %			
Flue-gas			550				2930	
CO_2		9.1 %	50	98		6 %	176	346
H_2O		18.2 %	100			-		
O_2		2.7 %	15			15 %		
CO		<1 %	<5.5	<6.9		10 mg/Nm³		29 g/t
NO_x		155 – 375 mg/Nm³		85 – 210 g/t		205 mg/Nm³		150 g/t
SO_2		-				100 mg/Nm³		300 g/t

Table 4.8: Emission data for cokeless cupola and hot blast cupola [170, Godinot and Carlier, 1999]

The following observations can be made:

- the cokeless cupola emits five times less flue-gases than the hot blast cupola. This is mainly due to the post combustion, which brings excess air into the combustion chamber of the hot blast cupola. As a consequence, the cokeless cupola can be equipped with a smaller flue-gas treatment system
- the cokeless cupola emits 3 to 4 times less CO_2 than the hot blast cupola
- the cokeless cupola emits more CO, which is combusted in the case of the hot blast cupola
- NO_x and SO_2 emission levels are low compared to current emission limit values (e.g. for France, 500 mg/Nm³ and 300 mg/Nm³ respectively)
- if dry filtration is applied, both techniques have low dust emission values.

Applicability

The technique applies to new installations, producing medium to large series. The cokeless cupola needs a constant and continuous working regime. Due to high oxidation losses and a high risk of bridging, the technique requires a clean feed with a steel content of max. 35 %. Since no sulphurisation occurs, the technique is of special interest for the production of nodular iron.

Economics

Data on operational costs (for 1999) are presented relative to operational costs of hot blast cupolas (set at 100%) in Table 4.9. The values apply for a 12 tonnes/h equipment and have been based on a study of 3 cokeless cupolas operating in Europe.

		Raw materials (%)	Auxiliary materials (%)	Melting energy + Fluids (%)	Comparative index
Grey cast iron	Cokeless gas cupola	83	6	11	116
	Hot Blast coke cupola	69	8	23	100
Nodular cast iron	Cokeless gas cupola	81	6	13	104
	Hot Blast coke cupola	69	8	23	100

Table 4.9: Operational costs for cokeless cupola, relative to hot blast cupola (set at 100%) [202, TWG, 2002]

The tabled values were calculated in 1999, however since then, there has been an increase of the price of coke. From this table it may be concluded that, in Europe a 12 t/h cokeless cupola:
- melts the more expensive grey cast iron
- melts nodular base iron with a price very similar to hot blast cupola.

The comparison is very dependent on the local price of energy and materials.

Driving force for implementation
To reduce cupola emissions.

Example plants
- Düker, Laufach (D): 15 tonne/h nodular iron
- Düker-Kuttner, Lingotes Especiales, Valladolid (E): 16 tonne/h grey an nodular iron
- Hayes Hydraulic Castings (GB), 5 - 6 tonne/h lammellar and nodular iron.

Reference literature
[32, CAEF, 1997], [110, Vito, 2001], [170, Godinot and Carlier, 1999]

4.2.1.10 Gas-fired coke-cupola

Description
The principle of the coke-gas cupola is to replace part of the coke with gas. There are two techniques for burning natural gas in the cupola:
- using air-gas burners, located above the tuyères
- using oxygas burners, located in the tuyères.

At present, the coke/air-gas cupola furnace finds limited implementation in Europe. This may be attributed to the difficulty in controlling the process and the increased complication of the furnace shell.

The oxygas burner was introduced in 1994. Besides oxygas firing, it allows the introduction of dust into the tuyères for recirculation, although in practice this option is not applied. The oxygas burners are placed in 1/3 – 1/2 of the tuyères. About 10 % of the coke energy is replaced by natural gas, leading to a gas consumption of 8 to 16 Nm^3/tonne. This is associated with a total oxygen consumption (burners + lances) of 40 to 60 Nm^3/tonne. The application of this technique allows a greater flexibility in the production and/or metallurgy.

The effect and use of the oxygas burner depends on the cupola concerned. In cold blast cupola furnaces, the technique is used to ensure easy restarts or to reduce the proportion of coke. In hot blast operation, the technique is used to increase the furnace capacity without modifying the melting bed. The replacement of part of the coke with CH_4 results in a reduction in flue-gas

volume. This is used as a means of increasing the furnace capacity, without over-saturating the installed flue-gas cleaning system.

The technique results in an increase in the carbon content of the melt and allows an increase in the amount of steel in the charge. The process provides a means of injecting FeSi, which is less expensive in powder form than as ore. These properties result in a beneficial economic effect.

Achieved environmental benefits
The replacement of part of the coke with CH_4 results in a reduction in the flue-gas volume. In addition, the flue-gas is made more combustible due to the higher CO and H_2 contents. If post combustion is present, the resulting flue-gases will show lower levels of organic compounds and CO.

The replacement of coke by natural gas reduces the emission levels of SO_2.

The technique allows the possibility of recirculating cupola dust into the melt. Although, after some initial trials, this application has not been fully developed.

Reducing the level of coke in the cupola increases the risk of bridging.

Cross-media effects
The production, storage and use of oxygen increases the safety risks. Oxygen production is done through cryogenic distillation or Vacuum (Pressure) Swing Adsorption, which both involve elctricity consumption. The consumption of the latter technique is 0.35 – 0.38 kWh/Nm³ O_2. Oxygen production is often done by an external supplier, who delivers the oxygen to a storage tank or directly through a pipeline.

Operational data
The AGA-Rayburn Foundry (Coalbrookdale, UK) equipped 3 out of 8 tuyères of their cold blast cupola with oxygas burners. This allowed a reduction in the overall proportion of coke from 15 % to 10 %. There was a resultant drop in the sulphur content of the produced iron, this then allowing a reduction to be made in the amount of pig iron used, and thus yielding an economic gain.

Fritzwinter foundry (D) equipped 3 out of 6 tuyères of their 20 – 25 tonnes/h hot blast cupola with oxygas burners. This allowed an increase in production capacity to 28 tonnes/h, without the need to change the melting bed, nor the flue-gas cleaning system. The effect on the flue-gas composition before burning is given in Table 4.10.

	With oxygen without oxygas burners	**With oxygen with oxygas burners**
H_2	0.8 – 1.2	2.2 – 2.4
CO	14 – 15	19
O_2	2	2

Table 4.10: Effect of oxygas burners on the flue-gas composition for a hot blast cupola values in %
[184, Godinot and Ressent, 2002]

Applicability
The technique may be applied on both cold blast and hot blast cupolas in both new and existing installations. The advantages drawn from the application (increased flexibility, economical benefit, reduced flue-gas volume, increased capacity) will depend on the specific melting conditions of the installation under consideration. The technique has been reported to cause difficulties for controlling the process and also increases the complication of the furnace shell required.

Economics
Operational costs before and after switching a cold blast cupola to oxygas operation for the above-mentioned Aga-Rayburn foundry (UK) are given in Table 4.11. Prices are forecasts as calculated by CTIF (F).

Input	Units	Unit price	Without burners		With burners	
		EUR	Consumption per tonne	Cost EUR/tonne	Consumption per tonne	Cost EUR/tonne
Coke	Tonne	198	0.15	29.7	0.1	19.8
Gas	Nm³	0.15	0	-	16.5	2.5
Oxygen	Nm³	0.38	14	5.4		
		0.23			40	9.2
Pig iron	Tonne	164.6	0.2	32.9	0	-
Scrap iron	Tonne	125.8	0.2	37.7	0.5	62.9
Total	EUR/tonne			105.7		94.4
All values per tonne molten metal						

Table 4.11: Operational costs for cold blast cupola with and without oxygas burners [184, Godinot and Ressent, 2002]

Operational costs decrease from EUR 105/tonne to EUR 94/tonne molten metal. The economic gain can mainly be attributed to the reduced proportion of pig iron. This also stresses the fact that the balance will differ for each specific foundry.

Driving force for implementation
To increase flexibility of the foundry and/or to increase the production capacity of existing installations without changing the installation layout.

Example plants
- AGA-Rayburn Foundry (Coalbrookdale, UK)
- Fritzwinter foundry (D)

Reference literature
[156, Godinot, 2001], [184, Godinot and Ressent, 2002]

4.2.2 Electric arc furnace

4.2.2.1 Shortening melting and treatment time

Description
Improved control methods can lead to shorter melting or treatment times. Some examples are:
- closer control of the composition (e.g. C, S, P content) and the weight of the charged materials and slag forming materials
- reliable temperature control of the melt, this can improve the yield of the refining reactions and avoid overheating
- more efficient methods for sampling and deslagging, these can reduce furnace downtime.

Secondary metallurgy, using AOD/VODC treatment, shortens EAF time and has a positive impact on energy conservation. The technique is discussed further in Section 4.5.7.1.

Achieved environmental benefits
Increased furnace efficiency through shorter melting times and reduced downtime.

Cross-media effects
No cross-media effects apply.

Applicability
This technique applies to all new and existing EAF furnaces.
Driving force for implementation
Increase the efficiency of the melting and treatment operation

Example plants
This technique finds widespread application in European foundries using EAF melting.

Reference literature
[32, CAEF, 1997], [202, TWG, 2002]

4.2.2.2 Foamy slag practice

Description
The *foamy slag practice*, currently in use in the steel production industry, consists in simultaneously injecting oxygen and carbon (in the form of coal dust) into the slag at the end of the melting. The foam of slag is produced by the action of CO bubbles. The CO gas comes from the oxidation of carbon in the metal by the injected oxygen and also from the reduction of the iron oxides (FeO) by the injected carbon.

Creating a foamy slag improves the heat transfer to the charged units and protects the refractory material inside the furnace. Because of the better arc stability and less radiation effects, slag foaming leads to a reduction in energy consumption, electrode consumption, noise levels and increased productivity.

Achieved environmental benefits
Reduction of energy consumption and electrode consumption, lower noise levels and reduction of flue-gas volume.

Cross-media effects
As the volume of the slag rises so larger slag buckets may be needed. After tapping, the slag degasses again. There is no reported adverse impact on the possibilities for re-use of the slag.

Operational data
Table 4.12 gives the operational data for a 60 tonne arc furnace and indicates the mains savings in energy, time, refractory and electrodes.

	Units	Normal slag	Foamy slag
Total power	MW	25	30
Radiation loss arc to flue-gas	MW	6	0
Flue-gas flow	m³/h	41000	28000
Final temperature	°C		
- metal		1630	1630
- slag		1603	1753
- flue-gas		1463	1607
- refractory		1528	1674
Energy-input	kWh/tonne		
- electricity		50.8	37.7
- fossile (coal)		37.1	22.6
Energy-output	kWh/tonne		
- metal (ΔH)		10.4	10.4
- slag (ΔH)		1.1	9.4
- furnace losses		20.7	14.1
- flue-gas losses		53.6	24.8
- other losses		2.5	1.6
Heating time 1584 - 1630 °C	min	11min 45sec	7min 30sec
Heating rate	°C/min	3.9	6.1

Table 4.12: Energy and temperature data for EAF furnace melting with normal slag and foamy slag
[202, TWG, 2002]

Slag density is reduced from 2.3 tonne/m³ to 1.15 – 1.5 tonne/m³.

Applicability

This technique applies to new and existing EAF foundries that practice oxygen injection.

Driving force for implementation

Increasing the efficiency of furnace operation.

Example plants

No specific example plants were reported, but the technique finds application in several European foundries.

Reference literature

[32, CAEF, 1997], [202, TWG, 2002], [211, European IPPC Bureau, 2000]

4.2.3 Induction furnace

4.2.3.1 Process optimisation: optimising charge materials, charging and operation

Description

Process optimisation options for coreless induction furnaces include:

- *Optimise feedstock condition*: This involves avoiding rusty and dirty inputs, utilising optimum size and density input/scrap, and using cleaner carburisers. These measures shorten the melting time, reduce the specific energy needed for melting and/or reduce the amount of slag formed
- *Close furnace lid*: Oxidation is reduced by avoiding badly fitting lids and unnecessary/prolonged openings, by quick charging, or by using a protective atmosphere over the melt (N_2). Opening times need to be minimised to prevent energy losses. The necessary opening times for charging, removing slag, temperature measuring, sampling and pouring vary between 50 % and 25 % of the shift time. The latter figure applies for new furnaces, working in optimised conditions. A well-fitted closed lid limits the surface heat loss to about 1 % of the input power. When open, the heat loss can amount to up to 130 kWh/tonne for a 10 tonne capacity unit. When melting under a closed lid, care should be taken not to overheat the furnace

- *Restrict holding to a minimum*: Since melting is the first step in the foundry process chain, a shortening of the holding time can only be obtained by an integrated process optimisation for the whole foundry process and by minimising delays, problems and irregularities in any of the foundry departments. During holding, composition adjustment is performed based on the results of an analysis made on a chill cast sample. Optimisation of the sampling, testing and adjusting procedures is another measure for reducing the holding time
- *Operate at maximum power input level*: Furnaces are more efficient in their use of energy when they are being operated at maximum power input levels, and best results are obtained when the available power can be fully utilised for the largest proportion of the melting cycle. This also includes reducing cold start melts (optimise production programme), and allowing follow-up using monitoring and computer control
- *Avoid excessive temperature and unnecessary superheating*: It is important that the metal reaches the required temperature just at the time that the moulding department is in a position to receive it. Good co-operation between the melting and moulding shop is essential in order to minimise the electricity usage
- *Optimise high temperature melts for slag removal* (good balance): Low melting point slag build-up can be reduced by heating the furnace up to elevated temperatures (1580 ºC vs. 1450 ºC normal). This results in a higher energy consumption, and can affect the metallurgical aspects of the melt. If the slag is allowed to build up on the furnace lining, this can affect the electrical efficiency of the furnace. Slag removal requires the opening of the furnace lid, and thus causes a thermal loss. A good balance needs to be found between increasing the melt temperature and the slag removal practice
- *Prevent slag build up*: More common and more troublesome are instances where high melting point build-up is involved. This mainly results from charging sand and, in the case of iron melting, metallic aluminium into the melt. Some furnace operators have attempted flux additions and cleaning routines but prevention is better than cure in this respect. This involves minimising the presence of sand and Al in the raw materials
- *Trickle the oxygen injection*: Instead of using conventional decarburisation
- *Minimise and control the refractory wall wearing:* The refractory life depends on the choice of materials as a function of the slag chemistry (acidic or basic), the operational temperature (steel, cast iron, non-ferrous), and the care taken upon relining (sintering). The lifetime may vary from 50 (steel, cast iron) to 200 – 300 (cast iron) melts. Operational control measures are taken to follow the refractory wear. These include visual inspection, physical measurement and instrumental monitoring programmes. Good charging practice measures prevent the cumulative effects of physical chokes and mechanical stresses. These include the use of automatic charging systems, hot charging, avoiding high drops and the use of compact and dry scrap.

Achieved environmental benefits
Increased furnace efficiency through shorter melting times and reduced downtime.

Cross-media effects
No cross-media effects apply.

Operational data
A typical coreless furnace can melt a tonne of iron and raise the temperature of the liquid metal to 1450 ºC using under 600 kWh of electricity. However, in practice, only a few foundries can achieve this level of specific consumption on a week-by-week basis. Some foundries consume in the region of 1000 kWh for every tonne of iron produced by their coreless furnaces. Prevailing circumstances in many foundries can restrict the scope for good energy management, but in fact almost all coreless melting operations could be improved in some way, in order to achieve a worthwhile saving in the quantity of electricity used per tonne of iron processed.

Applicability
This technique applies to all new and existing induction furnaces.

Driving force for implementation
Increasing the efficiency of furnace operation.

Example plants
Process optimisation measures are commonly applied in European foundries using induction furnaces.

Reference literature
[32, CAEF, 1997], [47, ETSU, 1992], [110, Vito, 2001], [145, Inductotherm], [225, TWG, 2003]

4.2.3.2 Change from mains frequency to medium frequency furnaces

Description
Medium frequency (250 Hz) furnaces have a higher power density (up to 1000 kW/tonne) than mains frequency (50 Hz) furnaces (300 kW/tonne). This allows the use of a smaller crucible (up to a factor of three smaller) which results in a smaller total heat loss. The thermal efficiency of medium frequency furnaces is 10 % higher than for the mains frequency types. Additionally, mains frequency units need to be operated with a molten heel of up to 2/3 of the crucible capacity to optimise specific energy consumption and also require specific starter-blocks for cold start-up. Medium frequency furnaces can readily be started with a cold charge and can be emptied at the end of each working shift or melting batch.
When a foundry converts from mains frequency melting to operating a medium frequency installation, it is important that the furnace personnel undertake some retraining. Operating techniques formally used to date will have to be abandoned, and new specific procedures designed to give good specific energy consumption will have to be adapted. If retraining is overlooked, the available improvements in energy usage may not be fully realised.

Achieved environmental benefits
Increased energy efficiency of the melting operation.

Cross-media effects
No cross-media effects apply.

Operational data
Operational data are given in Section 3.2.4.

Applicability
This technique applies to new installations and for major refurbishments of existing installations

Driving force for implementation
To increase the efficiency of the foundry operation.

Example plants
The technique is commonly applied in foundries installing a new furnace.

Reference literature
[47, ETSU, 1992]

4.2.4 Rotary furnace

4.2.4.1 Increasing the furnace efficiency

Description

All measures that increase the thermal efficiency of the furnace will in turn lead to a lower CO_2 output. A major improvement has been achieved by introducing oxygen instead of air as the combustion medium. This is discussed in Section 4.2.4.2.

Further improvements of furnace yield can be obtained through tight control and optimisation of:
- burner regime
- burner position
- charging
- metal composition
- temperature.

Achieved environmental benefits
The optimisation results in lower amounts of dust and residues and in higher energetic efficiency.

Cross-media effects
No cross-media effect apply.

Operational data
An optimisation programme on a 3 tonnes/h cast iron melting furnace suggested the following as good operational practice:
- use of clean scrap and loading in the following order: (1) ingots and materials with low Si-content; (2) internal return material and foundry scrap; (3) alloying elements and melt protection; (4) steel scrap
- melt protection: use of anthracite for melt protection (2 % of metal charge) and silicon (2 %)
- rotation: in discontinuous phase, 1/3 of a rotation every minute with a total of 7.5 turns until the phase change. During continuous rotation: 1.7 rotations/minute
- power and angle of burner: use a parallel burner-head position for the lower injectors. Start at maximum power during 20 minutes, reducing 10 % every 20 minutes until change of phase (60 minutes after start).

Using these measures, a metal efficiency (molten metal/charged metal) at >95 % could be maintained.

Applicability
The principles of the optimisation are generally valid for iron melting in rotary furnaces using oxygen burners. The operational data have been established for a 3 tonnes/h furnace. For furnaces of other sizes, a site-specific optimisation is necessary.

Driving force for implementation
Optimisation of furnace operation and to increase the melting efficiency.

Example plants
Process optimisation measures are commonly applied in European foundries using rotary furnaces.

Reference literature
[204, Carnicer Alfonso, 2001]

4.2.4.2 Use of an oxyburner

Description
Flame temperatures are increased by the application of pure oxygen instead of air in the burners used for melting or preheating the pouring ladles. This enables a more efficient heat transfer to the melt and reduces the energy use.

If the air supply is blocked by a tight closure of the recipient, no NO_x can be formed through the oxidation of atmospheric nitrogen. Additionally, the total flow of flue-gases from an oxyburner is smaller due to the absence of nitrogen ballast. This allows the application of a smaller dedusting installation.

Achieved environmental benefits
The techniques reduce energy consumption and lower the emissions of NO_x and CO_2, through higher combustion temperatures.

Cross-media effects
The production, storage and use of oxygen increases the safety risks. Oxygen production is done through cryogenic distillation or Vacuum (Pressure) Swing Adsorption, which both involve electricity consumption. The consumption of the latter technique is 0.35 – 0.38 kWh/Nm³ O_2. Oxygen production is often done by an external supplier, who deliver the oxygen to a storage tank or directly through a pipeline.

Fuel or heavy oil gives rise to SO_2 or NO_x emissions, depending on their S or N content. The use of cleaner carburants such as natural gas and propane will not cause any additional pollution, except for CO_2, as is the case for all combustion processes.

Operational data
Table 4.13 gives, for the "oxygas" melting of cast iron and various furnace capacities, the theoretical consumption of several fuels and of oxygen per tonne melted:

Energy source	Units	Furnace capacity (tonnes)				
		3	5	8	12	20
Light fuel oil	kg/tonne	33 – 38	33 – 38	33 – 38	32 – 37	32 – 37
Natural gas	Nm^3/tonne	38 – 43	38 – 43	38 – 43	38 – 42	38 – 42
Propane	Nm^3/tonne	15 – 17	15 – 17	15 – 17	14 – 16	14 – 16
Oxygen	Nm^3/tonne	130 – 150	130 – 150	130 – 150	130 – 145	130 – 145

Table 4.13: Table of energy consumptions (minimum melt)
[148, Eurofine, 2002]

Oxygen enrichment used in conjunction with a recuperator generally achieves a 30 % energy saving. Additionally, the higher combustion temperature assists in reducing the overall emissions. The exhaust gas volume is also reduced. Full oxy/fuel firing may offer energy savings of up to 50 %, and can reduce the exhaust gas volume by up to 72 %.

A German installation's change from oil-air firing to gas-oxygen firing caused a reduction in noise emissions of 15 – 18 dB(A) in the immediate vicinity of the furnace, dependent on the point of analysis. At the installation border, a value of 48 dB(A) was measured. With the application of energy recuperation for charge preheating, a total energy saving of 53 % was reported.

Applicability
This technique can be applied on any rotary furnace and in the preheating of pouring ladles. Oxyburners do not find implementation in non-ferrous foundries, although they are used e.g. in secondary copper smelting.

Economics
Investment costs: EUR 3400 – 4500.
Operational costs: dependent on process operation.

Driving force for implementation
Optimisation of furnace operation and to increase melting efficiency.

Example plants
This technique finds wide application in ferrous foundries using rotary furnaces.

Reference literature
[23, Brettschneider and Vennebusch, 1992], [32, CAEF, 1997], [110, Vito, 2001], [103, Vereniging van Nederlandse Gemeenten, 1998], [148, Eurofine, 2002], [163, UK Environment Agency, 2002], [232, Novem, 2000]

4.2.5 Selection of cupola vs. induction or rotary furnace for cast iron melting

Description
Given the fact that various melting techniques show overlapping fields of application, a basic technique is the selection of the melting technology. In this selection the decisive criteria include:

- metal type
- continuous or batch production
- size of the series
- metal throughput or capacity
- flexibility towards input material type and cleanliness
- flexibility towards alloy change
- type of product made
- emissions and other environmental considerations
- availability of raw materials
- availability of fuels/electricity.

The application of the different melting techniques is very dependent on the indicated criteria. From the discussions mentioned above, the following generalities can be deduced:

- *Metal type*: Electrical furnace better placed for nodular or alloyed cast iron
- *Continuous production:* Cupola is better placed
- *Batch production*: Electrical or rotary furnace is better placed
- *Flexibility towards input material type and cleanliness*: Cupola is better placed
- *Flexibility towards alloy change*: Induction and rotary furnace is better placed
- *Environmental considerations*:
  - cupola is better placed only if well de-dusted, cokeless show better environmental performance than HBC or CBC
  - induction has lower CO, SO_2, NO_x, dioxin, slag, but this it needs to be borne in mind there will also be emissions from the required electricity production.
- *Availability ofraw materials:* When cheap scrap is available, the cupola is better placed

In fact, all these criteria must be considered together. Table 4.14 gives a summary, based on the technical considerations. Economic data for the various cupola types and the induction furnace are given in Annex 1.

On the basis of the stated criteria, the replacement of the cupola by induction or rotary furnaces may be considered. The selection of induction or rotary furnaces is given priority over cold blast cupolas for small foundries casting a variety of products in several European countries (e.g. Austria, Belgium (Flanders)).

CRITERION		ONLY GREY CAST IRON					GREY + NODULAR	ONLY NODULAR CAST IRON			ONLY MALLEABLE CAST IRON
Type of product made		**Counter weights**	**Sewer castings, pipes, urban furniture**	**Enameled castings, heating appliances**	**Mechanical parts**		**Mechanical parts**	**Sewer castings, pipes, urban furniture**	**Mechanical parts**		**Mechanical parts**
Size of series		**Medium to large**	**All**	**Medium to large**	**Batch to small**	**Medium to large**	**All**	**All**	**Batch to small**	**Medium to large**	**Medium to large**
Cupola	Cold blast	++	++ (<10 - 15 t/h)	++ (<10 - 15 t/h)		++ (<10 - 15 t/h)			(+)		
	Hot blast	+	++ (>10 - 15 t/h)	++ (>10 - 15 t/h)	0	++ (>10 - 15 t/h)		++ (>10 - 15 t/h)	0	+ (>10 - 15 t/h)	
	Cokeless				0	+		+	0	+	
Induction			+	+	++	++	++	+	++	++	++
Rotary furnace		(+) batch			++	+	++	(+) batch or small series	++		++

++: technically more adapted;
+: technically adapted
(+): adapted in some cases
0: not adapted

Table 4.14: Technical choice of the melting equipment for cast iron melting [202, TWG, 2002]

Achieved environmental benefits
Replacement of a cupola by an induction or rotary furnace results in a reduction in the direct emissions of CO and SO_2 and a reduced amount of slag. Induction furnaces show a reduced emission of NO_x and a lower risk of dioxin formation. The indirect emissions generated by the use of induction furnaces, depend on the local electricity generation infrastructure.

Cross-media effects
Replacement of a cupola by an induction furnace generates a strong increase in electricity consumption.

Applicability
The replacement of a cold blast cupola by an induction or rotary furnace is applicable under the criteria stated above and upon major refurbishment of the installation.

For new installations, the criteria of Table 4.14, apply besides local and site-specific considerations. If cupola and induction or rotary furnaces are indicated as most adapted, the induction and rotary types may be preferred on the basis of their environmental benefits.

Economics
A survey of economic data for the various types of cupola furnaces and for the induction furnace is given in Annex 1.

In Table 4.15, a summary is given of cost data collected by an example Spanish foundry that wanted to replace an existing cupola by a rotary or electric furnace. No emission collection or filtration equipment costs are included. Data are from 1997 - 1998. The comparison involves the following three systems:
- cold blast cupola: 3.5 tonne/h capacity
- oxygas rotary furnace: 3 tonne capacity
- 2 medium frequency induction furnaces: 2 + 1 tonne capacity.

The cost calculation was performed for melting costs for a melting production of 1 tonne/h, working 8 hours/day. For the induction furnace a distinction is made between peak-time electricity costs and off-peak-time. Since electricity is the major component of the costs, this distinction makes a big difference to the final cost. Operation of the induction furnace during off-peak time (night-time) results in costs comparable to rotary furnace costs. The data show that the investment has a 5 – 9 years payback period.

Costs in EUR/tonne of molten metal	**Cupola**	**Rotary**	**Induction**	
Energy	30.7	29.8	40.8 27.2	(peak) (valley)
Refractory	3.6	1.3	1.4	
Man power	52.9	22.7	22.7	
Raw materials	205	205	205	
Total cost	292	259	270	
Yearly costs in EUR				
Cost for melting 1320 tonne/year	385000	341000	356000 338000	(peak) (valley)
Savings	none	44000	29000	(peak)
			47000	(valley)
Investment	none	250000	260000	
Building		Not needed	Needed	

Table 4.15: Example plant cost data for replacement of an existing cupola with a rotary or induction furnace
Data from 1997 - 1998, Spain
[202, TWG, 2002]

Driving force for implementation
Reduction of direct emissions from cast iron melting.

Example plants
Most Austrian foundries, which are small and medium-sized enterprises, have changed from cupola melting to induction furnaces. As a consequence there are only three Austrian foundries left which still use cupola melting.

Reference literature
[202, TWG, 2002], [110, Vito, 2001], [225, TWG, 2003]

4.2.6 Hearth type furnace

4.2.6.1 Use of an oxyburner

See Section 4.2.4.2.

4.2.7 Other furnace types

4.2.7.1 Alternatives to the use of SF_6 as a cover gas for Mg-melting

Description
Alternative covering gases for magnesium melting are of big interest due to the high global warming potential of the generally used SF_6. The substitution of SF_6 has been the topic of research for several years. A worldwide research project to develop and propose alternatives is currently being co-ordinated by the International Magnesium Association and will be finalised in 2004. Gas mixtures containing HFC-134a (CF_3CH_2F) and Novec 612 (perfluoroketone, $C_3F_7C(O)C_2F_5$) have been successfully tested. Research is on-going on the applicability of both compounds. HFC-134a falls under the restrictions of the Kyoto protocol. Both compounds show a lower global warning potential than SF_6: SF_6 GWP = 23900; HFC-134a GWP = 1300; Novec 612 GWP = 1.

At present, SO_2 is a viable alternative. Some magnesium foundries have long experience with this gas, and never turned to SF_6 when this gas was first introduced at the beginning of the 1970s. SO_2 reacts with liquid magnesium and builds a protective film on the surface. A mixing unit for blending a low concentration SO_2-air mixture is available. Furthermore, handling procedures for SO_2 have been established to reduce workers exposure and risk.

The protective gas is supplied through a manifold with several outlets. The positions of the outlets are chosen to give protection to all areas of the metal surface. Areas closer to hatches that will be opened frequently during operation need a higher flow of gas than areas where interaction with the surrounding atmosphere is small.

In order to optimise safety and minimise gas consumption, totally encapsulated melting and casting processes are applied.

If replacement is not feasible, the following technical measures allow a reduction of SF_6 consumption and emissions:
- improved sealing of furnaces
- fully automatic cover gas dosage
- electronic control of both gas mix and flowrate
- reduction of overdosing.

Achieved environmental benefits
The replacement of SF_6 avoids using this greenhouse gas, which has a GWP of 22200 over a 100 years time horizon.

Cross-media effects
SO_2 is a toxic gas and exposure limit values for workers should be taken into account. The occupational exposure limit in most countries is 2 ppm (5 mg/m³) over 8 hours. Sulphur- and oxygen-containing deposits may form on the furnace wall. Under unfavourable conditions these deposits can be immersed into the molten metal where they cause reactions leading to metal eruptions from the surface. Frequent removal of scaling can prevent this from happening.

The technique results in emissions of small amounts of SO_2, the amount depending on the foundry capacity and the number of furnaces. One estimate could be 50 – 500 kg per year for melt protection.

Operational data
The consumption of SF_6 depends on the melting technique used, and varies between less than 0.1 and 11 kg/tonne of finished castings. Technical improvements and measures have resulted in a reduction in the average specific SF_6 consumption, from over 3 kg/tonne of casting to 0.9 kg/tonne. Application data are given in Section 3.4.1.

In an undisturbed melt, the use of SO_2 would be typically 0.7 % in air at a flowrate of 5 to 10 litre/minute. In closed (but not airtight) furnaces, such as the melting and dosing furnaces of die-casting machines, pure SO_2 is applied. Small amounts of air entering through the lid are needed to provide the covering action. If a carrier gas is used, nitrogen is the preferred gas because of its inertness. The SO_2 is then mixed in concentrations of 1 – 2 %.

Mass balance data for the fluxless re-melting of magnesium scrap are given in Section 4.1.6.

Applicability
There is a great potential to reduce the SF_6 consumption, but at the moment it does not seem possible to fully replace it during non-standard situations. SO_2 may be applied in general during normal melting operations. When repairing the furnace, SF_6 remains needed as a protection gas, due to the health risks correlated with SO_2 exposure. Additionally, SO_2 cannot be used to extinguish magnesium fires. In this case also, SF_6 remains in use.

Economics
The price of SF_6 has increased dramatically over the last few years. Conversion from SF_6 to SO_2 will therefore have an associated economic cost. Table 4.16 gives estimates for the running expenses for the use of SF_6 and SO_2 based on information from a die-caster running three die-casting machines and the results from industrial scale trials. Even though the figures are only rough estimates, they clearly show that there is a large cost saving potential when substituting SO_2 for SF_6.

Property	Units	SF_6	SO_2
Concentration of gas	%	0.4	0.7
Price	EUR/kg	36.5	4.5
Inverted density (at 0 ºC and 1 atm)	l/kg	153	350
Yearly consumption of gas	kg/yr	339	259
Cost/year	EUR	12373	1165
Data for 3 die-casting machines, run at 300 days/yr, 24 h/day with flowrate of gas to each machine of 10 l/min			

Table 4.16: Cost comparison between SO_2 and SF_6 used for protective gas atmospheres [190, Schubert and Gjestland]

If a new investment is considered, the SO_2 gas system, meeting all modern safety and dosage requirements, costs EUR 70000, for a 1000 tonnes/yr plant. A new SF_6 system costs EUR 23300. Operational data, accounting for this investment and for the use of 1.5 % of SO_2 and 0.2 % of SF_6, both in nitrogen, are given in Table 4.17. The total annual cost for SO_2 is some EUR 2500 more than for SF_6, on the other hand 12300 tonnes of CO_2 equivalent emissions are avoided. The bigger the plant, the less the annual costs differ between the two systems. At an annual output of 1500 tonne/yr, the turning-point is passed and the CO_2 reduction cost turns negative.

General Casting Data		
Capacity of the ovens	2000 kg	
Maximum smelting performance	1000 kg/h	
Casting time per day (Cold chamber)	13.2 h	
Working days	250/yr	
Utilisation	76 %	
Gross melting weight (shot weight)	2000 t/yr	
Scrap factor	50 %	
Net weight of the Mg parts	1000 t/yr	
Sales per year (EUR 15.00/kg)	EUR 15 million	
Surface of the Mg baths	6 m^3	
Gas (carrier + cover gas) per m^2 surface	300 litres per hour, all year long	
Extra gas dosage while charging	+ 25 %	
Gas Data	**SF_6**	**SO_2**
Carrier gas	nitrogen	nitrogen
Cover gas concentration in carrier gas	0.2 vol. %	1.5 vol. %
Cover gas dosage per hour	46.9 g	154.2 g
Cover gas dosage per year	514 kg	1688 kg
Coefficient cover gas/net Mg output	0.51 kg/t	1.69 kg/t
Emissions in tonnes CO_2 equivalent	12278	-
Cost Data	**SF_6**	**SO_2**
1 kg cover gas	EUR 20.00	EUR 3.00
1 m^3 carrier gas (nitrogen)	EUR 0.20	EUR 0.20
Invest-cost of new gas equipment	EUR 23333	EUR 70000
Discount rate per year	10 %	10 %
Depreciation period	10 yr	10 yr
Annualised invest cost of equipment	EUR 3797	EUR 11392
Operating cost of cover gas	EUR 10274	EUR 5065
Annual running cost (without nitrogen)	EUR 14072	EUR 16457
Additional total cost of using SO_2	-	EUR 2385
Specific emissions reduction cost	-	EUR 0.19/tonne CO_2 eq.
Share of additional cost in sales		0.02 %
Note: Most data are valid only for this 1000 tonne/yr plant and will change with plant size		

Table 4.17: Operational and cost data for a new die-casting plant of 1000 tonne/yr Mg output [218, Harnisch and Schwarz, 2003]

For existing installations, the reduced cost for SO_2 consumption needs to pay back the investment cost for the conversion of the cover gas installation. The payback time is dependent on the actual cover gas consumption. Based on an SF_6 consumption of 0.9 kg/tonne, the turning point at which the total costs of using SO_2 get lower than the comparable cost of SF_6 is below 900 tonne/yr output. At 500 tonnes/yr the SO_2 is still more expensive, but the specific reduction cost of 1 tonne CO_2 eq. amounts to EUR 0.31. The share of additional costs in the plants sales amounts to 0.04 %. Therefore at this capacity, the technique can also be considered.

As a conclusion, it is found to be economic to use SO_2 instead of SF_6 as a cover gas in magnesium die-casting, at least in plants with an annual metal output of 500 tonnes and more, regardless of whether the plant is to be newly built or still runs with SF_6.

Driving force for implementation

Reduction measures for greenhouse gas emissions, in particular, the Kyoto climate protocol controlling the use of fluorinated gases: HFCs, PFCs and SF_6. These gases have a high global warming potential but are not ozone depletors. This will form the basis for the EU Directive on the use of fluorinated gases. Furthermore, some regions have already issued proposals to ban its use, such as e.g. Denmark, Germany and Austria.

Example plants

LM Leichtmetall Systemtechnik, Felbach (D)

In Austria, Denmark and Sweden SF_6 is no longer used as a cover gas.

Reference literature
[182, Closset, 2002], [190, Schubert and Gjestland], [191, IMA, et al.], [192, Gjestland and Westengen, 1996], [194, UNEP IPCC, 2002], [218, Harnisch and Schwarz, 2003]

4.2.8 Non-ferrous metal treatment

4.2.8.1 Aluminium degassing and cleaning using an impeller station

Description
The degassing of aluminium is needed to remove hydrogen from the melt. The removal or reduction of small amounts of undesirable elements and impurities necessitates treatment of the melt with halogens, such as chlorine, fluorine or bromine. This treatment is referred to as cleaning, and is usually combined with the degassing treatment.

Adequate degassing with physically operating treatment processes does not achieve sufficient cleaning in most aluminium castings. Vacuum degassing achieves a very low hydrogen content in the melt but, at the same time, the lower number of nuclei means that crystallisation is less effective.

In a combined degassing and cleaning process, gas mixtures of argon and chlorine or nitrogen and chlorine are introduced into the melt. The chlorine concentration in the carrier gas must be optimised in order to ensure good cleaning as well as low emissions. In most cases, only a degassing treatment is necessary. This treatment is done without Cl_2-gas. Depending on the treatment vessel, the efficiency of the degassing can be improved with porous plugs and impellers.

In some isolated cases, an Ar/SF_6-mixture has been used. The latter is a greenhouse gas with a high global warming potential, which falls under the Kyoto protocol. (see also Section 4.2.7.1)

Achieved environmental benefits
The use of an impeller with Ar/Cl_2 or N_2/Cl_2 avoids the use of hexachloroethane in the cleaning treatment of aluminium. The use of hexachloroethane was banned from 30 June 2003 in the EU.

Cross-media effects
The application of this type of degassing unit has allowed an end to using hexachloroethane for degassing and cleaning purposes.

Operational data
A mixture of nitrogen with 3 % Cl_2 is generally used for combined degassing and cleaning. For degassing only, Cl_2 is not necessary.

A mobile impeller station can be used for holding furnaces and ladles of 50 – 250 kg of Al. The treatment takes 3 to 5 minutes. A metal treatment unit is used for capacities from 400 to 1000 kg Al. The melt is treated for 1.5 to 5 minutes with a gas flow between 8 and 20 litre/minute. The graphite rotor has a life of 100 – 150 treatments, depending on the temperature of the melt.

Applicability
Impeller stations have been developed for holding furnaces and ladles from 50 to 1000 kg of molten aluminium.

Economics
Investment costs are given Table 4.18.

Description	Cost (EUR)
Impeller plant including accessories	15000
Facilities for mixing of argon gas with chlorine	40000
Total	**55000**

Table 4.18: Investment costs for an impeller station [178, Wenk, 1995]

Driving force for implementation
European Directive 97/16/EC prohibiting the use of hexachloroethane in the manufacturing or processing of non-ferrous metals.

Example plants
The technique is commonly applied in aluminium foundries.

Reference literature
[175, Brown, 1999], [178, Wenk, 1995],

4.3 Mould- and core-making, including sand preparation

4.3.1 Selection of the mould type

The selection of the mould type is mainly based on technical criteria. The applicability of the various moulding types is summarised in Table 4.19. Additionally, Table 4.20 gives the general properties of various systems.

	Lost moulds				Permanent moulds				
	Moulding methods				Casting technique				
	Green sand moulding	Shell sand	Phenol/Furan	Pep set/water glass	Low-pressure die-casting	Pressure die-casting (hot)	Pressure die-casting (cold)	Centrifugal casting	Continuous casting
Cast Iron									
Grey cast iron	X	X	X	X	O			X	X
Nodular cast iron	X	X	X	X				X	X
Malleable cast iron	X	O	X	O					
White cast iron	X	X	X						
Steel									
Unalloyed	X	X	X	X				X	
Low alloy steel	X	X	X	X				X	
Highly alloyed manganese steel	X	X	X	X				X	
Stainless and heat resistant	X	X	X	X			O	X	
Heavy Metals									
Brass	X	X	X	X	X				
Bronze	X	X	X	X					
Copper	X	X	X	X	X		X	X	X
Zinc alloys					O		X	X	
Light Alloys									
Aluminium alloys	X	X	X	X	X		X		X
Magnesium alloys	X	O	X	X	X	X	X		
Titanium	O	O	X	X	O				

X: The method can be used
O: The method is possible but not often employed

Table 4.19: Applicability of the various moulding types
[126, Teknologisk, 2000]

	Green sand casting	Chemically-bonded sand	Low-pressure and gravity die-casting	High-pressure die-casting
Relative cost in quantity	Low	Medium high	Low	Lowest
Relative cost for small number	Lowest	Medium high	High	Highest
Permissible weight of casting	Up to about 1 tonne	Up to a few hundred tonnes	50 kg	30 kg
Thinnest section castable, centimetres	0.25	0.25	0.3	0.08
Typical dimensional tolerance, centimetres (not including parting lines)	0.03	0.02	0.07	0.02
Relative surface finish	Fair to good	Fair to good	Good	Best
Relative mechanical properties	Good*	Good*	Good*	Best
Relative ease of casting complex design	Fair to good	Good	Fair	Good
Relative ease of changing design in production	Best	Fair	Low	Lowest
Range of alloys that can be cast	Unlimited	Unlimited	Copper base and lower melting point metals preferable	Aluminium base and lower melting preferable
(*) Mechanical properties may be enhanced by heat treatment				

Table 4.20: Technical properties of the various moulding types [42, US EPA, 1998]

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

4.3.2.1 Preparation of clay-bonded sand by vacuum mixing and cooling

Description

The mixing and cooling process are combined into a single process step. This is achieved by operating the sand mixer under reduced pressure, which results in cooling by the controlled vaporisation of the water. The special mixer needs to be hermetically closed. It has a pressure casing and is connected to a vacuum system. The layout of the system is given in Figure 4.6.

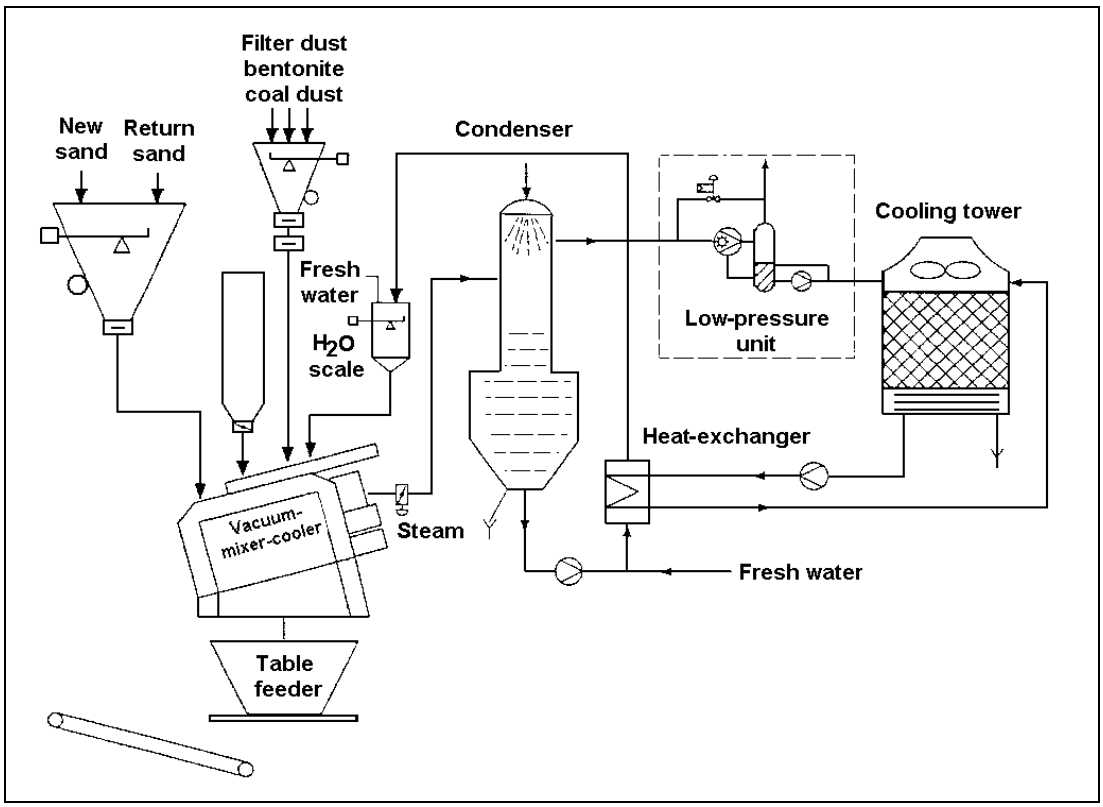


Figure 4.6: Moulding-sand preparation plant with vacuum mixer-cooler [207, Drews, 1996]

As compared to a normal mixing plant (Figure 2.28), this technique does not require a separate cooler and associated equipment. The vacuum plant therefore is a more compact size. Since the total airflow is reduced, the vacuum installation has a smaller central dust extraction filter. The size and energy consumption of the filter are 50 % of that of a conventional plant. The reduction of the airflow, results in a reduced removal of active bentonite and thus in an overall reduction of additive consumption. Due to the enclosed operation, the technique is not affected by outside climatic conditions.

The use of steam in the absence of air leads to a quick activation of the bentonite, resulting in a very quick attainment of the optimal compressive strength for the bonded sand.

Water is added in two separate stages:
- water to moisten the return sand to the prepared sand moisture content
- water to cool the sand by vaporisation to the required temperature of 38 – 40 ºC.

The disadvantage of the system is the operation and management of the vacuum system. The process also affects the sand technical properties (e.g. compressive and tensile strength, permeability), which diminish after 72h ("the 72h effect"). This can be prevented by re-mixing for about 90s.

Achieved environmental benefits
Reduction of the total airflow results in a reduced off-gas volume and amount of dust for disposal, as well as a reduced consumption of binder as compared to conventional cooling and mixing plants (although this also depends on the efficiency of the regeneration plant). Additionally, the system uses less energy.

Cross-media effects
No cross-media effects apply.

Applicability
The technique is applicable in new green sand installations.

Economics
The commercial limits of application appear to be processes where sand cooling is required and which have a capacity of >60 tonnes of sand per hour.

Driving force for implementation
Reduction of dust for disposal and minimisation of additives consumption. Limitation of space.

Example plants
In Japan, a vacuum mixing and cooling plant has been in operation since 1993, with a prepared sand throughput of 100 m^3/h.
Various installations are also currently running in Italy, France, Germany and England.

Reference literature
[143, Inasmet and CTIF, 2002], [207, Drews, 1996], [214, Gerl, 2003]

4.3.3 Moulding and core-making with chemically-bonded sand

4.3.3.1 Minimisation of binder and resin consumption

Description
The minimisation of chemicals consumption can be achieved through optimisation of the process controls and material handling. The latter category is dealt with in Section 4.1. In this section process measures are discussed.

Overuse to compensate for poor process control is the most common way in which binder chemicals are wasted. For instance, key parameters that relate to good binder management include:

- *Sand consistency*: Use of a sand quality which is consistent with the binder system. Good management of sand storage and sand testing (purity, grain size, shape, moisture) are of the main importance. A low content of fines and maximum amount of re-used sand will reduce the amount of resin needed
- *Temperature control*: The sand temperature must be maintained in a narrow range, with regular checks and adjustment of the amount of hardener addition. Positioning the sand heater just before the mixer allows close temperature control
- *Mixer maintenance and cleaning*
- *Mould quality*: Checking, solving and preventing moulding defects
- *Addition rates*: The appropriate binder addition depends on the binder type, the surface area of the sand and the size of the casting
- *Mixer operation*: Optimisation of the mixer performance involves monitoring and control of its operation.

Table 4.21 lists the mixing process variables that are easy to measure using readily available instrumentation. Interfacing the controls with an alarm system allows the operator to be alerted to any ‘out-of-specification’ condition. This needs to be corrected by cleaning, maintenance and recalibration before a major problem develops.

Process variables	Comments	Instrumentation
Sand flow	Can vary as a result of obstructions at the discharge gate that reduce/stop the sand flow or worn/loose stop nuts that produce a faster flow	Impact plate flowmeters
Sand temperature	Determines the speed of hardening and the amount/type of hardener required	A process control instrument can be used to adjust hardener additions to compensate for changes in sand temperature
Power consumption	Provides an indicator of mixer cleanliness	Motor load monitor
Resin and hardener flowrate	Can vary as a result of worn pumps, viscosity changes with temperature, blockages or leaks in pipework and nozzles, sticking of non-return valves, etc.	Positive displacement, electromagnetic or coreolis flowmeters
Operating hours	Useful for assessing performance against capital and maintenance costs	

Table 4.21: Process variables and how they indicate mixer performance [71, ETSU, 1998]

For foundries that require greater sophistication, a range of fully automated mixer control systems are available. These systems use microprocessor technology to provide automatic corrective control of mixed sand production and need only limited operator involvement. The additional benefits achievable with automated control systems are mainly due to the much reduced dependence on the operator and the more rapid correction of variations in conditions. The latter is also performed without having to stop production.

Achieved environmental benefits
Optimisation of the binder and resin use results in a minimisation of the consumption of chemical additives.

Volatile organic compounds make up to 50 - 60 % by weight of the binder components. The amount depends on the binder system type. Most are emitted during sand mixing and metal pouring. A reduction in the use of binder results in a corresponding reduction of VOC emissions.

Cross-media effects
No cross-media effects apply.

Operational data
In most cases, reductions of 5 % in binder levels and 1 % in scrap moulds are easily achieved using modern mixer control systems. Many foundries have realised savings that have been considerably higher. Reductions in binder addition of 5 to 25 % have been reported for various foundries, as well as almost eliminating scrap moulds production.

The installation of an automated mixer control system in an iron foundry using cold-setting resins allowed the foundry to reduce the resin addition rate from 10 kg/minute (1.22 % resin to sand weight) to 8.89 kg/minute (1.09 %), which correspondingly resulted in a 10 % saving in the amount of catalyst used. The number of defective moulds fell by over 60 % and cost savings of over GBP 37000/year (1995 UK prices) were achieved.

Applicability
This technique applies to all new and existing foundries using chemically-bonded sands. Mixing monitoring control equipment can be retrofitted to existing plants.

Economics
For a tonne of mixed sand, the binder addition is typically only 1 – 3 % by weight, but in terms of cost, binders account for 30 – 60 % of the total raw material cost. It is estimated that cost savings of 5 – 10 % could be achieved through better management of binder materials.

Incorporating all the equipment suggested in Table 4.21 in a mixer system costs around GBP 10000 (1997 UK prices). However, due to the significant improvement in process control, this capital investment will have a relatively short payback time. Although the cost of installing an automated control system is approximately twice that for simple on-line monitoring, substantial cost savings are possible.

Some example economic data are given in Table 4.22. These refer to the iron foundry described under the "operational data" heading of this section.

Cost type	**EUR**
Saving due to 60 % reduction in defective moulds	6416
Saving due to 10 % reduction in resin use	29966
Saving due to 10 % reduction in catalyst use	9050
Total saving in material cost	**45433**
Annual running cost	320
Estimated annual maintenance cost	24
Net cost saving	**45088**
Purchase cost of unit	24166
Payback period	7 months

Table 4.22: Annual savings, cost and payback for example plant mixer control (1995 prices)
[75, ETSU, 1996]

Driving force for implementation
Optimisation of operational costs and minimisation of VOC emissions.

Example plants
Good binder management measures are used in the vast majority of the foundries using bonded sand.

Reference literature
[71, ETSU, 1998], [75, ETSU, 1996], [202, TWG, 2002], [225, TWG, 2003]

4.3.3.2 Minimisation of mould and core sand losses

Description
Modern mould and core-making machines allow the production parameters of the various product types to be saved in an electronic database. This allows easy change-over to new products, without the loss of time and materials from finding the right parameters by simply using trial and error. For new products, the settings for similar products may be used to shorten the optimisation time.

Achieved environmental benefits
Reduction of the amount of waste sand and energy, through minimisation of the test run period.

Cross-media effects
No cross-media effects apply.

Applicability
Series production of small series with high production throughput. An errorless change-over requires good control and continuity of the sand quality.

Economics
The investment cost for a core shooting machine depends on the core volume, and range from EUR 150000 (5 l) to EUR 400000 (100 l). Operational costs are 5 – 10 % of investment costs per year.

Driving force for implementation
Optimisation of processes that require frequent change of core or mould type.

Example plants
This technique is applied in several foundries around Europe.

Reference literature
[110, Vito, 2001]

4.3.3.3 Best practice for cold-setting processes

- *Phenolic*: The temperature of the sand is kept as constant as possible, i.e. at around 15 ºC - 25 ºC, which is low enough in order to prevent emissions caused by evaporation. Direct contact between the resin and catalyst has to be avoided as the reaction is exothermic and can be violent

- *Furan*: The temperature of the sand is very important for this process and is kept as constant as possible, around 15 – 25 ºC; in order to control the setting time of the binder and to minimise catalytic additions. Direct contact between the resin and catalyst needs to be avoided as the reaction is exothermic and can be violent

- *Polyurethane (phenolic isocyanate):* The sand temperature is kept between 15 and 25 ºC, to maintain process control and to minimise emissions. Best practice is to work with three pumps and to mix the catalyst and the phenolic resin with isocyanate and sand directly in the mixer [202, TWG, 2002]

- *Resol – ester* (Alkaline phenolic ester hardened): The temperature of the sand is controlled and kept at an optimal level of 15 – 35 ºC. The process is less sensitive to temperature fluctuations than other self-hardened systems. The velocity of hardening is managed by the choice of the hardener type [225, TWG, 2003]

- *Ester silicate:* The sand temperature is controlled within the range 15 – 25 ºC. As moulds and cores pick-up moisture, they need to be used as quickly as possible after achieving full strength. Prolonged storage can only be done in dry conditions.

4.3.3.4 Best practice for gas-hardened processes

- *Cold-box:* Amine vapours need to be captured at the core-making machine. Any excess amine is captured through the core-box. Additionally, it may also be necessary to ventilate the core storage area. When possible, hoods are placed over the moulding or coring machines as well as over the temporary core storage area.
  Amine consumption can be minimised to the extent that its consumption matches the production needs of the sand cores, since the cost of the raw material and its treatment is high. Minimisation of amine consumption is helped by optimising the amine distribution process within the core, typically through a simulation and optimisation of the gas flow [202, TWG, 2002].

The sand temperature has to be maintained as constant as possible, between 20 and 25 ºC, otherwise a too low temperature will involve a longer gassing time, thus resulting in a larger amine consumption. A too high temperature drastically reduces the lifetime of the prepared sand.
Water is detrimental to this process. The moisture of the sand has to be maintained below 0.1 %, and the gassing and purging air must be dried.
Note: Amines are flammable and explosive in some proportions with air. Considerable care is required in their storage and handling, and the supplier's instructions need to be observed at all times.

- *Resol (Alkaline phenolics methy formate hardened):* It is advisable to ventilate the working area, at least in order to prevent any danger of fire. Methylformate consumption needs to be minimised to such an extent that its consumption matches the production needs of the sand cores. The sand temperature has to be maintained higher than 20 ºC, in order to prevent the condensation of methylformate. Methylformate vapours are heavier than air; this should be kept in mind when designing the exhaust system.
  Note: Methylformate is flammable when its concentration in air reaches 6 to 20 % and explosive in some proportions with air. Considerable care is required in storage and handling, and the supplier's instructions need to be observed at all times.

- *Resol-CO_2:* The resin has low contents of unreacted phenol and formaldehyde, and their emission levels, even during the gassing and purging periods, are very low. It is advisable to ventilate the working area. [225, TWG, 2003]

- *SO_2 hardened phenolic or furan:* The working area has to be ventilated, and the emissions collected at the emission point by totally hooding the moulding or coring machines and by applying venting.
  These collected gases must be treated before emission. This is easily completed by a scrubber containing a sodium hydroxide solution. The pH and the concentration of the scrubbing solution have to be continuously supervised. The scrubbing solution needs to be occasionally replaced to remove concentrated salts, it then requires disposal as a hazardous waste.
  Sulphur dioxide consumption needs to be minimised to the extent that its consumption matches the production needs of the sand cores.
  Normally, the purging cycle lasts 10 times longer than the gassing cycle.

- *SO_2 hardened epoxy/acrylic (free radical curing).* As for gassing and purging, collection and treatment are described in the SO_2 hardened furan resins section. The best gassing conditions for achieving cores with good characteristics require:
  - the sand to be dry before use
  - the blowing or shooting air to be dried too
  - the concentration of sulphur dioxide in CO_2 or nitrogen to be from 5 % to 100 %, depending on the resin used (minimal for acrylic, maximal for epoxy/acrylic)
  - the purging cycle to last 10 times longer than the gassing cycle.

4.3.3.5 Replacement of alcohol-based coatings with water-based coatings

Description
Coatings are applied to the surface of moulds and cores to create a refractory barrier at the mould-metal interface and to ensure a good surface appearance. Coatings serve to reduce veining, erosion and metal penetration defects and also help to reduce finishing operations. Alcohol-based coatings are mainly based on isopropylalcohol. The coating is dried by evaporation or by a burning-off of the solvent. This produces VOC emissions. Water-based coatings have been developed as an alternative.

The advantages of water-based coatings are:
- safety (no fire risk)
- workers health (less exposure to organic vapours)
- reduced costs of reagents (water vs. alcohol)
- mostly better surface finish of castings.

The difficulties for implementation are:
- the need for greater (process) time and space. Also cores need a longer drying time, which results in the need for a drying line, passing through a drying furnace
- changing the process requires a case-by-case optimisation period
- growth of bacteria, which cause short shelf-life of coatings (1 - 2 weeks) and causes odour emissions
- cost of re-approval by specific customers in aerospace and defence related applications.

Water-based coatings can be dried in ambient air, or by using a drying furnace or a microwave or an infra-red furnace. They generally need a longer drying time compared to alcohol-based coatings. The drying does not generate noxious emissions, but may cause odour emissions. Drying is done using a drying line, which transports the cores from the core-making to the mould assembly, thus allowing for the necessary drying time. The line may also pass through a drying furnace. Microwave and infra-red drying is applied for small, medium and large series.

The different rheological properties of water-based coatings compared to solvent-based coatings has necessitated the development of new application techniques. These allow a constant coating quality.

Achieved environmental benefits
A life cycle assessment (LCA) study evaluated the impacts of water- and alcohol-based coatings. The use of water-based coatings with drying in ambient air shows clear environmental benefits, mainly due to the reduced emission of VOCs and the low energy use. When a stove is used for drying, the reduced emissions are partially counterbalanced at the LCA-level by an increased energy use. The overall environmental index using a drying stove shows a small benefit over isopropyl alcohol (IPA) use and burning-off.

Cross-media effects
Aqueous coatings contain a variety of (organic) chemicals to enhance their properties. This may affect the emission profile upon shake-out.

Drying the aqueous coating results in an increased volatilisation of binder solvents. This may cause increased odour emissions, due to the evaporation of BTX-containing core solvents.

Water-based coatings require a higher use of energy due to transport (during air drying) and drying in a furnace.

Drying in ambient air may result in a reduction of the air temperature in the foundry. In a Dutch foundry, an overall reduction of the ambient temperature of 2 ºC was experienced. This results in a higher consumption of fuel for heating during wintertime.

Operational data
Changing from IPA-based to water-based coatings is becoming more widespread in various foundries nowadays. Automotive foundries have changed the majority of their production to water-based, leaving solvent-based coatings being used only for specific applications (see applicability).

Operational data were obtained from a Dutch foundry. When drying in ambient air, the air velocity is the main factor (rather than temperature or humidity). In order to allow sufficient air velocity over the drying trajectory, additional fans and ventilators were installed in the foundry. In order to reach a good and constant quality, the fines content of the (regenerated) core-making

sand was reduced. Water-based coatings can cause a swelling of the fine residual (bentonite and coal dust) particles, which then causes core defects.

Operational data were obtained from a foundry in France, operating a stove with a capacity of 540 cold-box cores, which is heated with a natural gas burner. Two ventilators are used to evacuate the fumes and to mix the fresh air. The design temperature of the hot air is 165 ºC. A heat balance was set-up on the basis of measurements using 0.4 kg cores with a humidity of 5.5 %. The balance, as given in Figure 4.7, applies for a throughput of 390 cores, which is equivalent to 72 % of full capacity.

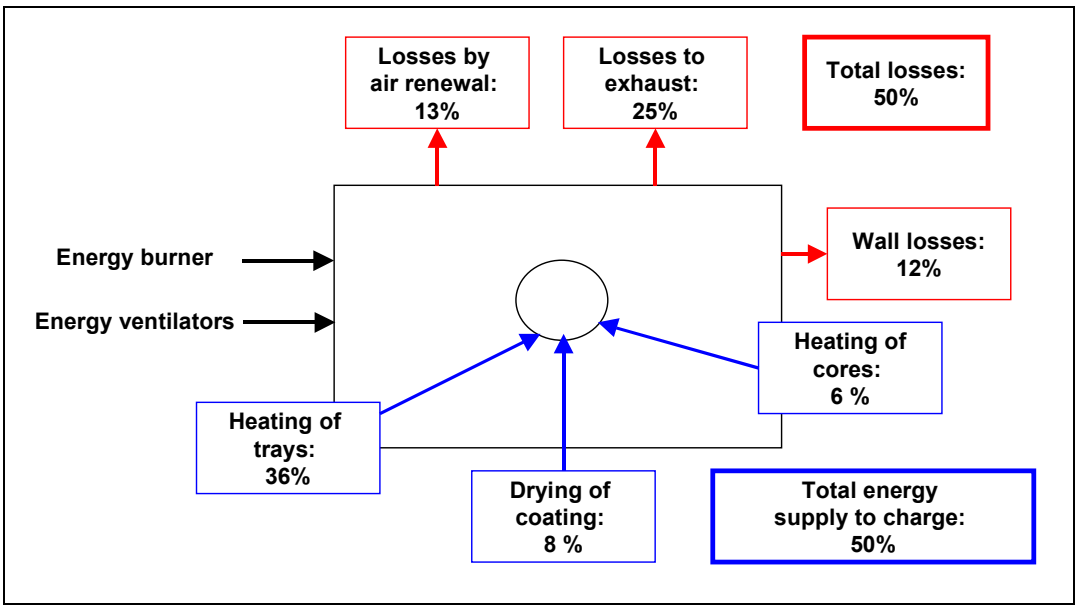


Figure 4.7: Thermal balance of a stove for core drying, working at 72 % capacity [143, Inasmet and CTIF, 2002]

The balance shows that 50 % of the energy is lost, with indeed effectively less than 10 % being used for core drying. The balance gives a consumption of 8.5 kWh per kg of water evaporated, which corresponds to 465 kWh per tonne of cores at a throughput of 156 kg/h. When the stove works at a lower capacity rate, the losses increase further. Similar measurements in another foundry confirmed the high (>50 %) losses and low (<10 %) effective energy use. Energy efficiency can be increased using microwave drying. This will be discussed in Section 4.3.3.6.

Applicability

Water-based solvents can be used in most situations. However, alcohol-based coatings cannot be replaced in some specific applications and will still need to be used:

- for big or complicated moulds/cores, where drying problems may occur due to difficult penetration of drying air
- for water glass bonded sands
- in Mg casting: water creates $Mg(OH)_2$ and thus causes technical problems
- in the production of manganese steel with MgO-coating.

The implementation of water-based coatings is applicable for new and existing large-scale, large series foundries. For new and existing small-scale foundries, the implementation may be hindered by technical or economic factors.

Economics

The investment cost depends on several factors, such as the available space for a drying line in the foundry, the choice of the drying technique, and the need to adapt the sand mix.

The complete replacement of alcohol-based coatings by water-based coatings in a Dutch iron foundry, using ambient air drying involved a total investment of EUR 71000. This included the installation of ventilators and optimisation of the sand quality. A reduction of the IPA-emission of 161 tonne/yr corresponded to EUR 62.5/tonne IPA emission reduction.

The operational costs involve increased controls of the coating and cores (viscosity, layer thickness, water content, product quality) and amount to EUR 9000/yr. Drying 1 tonne of coating consumes 2100 kWh of energy.

On the benefits side of the economics balance is the reduction in expenses for the purchasing of solvent. For bigger foundries, examples exist where investment in a water-based system was paid back in 2 years, on the basis of the reduced purchasing costs of the alcohol only.

The operational cost of drying is EUR 0.01/kg (non-ferrous foundry in France).

Driving force for implementation
Pressure from authorities increasing attention to the emissions of organics.

Example plants
- PSA Sept-Fons (F)
- Fonderie Bréa, Montluçon (F)
- De Globe b.v., Weert (NL).

Reference literature
[129, infoMil, 1999], [143, Inasmet and CTIF, 2002], [149, Beauvais and Choplin, 2001]

4.3.3.6 Microwave drying for water-based coatings

Description
Water-based coatings require a drying treatment. The application of microwave furnaces for this purpose gives operational advantages over the use of ambient or heated air drying. Microwaves of 2450 MHz frequency are used, and have the following properties:
- good selectivity of energy transfer: The microwave energy is transferred preferentially to the water molecules, rather than the sand material. This implies a preferential and homogeneous drying of the surface, even for complex cores
- self adaptive coupling: The drying mechanism provides a self-controlling homogenisation of the humidity of the material
- quick drying: The speed of drying depends on the applied power. The high drying velocity results in a limitation of the water-core contact time. This results in a good mechanical stability of the cores.

The application of microwave drying presents difficulties in the following cases:
- heterogeneous loading of the furnace (with a range of core masses and volumes)
- use of cores or inserts with iron
- inhomogeneous drying of thicker parts of the coating
- risk of deformation of complex cores.

Achieved environmental benefits
Increased energy efficiency of the drying process.

Cross-media effects
Microwave drying also brings polymerisation reactions to a further completion. This reduces the gaseous emissions in the proceeding stages of the foundry process (i.e. pouring, cooling, shake-out).

Operational data

The use of microwave drying has not been implemented on an industrial scale, although large-scale industrial tests have been performed. The results of these tests are given below. One test campaign has been run using a 50 kW microwave furnace. The stove was loaded to 50 % of its capacity with a charge of 800 kg of cores. Cores are placed on plastic trays, which are not heated by the microwaves. The thermal balance is given in Figure 4.8. It shows that more than 30 % of the energy input is used for drying. Additionally, the cores are only slightly heated up (temperature at exit = 40 ºC), which allows immediate handling. The data from two measurement campaigns are given in Table 4.23, and compared to analogous campaigns on hot air furnaces (as discussed in 4.3.3.5).

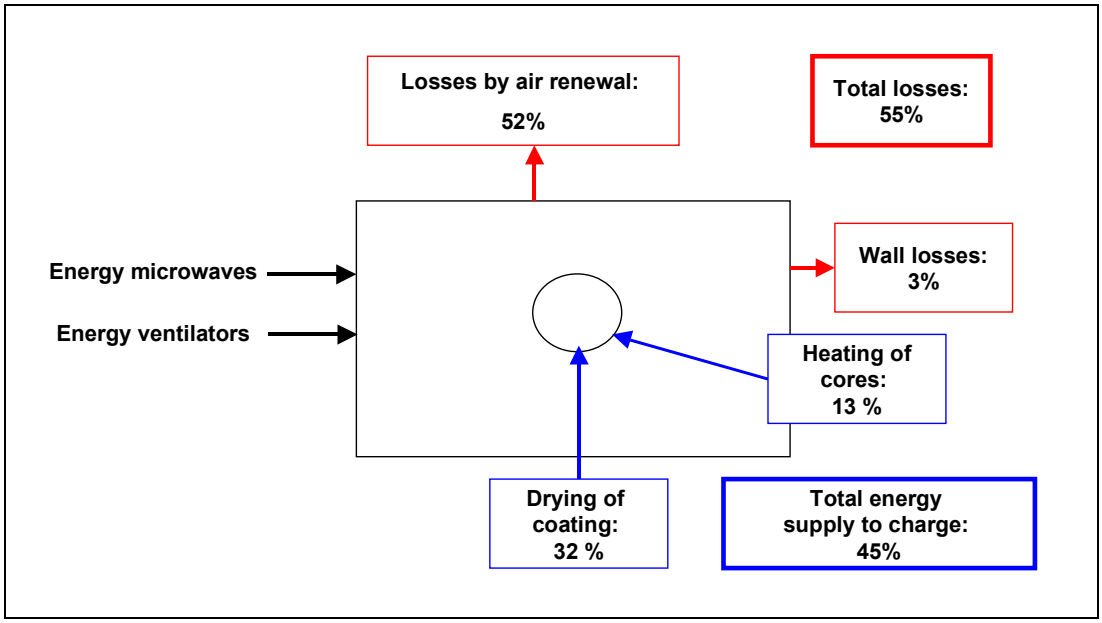


Figure 4.8: Thermal balance for the microwave drying of cores for a 50 kW furnace working at 50 % capacity [143, Inasmet and CTIF, 2002]

Furnace type	Foundry A Hot air	Foundry B Hot air	Foundry B Microwave	Foundry C Microwave
Core load	156 kg/h	270 kg/h	800 kg/h	500 – 900 kg/h
Humidity	5.5 %	2.7 %	2.7 %	2 – 3.2 %
Thermal energy supply	73 kW	70 kW	50 kW	40 kW
Duration	48 min	113 min	8 min	8 min
Specific consumption per kg evaporated water	8.5 kWh	9.3 kWh	2.3 kWh	2 kWh
Specific consumption per tonne wet cores	465 kWh	280 kWh	63 kWh	-

Table 4.23: Results of test campaigns on core drying, using hot air and microwave furnaces [143, Inasmet and CTIF, 2002]

The data show that the drying time is considerably reduced from 1 – 2 h to less than 10 minutes. Additionally, the energy consumption is reduced by a factor of 4 – 5, and the throughput is increased.

Applicability

This technique is applicable for the drying of all water-based coatings. Furthermore, it allows the greater applicability of water-based coatings to more complex core shapes and smaller series.

Economics
Microwave drying represents high investment costs. The actual investment is proportional to the power requirement, which corresponds to the amount of water to be evaporated. The high investment is partially counterbalanced by:

- higher energy efficiency, though the technique uses electricity rather than gas in the hot air furnace
- reduced solvent cost for water-based vs. solvent-based
- reduced maintenance costs due to a more compact installation compared to the use of (hot) air drying or a cooling line.

Driving force for implementation
Pressure from authorities, with increasing attention being paid to the emissions of organics, combined with the need for higher energy efficiency.

Example plants
The technique is reported to be applied in foundries in France and Spain.

Reference literature
[143, Inasmet and CTIF, 2002], [225, TWG, 2003]

4.3.3.7 Use of non-aromatic solvents for cold-box core production

Description
Classical cold-box systems use organic solvents. These cause releases of noxious and odorous VOCs during core production and storage. Furthermore VOC emissions (benzene, toluene, xylene) occur during pouring, cooling and shake-out. Alternative solvents for cold-box core production are based on protein or animal fat (e.g. vegetable-oil methyl esters) or on silicate esters. These solvents are not noxious to workers health, nor inflammable and therefore transport and storage are easier.

The low volatility of the vegetable-oil methyl esters enhances the storage capabilities in humid atmospheres and their persistence when applying water-based coatings.

The resulting cores have a higher strength, lower sticking of the sand and good shake-out properties.

Achieved environmental benefits
There is no vaporisation due to the high boiling point (about 300 ºC) and thus there is no solvent odour emission during storage.
VOC emissions are reduced during core manufacturing and storage, and (more importantly) during pouring, cooling and shake-out.

Cross-media effects
Vegetable-based solvents cause increased fume production during pouring and (in the case of die-casting) upon opening of the die. This is due to the low evaporation and consequently high residual solvent content upon pouring. This effect does not occur with silicate ester solvents.

Protein and animal fat based solvents produce a distinctive odour, and have been reported to cause odour problems inside the foundry.

Operational data
Table 4.24 shows operational emission values for benzene, toluene, xylene and phenol, as measured in one aluminium green sand foundry. Measurements were performed both at the shake-out grate and in the exhaust-air stack. Data are given for the traditional cold-box system

and for one using vegetable-oil based solvents. A clear reduction in BTX and C-emissions is observed (25 – 50 % of stack emissions).

Compound	At shake-out			At exhaust-gas stack		
	Aromatic based (mg/m³)	Vegetable-based (mg/m³)	Difference (%)	Aromatic based (mg/m³)	Vegetable-based (mg/m³)	Difference (%)
Benzene	0.08	0.05	- 44	0.1	0.07	- 30
Toluene	0.12	0.05	- 58	0.08	0.06	- 25
Xylene	0.09	0.04	- 56	0.09	0.05	- 41
Phenol	14.8	14.6	- 2	7.2	6.57	- 9
Total C	61.0	29.5	- 52	37.0	18.5	- 50

Table 4.24: Emission data for cold-box core systems in an aluminium foundry, measured at the shake-out grate and in the exhaust-air stack
[189, Hüttenes-Albertus, 2002]

Results of emission measurements in a German iron foundry are given in Table 4.25. For this table, the measured emission of each compound is expressed relative to the emission of the same compound for the aromatic-based system. For example: the emission of toluene at the second cooling is only 58 % of the toluene emission for the aromatic system. The table shows a clear reduction of VOC emissions in the second cooling and shake-out phase.

	Benzene	Toluene	Xylene	Phenol
Pouring and cooling 1	83	100	100	100
Cooling 2	78.5	58	46	74
Shake-out	78	78	78	12
Emission data expressed as %, relative to emission of the aromatic based system (set at 100 % for each measurement)				

Table 4.25: Emissions (%) of selected compounds from vegetable-based cold-box core systems
[216, Hobelsberger, et al., 1997]

The total mass flow reduction of the specified compounds was:
- benzene: - 21 %
- toluene: - 26 %
- xylene: - 30 %
- phenol: - 62 %

A survey measurement of the total carbon emission over the full foundry process is given in Figure 4.9. The data show that the vegetable-based solvents partially result in a shift of emissions from the core-making area to the finishing area. Nevertheless an overall reduction of 17 % carbon emission reduction is reached.

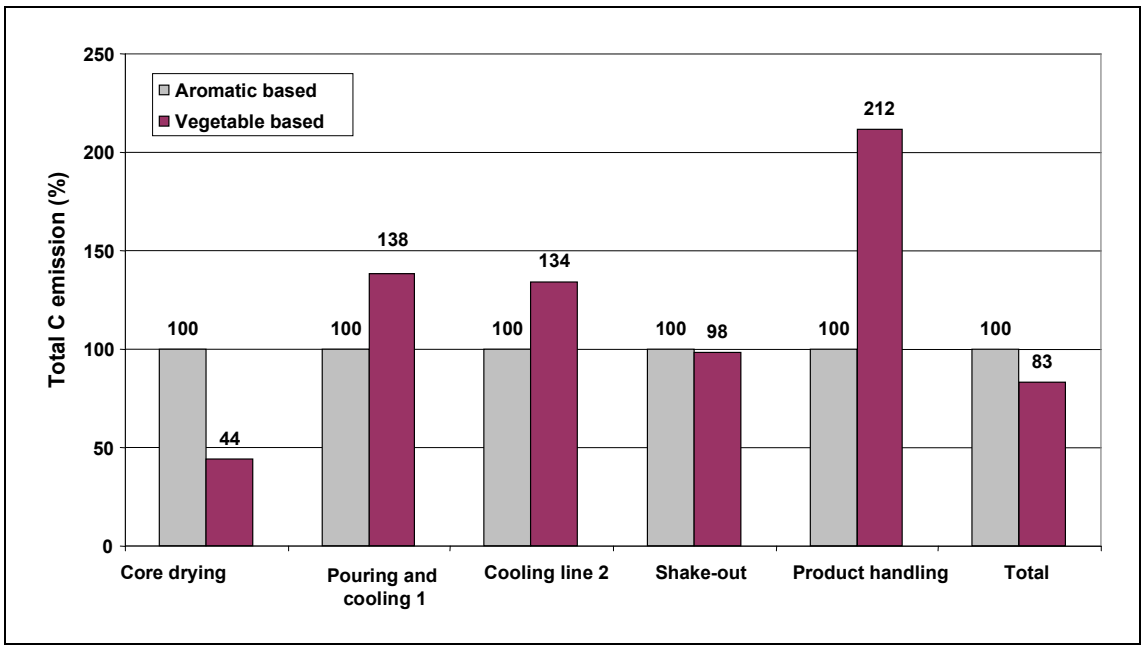


Figure 4.9: Total carbon emissions from various process steps, using aromatic- and vegetable-based solvents
(values in % expressed relative to emission of the aromatic based system)
[216, Hobelsberger, et al., 1997]

Applicability
Non-aromatic solvents can be applied in all processes using cold-box sand. The technique is relatively new and operational results as stated above need to be confirmed through repeated application. The technique has been implemented in foundries for the full range of automotive castings, as well as in castings for machinery, and in the construction and electronics industry. Both ferrous and non-ferrous applications are reported.

Economics
Data from the Italian foundry association indicate that non-aromatic solvents have a cost that is double that of the aromatic equivalent, e.g. EUR 0.82/kg against EUR 0.36 – 0.48/kg.

Operational data from a large series ferrous foundry showed that binder prices for aromatic cold box were around EUR 2/kg (2001) and went up with some 30 %, upon changing to the non-aromatic system. After one year (2003), the price lowered again however, to a level 10 % above the price of the traditional system.

Driving force for implementation
To reduce VOC and odour emissions.

Example plants
The technique is reported to be used in large-scale foundries in Germany.

Reference literature
[143, Inasmet and CTIF, 2002], [189, Hüttenes-Albertus, 2002], [202, TWG, 2002], [216, Hobelsberger, et al., 1997], [225, TWG, 2003]

4.3.4 Alternative moulding/core-making methods

4.3.4.1 Lost Foam casting

Description
The general principles of Lost Foam casting have been described in Section 2.5.7.1. Due to the absence of binders, the technique produces a reduced amount of solid waste and emissions compared to sand casting methods.

The technique allows the production of pieces with tighter tolerances, less feeder and riser channels and better as-cast features. This all results in less machining and clean-up time.

Lost foam foundries include a foam workshop, a melting shop and a casting shop. They do not have an extensive core-making shop and finishing shop. The foam shop involves foaming machines, steam generators and coolers and ambient air dryers.

The Lost Foam models are made of polystyrene (EPS) or PMMA, with small amounts of pentane, glue and a mineral coating. Since both EPS and pentane are pure hydrocarbons, organic carbons are formed upon pyrolysis of the model. In order to minimise emissions of the organic decomposition products of EPS, post combustion of the off-gases is performed.

The technique uses unbonded sand, which results in no binder–related emissions upon pouring and shake-out and which may be internally re-used without major treatment. EPS pyrolysis results in a slow build-up of organic material in the sand. This may be prevented by de-dusting and partial renewal of the circulating sand. A 5 % renewal is sufficient to maintain sand quality. The evacuated sand may be thermally regenerated for internal re-use.

Achieved environmental benefits
Since unbonded sand is used, the technique shows no binder-related emissions upon pouring. However pyrolysis of the EPS or PMMA results in organic decomposition products, which necessitate post combustion.

The use of energy in the Lost Foam process is significantly lower than in conventional casting methods. This is mainly due to the reduced energy uses for post casting operations, melting and sand preparation. The production of cores for conventional moulding methods is relatively more energy intensive than the production of the foamed model.

LCA analysis has confirmed that the environmental benefit as stated above, can be extended to an overall better environmental performance of the Lost Foam process over sand casting, in as far as the casting of core-intensive castings are concerned. For simple castings (e.g. lids), the life cycle approach shows that there is no overall better performing process.

Cross-media effects
The technique represents a reduction in energy consumption and a decrease in mould making and casting finishing operations. The off-gases show increased values of BTEX and formaldehyde, but emissions only occur during pouring and they can be more easily captured and treated. The technique produces a reduced amount of residual sand and dust and the sand may be more easily regenerated (shortened thermal treatment).

An LCA-based assessment of the Lost Foam process (also taking into account processes outside the foundry borders) shows a lower overall environmental impact for the production of core-intensive castings.

Operational data
Emission data and data on residue production have been given in Section 3.9.6.1. The technique results in lower residue production compared to a sand foundry of equal capacity. Flue-gases need more intensive cleaning (post combustion) and (after cleaning) result in higher organic compound (BTEX, formaldehyde) stack emissions.

Comparative consumption levels for the production of a comparable compressor casing using sand casting and Lost Foam casting are given in Table 4.26. This shows the higher amount of return material in the melt and the lower weight of the casting. For the Lost Foam method, the total amount of moulding-sand is greatly increased, while no cores are used.

Input material	Green sand	Chemically-bonded sand	Lost Foam
Cast iron	98.0	98.0	96.1
Foundry returns	30.0	30.0	38.1
Weight casting	68.0	68.0	58.0
Moulding-sand	256.8	233.0	1101.4
Core sand	122.0	150.7	n.a.
Weight foam model + feeder	n.a.	n.a.	0.212
All data in kg n.a: not applicable			

Table 4.26: Operational data for the production of a similar cast iron compressor casing, using various methods
[130, de Wilde and ten Houten, 1999]

Applicability

This technique applies to the serial production of small and medium sized products in ferrous and non-ferrous metal. Maximum casting sizes are 1000 x 1000 x 550 mm. The technique finds most of its implementation in aluminium foundries and has a 2 % share of aluminium casting.

Since the technique implies a basic change in the mould making procedure and infrastructure, it applies primarily to new installations. Application in existing foundries requires a conversion of the foundry process with regard to the moulding, pouring and finishing operations and a review of these stages for each of the castings produced. To introduce Lost Foam for a given casting requires funds, manpower and the necessary time and flexibility, as well as the co-operation of the customer.

Economics

Economic data for an aluminium Lost Foam installation are given in Table 4.27. Investment costs include equipment, installation, start-up and training.

Investment costs	Description	EUR
Model making equipment	Model making machine Steam generator Coating installation	1300000
Casting equipment	Automatic casting machine	2540000
Off-gas cleaning	Dry dedusting Thermal regenerative treatment	608000
Sand preparation	Sieving, cooling, transport	160000
Total	*Investment, installation, start-up, training*	*4608000*
Operational cost		**EUR/tonne good casting**
Consumption	EPS-granules, glue, coating, steam, combustibles	202
Foundry details: aluminium castings, 5500 tonne/yr production good castings, 6864 tonne/yr production molten metal		

Table 4.27: Economic data for an aluminium Lost Foam foundry
[96, Spillner, 1997]

Driving force for implementation

To reduce wastes from sand casting and to reduce energy consumption.

Example plants

Several example plants are reported in Germany and France.

Reference literature
cast iron: [130, de Wilde and ten Houten, 1999]
aluminium: [96, Spillner, 1997], [143, Inasmet and CTIF, 2002]

4.3.4.2 Ceramic shell moulding

Description
Ceramic shell moulding is a patented process (Replicast®) in which a polystyrene model is covered with a ceramic shell (2 – 3 mm thickness), based on ethyl silicate and refractory sand. The shell is hardened using ammonia and sintered at 1000 ºC. The sintering cures the shell and burns away the polystyrene model. The metal is then poured into the shell.

The sintering furnace is equipped with post combustion to reduce emissions.

The technique allows a casting design with no parting lines, cores and draft angles and reduced feed metal. This reduces the need for finishing and machining operations.

Achieved environmental benefits
The technique results in a minimisation of dust emissions from moulding and finishing, as compared to sand moulding. The emissions of VOC are eliminated as no gas is emitted for the inert ceramic mould. Additionally the amount of waste (dust, metal) is reduced. The reduction of feeder systems results in a higher yield of castings per melt.

Cross-media effects
No cross-media effects apply.

Operational data
Operational data from the owner of the technique are reported in Table 4.28, for the casting of valves, as compared to sand casting.

Property	Relative weight reduction (%)
Finished weight of castings	20 – 26
Feed metal	24 – 60
Poured metal	24 – 50

Table 4.28: Relative weight reduction for ceramic shell casting of valves as compared to sand casting
[219, Castings Technology International, 2003]

Applicability
The technique applies for the fabrication of castings which need a high surface finish, in low-carbon alloys such as ultra low carbon stainless steel and nickel-based alloys with a finished weight of up to 550 kg. The ceramic shell process is a patented process and may only be used in accordance with the terms and conditions of the licence granted to the licensee.

Driving force for implementation
Regulation of VOC emissions and high disposal costs for residual wastes.

Example plants
- CMS srl, Urbisaglia (I): 2 automated shelling lines, producing steel valves up to 150 kg finished weight
- Saint-Gobain SEVA, Chalons-sur-Saone (F): steel and super alloy components for glass industry.

Reference literature
[110, Vito, 2001], [219, Castings Technology International, 2003]

4.3.5 Permanent (metal) moulds and pressure die preparation

4.3.5.1 Minimisation of release agent and water consumption

Description
A water-based solution of release agent is sprayed on the open HPDC die before closing it. This allows cooling and coating of the die. Some simple process measures allow the minimisation of the release agent and water consumption. These will also prevent the formation of a mist. These measures are:

- *Automated spraying process*: Robotisation of the spraying process allows a careful control of the amount of release agent used and adaptation of the amount used to the local needs of the cast piece
- *Optimise dilution factor*: The release agent dilution factor should be chosen such that the spraying action has the required balance between coating and cooling of the die
- *Apply in-die cooling*: The cooling action may be partially taken over by internal cooling using an integrated water circuit.

Achieved environmental benefits
Minimisation of water and chemicals consumption. Prevention and/or reduction of (diffuse) emissions.

Cross-media effects
No cross-media effects apply.

Applicability
This technique applies to HPDC foundries. The extent to which the minimisation can be applied depends on the type of castings and the machines used.

Driving force for implementation
Minimisation of consumptions and emissions.

Example plants
This technique is applied in major HPDC plants, e.g. in the manufacture of car parts (D, F).

Reference literature
[202, TWG, 2002]

4.3.5.2 Closed-mould application of release agent

Description
A release agent is applied to the closed die-casting mould in a vaporised form. The high temperature results in a condensation and deposition of a release agent film. This technique is an alternative to the spraying of a water-based solution of the release agent onto the open die. It allows the water usage to be reduced and also reduces the consumption of release agents. The active substances for the process, i.e. getting the casting out of the die, are very similar to the open-mould technique: paraffin wax, aliphatic carbons, polysiloxanes, polyglycol.

Water spraying, however, also causes the necessary cooling of the die surface. The alternative technique therefore requires enhanced temperature management (mainly by a cooling effect), by means of an internal die cooling system. This may be obtained by reducing the thermal oil temperature. Combined water spraying and closed-mould release agent application is possible in places where the moulds cannot achieve complete thermal equilibrium by means of internal cooling systems alone.

Achieved environmental benefits
The technique allows a reduction in the usage of both water and the release agent. This results in a lower amount of waste water and reduced emissions of steam containing oily particles. The active compounds of the release agent are comparable to the traditional ones. Emissions due to decomposition of the release agent (and upon opening the die to get the casting out) therefore are comparable in nature to those with the open-mould technique.

Cross-media effects
The technique requires an increased effort to cool the dies. In simple cases, this may involve a lowering of the thermal oil temperature, but for more complex dies, it may involve the application of an additional cooling circuit.

Operational data
Some operational examples in aluminium foundries have been reported. These result in a 50 – 80 % reduction in the spraying time, and a 80 % reduction in sleeve-parting agent consumption.

Applicability
The technique is applicable in existing installations, but may require the production of specific dies with integrated or adapted cooling circuit. The applicability is limited to specific types of castings, dies and casting machines and is mainly based on technical considerations. This technique is not a general alternative for the application of release agents.

Driving force for implementation
Foundry strategy to reduce waste water production and to reduce the consumption of water and chemicals.

Example plants
Some operational examples in aluminium foundries have been reported.

Reference literature
[189, Hüttenes-Albertus, 2002], [202, TWG, 2002]

4.4 Metal casting

4.4.1 Improvement of metal yield

Description
Metal yield is defined as the ratio of metal melted to the weight of finished castings. The difference between the two values is due to metal losses (e.g. melting losses, spilt metal, grinding losses) and return metal (e.g. pigged metal, runners, scrap castings). An improvement of the metal yield involves reducing the metal loss and amount of return metal.

Improving metal yield is possible using one or more of the following measures:
- applying on efficient method: proper design of runners, risers, ingates, pouring basin and optimised box yield (castings/metal poured in a mould). A valuable tool in designing on efficient method is the use of computer aided simulation of pouring and solidification
- applying good procedures in melting and pouring operations: in order to reduce melting losses, excessive pigging, scrap rates, etc.
- applying good practice in the moulding and core-making departments: in order to reduce scrap due to deficiencies in the mould- and core-making operations.

Achieved environmental benefits
Increasing the metal yield results in a lower consumption of energy, sand and additives per unit of good casting. The overall efficiency of the process is increased.

Cross-media effects
No cross-media aspects apply to this technique.

Operational data
Table 4.29 provides a guide to the typical yields obtained for different types of iron casting production. It is not possible to recommend a target yield figure which can usefully be adopted by a particular foundry, as so much depends on the type of metal, type of casting, the production facilities and the market which has to be served. It is therefore necessary that a foundry sets individual targets, based on an analysis of its own current performance.

Casting type	Yield (%)
Heavy grey iron, simple shape	85 – 95
Medium sized grey iron jobbing or small batch	65 – 75
Mechanised repetition, general quality small to medium sized grey iron engineering and municipal castings	65 – 75
Mechanised repetition, high quality small to medium sized grey iron engineering castings, relatively simple design	60 – 65
Mechanised repetition, high quality small to medium sized grey iron engineering castings, complicated heavy cored design	55 – 60
Medium sized nodular iron jobbing or small batch	50 – 60
Small or very small grey iron repetition	45 – 55
Mechanised repetition of malleable iron and small nodular iron castings	40 – 50

Table 4.29: Typical metal yields for different iron casting types
[45, ETSU, 1990]

In response to a questionnaire, 82 UK foundries reported their metal yield performances for the period 1981 - 1987. The improvement in yield per metal type (weighted average) are given in Table 4.30.

	Yield in 1981 (%)	Yield in 1987 (%)	Improvement in yield (%)
Grey iron	60.5	63.0	2.5
Nodular iron	51.8	55.7	3.9
Malleable iron	36.4	39.2	2.8

Table 4.30: Weighted average of yield performances in 82 UK ferrous foundries, 1981 - 1987
[45, ETSU, 1990]

Applicability
The technique is applicable in all existing ferrous and non-ferrous foundries.

Economics
Improving the metal yield is possible through simple low-cost practical measures and controls. The benefits may be high since every percentage improvement results in a corresponding reduction of melting energy consumption and a reduction in the consumption of sand and chemicals.

The introduction of a computer-aided simulation for pouring and solidification requires investment and training costs.

Driving force for implementation
Optimisation of process efficiency.

Example plants
Metal yield considerations are part of good operational practice in the majority of European foundries.

Reference literature
[45, ETSU, 1990], [140, EU Thematic Network Foundry Wastes, 2001]

4.5 Fume, flue-gas and exhaust air capture and treatment

4.5.1 General principles

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

Furnace sealing (or the use of sealed furnaces) combined with process control may be applied to prevent or contain emissions from a process plant. Sections 4.5.2 – 4.5.6 covering furnaces indicate where furnace sealing is possible and where other collection techniques may be used to provide integral gas collection.

Other techniques are available to collect the emissions that cannot be prevented or contained. Gases and fumes that escape from the processes are released into the working area and then escape into the surrounding environment. They may affect operator health and safety and contribute to the environmental impact of the process. Process gas collection techniques are used to prevent and minimise these fugitive emissions. Hoods are designed to be as close as possible to the source emission while leaving room for process operations. Movable hoods are used in some applications. Some processes use hoods to collect primary and secondary fumes.

Fugitive emissions may be very important, but are hard to measure and quantify. Methods of estimating ventilation volumes or deposition rates can be used to estimate them. One reliable method, which has been applied to primary copper smelting, shows that the magnitude of fugitive emissions can be much more significant than collected and abated emissions. Fugitive emissions can be more than two to three times the quantity of controlled emissions. [155, European IPPC Bureau, 2001]

The melting shop, core-making shop, sand plant and post-casting shop are considerable sources of emissions. The emitted air pollutants are mainly dust (possibly with heavy metal particles), sulphur dioxide, carbon monoxide and odorous organic compounds. Table 4.31 gives the results of a survey of the pollutants generated in the different parts of the ferrous foundry process. Both inorganic and organic compounds are listed as individual and group compounds. Dust emissions are of specific importance, since thermal processes can generate considerable amounts of heavy metals.

SOURCE → / RELEASES ↓	Raw material storage and handling	Furnace operations	Desulphurisation of molten iron	Nodularisation	Preparation of cores and moulds	Casting	Shake-out, reclamation	Fettling, dressing and finishing of castings
Oxides of sulphur		X	X		X	X	X	
Oxides of nitrogen		X			X	X	X	
Carbon dioxide		X	X	X	X	X	X	
Carbon monoxide		X	X	X	X	X	X	
Hydrogen sulphide					X	X	X	
Ammonia					X	X	X	
Oxides of iron		X	X	X		X	X	X
Alkali metal compounds		X	X					
Alkaline-earth metal compounds		X	X	X		X		
Metal oxide particulates		X	X	X		X	X	X
Non-metallic particulates	X	X	X		X	X	X	X
Metallic iron		X						X
Hydrogen cyanide					X			
Sulphur			X					
Amines/amides					X	X		
Dioxins		X						
Volatile organic compounds		X			X	X	X	
Acid vapours		X			X	X		
Noise		X			X		X	X

Substances include their compounds, except where separate reference to the compound is made.

Releases to air may also be released to land or water, depending upon the abatement technology employed, e.g. via collected dusts, sludges or liquors.
Some releases are specific to a particular binder system

Table 4.31: Survey of air emissions from different ferrous foundry stages [160, UK Environment Agency, 2002]

The principles and techniques for waste gas collection and treatment are the same for foundries and (primary) non-ferrous metal industries, therefore for a full discussion of the principles the reader is referred to the BREF document on non-ferrous metal industries. Section 4.5.1.3 details a short survey of the techniques that apply.

4.5.1.1 Reduction of fugitive emissions

Description
Fugitive emissions occur when emissions from specific process sources are not collected. Besides the process-related emission sources mentioned in Section 4.5.1, potential sources of fugitive emissions to air include:

- storage areas (e.g. bays, stockpiles, heaps)
- the loading and unloading of transport containers
- transferences of material from one vessel to another (e.g. furnace, ladle, silos)
- the mixing and curing of chemical binders (inorganic and organic chemical emissions)
- mould coatings (solvents)
- conveyor systems for moving material around
- pipework and ductwork systems (e.g. pumps, valves, flanges, catchpots, drains, inspection hatches, etc.); these type of emissions are discussed in detail in the LVOC-BREF
- poor building containment and extraction
- bypass of abatement equipment (to air or water)
- an accidental loss of containment from a plant or equipment failure, including leakages, e.g. from the sand reclamation plant
- spills.

In order to minimise fugitive dust emissions, the following techniques may be employed:
- the covering of skips and vessels
- the avoidance of outdoor or uncovered stockpiles
- where outdoor stockpiles are unavoidable, using sprays, binders, stockpile management techniques, windbreaks, etc.
- cleaning wheels and roads (i.e. avoiding the transfer of pollution to water and wind)
- using closed conveyors, pneumatic conveying (although note the higher energy needs), and minimising drops
- vacuum cleaning of the moulding and casting shop in sand moulding foundries, with the exception of areas where the sand has a technical or safety-related function, e.g. the pouring area, and with the exception of hand-moulding jobbing foundries
- keeping outside doors shut, e.g using an automatic shutter system or flaps
- carrying out good housekeeping, i.e. ensuring that regular inspections are carried out by responsible and delegated staff as a practice of good housekeeping and keeping up-to-date records.

Fugitive emissions to water may arise from subsurface structures or defective surfacing. These types of fugitive emissions can be minimised by the following actions:
- establishing and recording the sources, direction, and destination of all installation drains
- identifying and recording all subsurface sumps and storage vessels
- carrying out routine programmed inspections
- having an inspection and maintenance programme of impervious surfaces and containment kerbs
- being able to justify where operational areas have <u>not</u> been equipped with:
  - an impervious surface
  - spill containment kerbs
  - sealed construction joints
  - connection to a sealed drainage system.

Achieved environmental benefits
A reduction of uncontrolled emissions.

Cross-media effects
No cross-media effects apply.

Applicability
These techniques are applicable to all new and existing installations.

Driving force for implementation
Limiting fugitive emissions will limit the overall odour and dust emissions to the close vicinity of the plant. For installations in crowded areas, maintaining good relations with neighbours could therefore be a driving force for implementation.

Example plants
Vacuum cleaning of the moulding and casting shop: applied in various visited green sand foundries.

Reference literature
[160, UK Environment Agency, 2002], [163, UK Environment Agency, 2002], [155, European IPPC Bureau, 2001]

4.5.1.2 Use of a multi-flue stack

Description
In order to obtain maximum advantage from thermal buoyancy, hot emissions may be combined into the minimum practicable number of chimneys. A multiplicity of discharge points may thus be avoided. This is particularly important when new plants are being designed or when changes are being made to existing processes.

Achieved environmental benefits
Gathering multiple off-gas streams into one stack allows control of the emissions and increases the total volume (and load) going to treatment and thus reduces the total emission level.

Cross-media effects
No cross-media effects apply.

Applicability
This technique can only be implemented in new plants or when existing installations require substantial changes.

Driving force for implementation
To increase the possibility to measure and control the foundry operation.

Example plants
This technique finds multiple implementation around Europe.

Reference literature
[160, UK Environment Agency, 2002]

4.5.1.3 Abatement techniques

Description
For cleaning collected off-gases, various wet and dry systems may be used. Selection of the appropriate technique depends on the composition, flow and conditions of the off-gas stream. The design of the abatement process is critical. Factors such as efficiency, suitability of the method and the input and output loading of the material to be collected are used. A full discussion of the working principles is given in the BREF document for non-ferrous metal industries. The following techniques are used in the foundry industry.

- Dust and particle removal:
  - cyclones
  - fabric or bag filters
  - wet scrubbers
- Gas scrubbing systems (SO_2, Cl, amine removal):
  - wet scrubbing using scrubber towers, venturi scrubbers and disintegrators.
- Oil-mist separators:
  - wet electrostatic precipitators
- CO and organics removal:
  - post combustion
  - biofilter.

For dust and particle removal, both wet and dry systems are used. The main advantage with using dry systems is that the dust is captured dry, which allows its subsequent re-use. Furthermore, no pollution is transferred to another medium, as is the case for wet systems. For gaseous compounds, such as SO_2 and chlorides, bag filters are inefficient, since they are not adsorbed onto the filter surface. Experiments with lime injection have not provided good results. The following describes the system used for dust and particle removal:

- *Cyclones*: If the right measures are taken (i.e. heat resistant steel, refractory lining) a cyclone filter may be used for dedusting hot flue-gases (500 – 600 ºC). The efficiency is too low to achieve emission levels in the 20 mg/Nm³ range. The cyclone is mainly used as a spark separator in front of a bag filter. Cyclones are used as a pretreatment step to other abatement systems
- *Multicyclones*: The separation efficiency of a cyclone increases with decreasing diameter. The use of a parallel series of small cyclones allows the separation of small dust particles, without a sharp increase in the pressure drop over the cleaning equipment
- *Bag filter*: This type of separator is widely applied in various parts of the foundry process, due to its good efficiency and low emission values. It can achieve good efficiencies in controlling the fine particulate matter found in melting operations. Sub-micron particles such as metallic oxides may be separated as well. For proper operation, the following measures need to be taken: flue-gas cooling (T = 130 - 160 ºC) and separation of sparks (using a cyclone). The post combustion of organic material (to reduce the fire risk) may be applied for an off-gas with a high VOC content. Post combustion as a "firewall" for bag filter protection has been reported in some cases for off-gas from the unpacking of drums. This technique is not applied in general; instead waste gas streams with high dust loads are mixed with gas streams with increased VOC contents to prevent the filter and the exhaust ducts from becoming sticky. A view of the inside and outside of a bag filter unit is given in Figure 4.10.

Figure 4.10: Bag filter units; inside (l.) and outside (m., r.) views
[237, HUT, 2003]

- *High temperature filter systems (using a ceramic filter medium):* These are available on the market but not currently applied in the foundry industry

- *Electrostatic precipitators (ESP):* These are not widely applied for foundry flue-gas dedusting. Due to their sensitivity to gas flow, gas temperature and humidity, they are only suitable for continuous melting regimes. They also incur a considerable explosion risk, due to the high gas volume they contain. The removal of dust to reduce this risk requires frequent cleaning, and therefore might incur economic problems. The main field of application for electrostatic precipitators in foundries is oil/mist removal from pressure die-casting exhaust gases.

Wet dedusting systems, such as venturi and disintegrators, are applied in melting flue-gas treatment. Scrubber towers are used for dedusting of non-melting off-gas. Compared to dry systems the wet systems have the following disadvantages: higher energy consumption, higher maintenance (corrosion, bacteria), and they result in waste water and a sludge for disposal.

Advantages are the capture of water-soluble compounds (such as SO_2, chlorides), quick cooling - which prevents dioxin reformation, low investment costs, and less restriction on input temperature.

- *Venturi scrubbers*: Water is sprayed into the gases as they pass through a venturi. The acceleration of the gas flow in the venturi throat causes an intensive mixing of both media. The dust particles are damped, making them heavier, so that they can be separated in a cyclone or other system placed downstream. If the gas flow drops, the venturi throat is adjusted to maintain the collection efficiency
- *Disintegrators*: These so-called dynamic scrubbers consist of concentric rotor and stator mounted pins through which the gas stream is driven by means of a fan placed downstream or by fan blades at the outer end of the rotor. Water injected into the centre of the rotor, is broken into fine droplets by the pins and dispersed in the gas stream. The wet particles impinge on the stator walls and are collected at the bottom of the disintegrator. The system works efficiently when the gas flow is reduced.

Post combustion systems and biofilters will be discussed in Sections 4.5.2 and 4.5.9, respectively.

Achieved environmental benefits
Reduction of emissions to the atmosphere.

Cross-media effects
Wet scrubber systems result in the production of a waste water flow, which then needs treatment. The cleaned water may be recirculated into the process. Sludge cakes, produced from the waste water treatment need to be disposed of.

If the foundry is located in a cold climate (heating season more than 6 months), all increases in air ventilation will also cause a growth in the energy consumption, since the workplace has to be heated more.

The use of all abatement systems require the use of energy to induce the draught of the gases through the abatement system.

Operational data
A comparison of the properties of wet and dry systems is given in Table 4.32. In the subsequent sections, techniques that are specific for the various melting furnaces and for the various process stages will be discussed.

Abatement techniques	Dry systems		Wet systems	
	Multi cyclone	Bag filter	Venturi	Disintegrator
Dust emission level*	100 – 200 mg/Nm³	<5 – 20 mg/Nm³	<20 – 150 mg/Nm³	<20 – 150 mg/Nm³
Investment cost	Low	High	Low	Medium
Energy consumption	Low	Low-medium	High	High
Advantages/reason for choice	Applicable for pre-cleaning of gases prior to other methods	Good performance for suitable dusts if well monitored. The potential to recycle dust to the process	Partial SO_2-capture Low risk of *de novo* synthesis	Compact installation Low risk of *de novo* synthesis
Disadvantages	Low efficiency when there is a disturbed flow pattern (dust blocking of distributor). limited efficiency for fine particles	Fire risk, large volume, blocking upon condensation	Wet sludge, waste water treatment, a loss of efficiency with wearing	Higher energy use, wearing, wet sludge, waste water treatment
* Values from operational practice, that can be maintained throughout the service life of the installation				

Table 4.32: Properties of wet and dry abatement systems for foundries [110, Vito, 2001], [155, European IPPC Bureau, 2001], [202, TWG, 2002]

Figure 4.11 gives a comparison of the operational conditions for hot blast cupola furnaces with a wet and dry dedusting system. The main differences are the temperature profile of the flue-gas and the energy consumption.

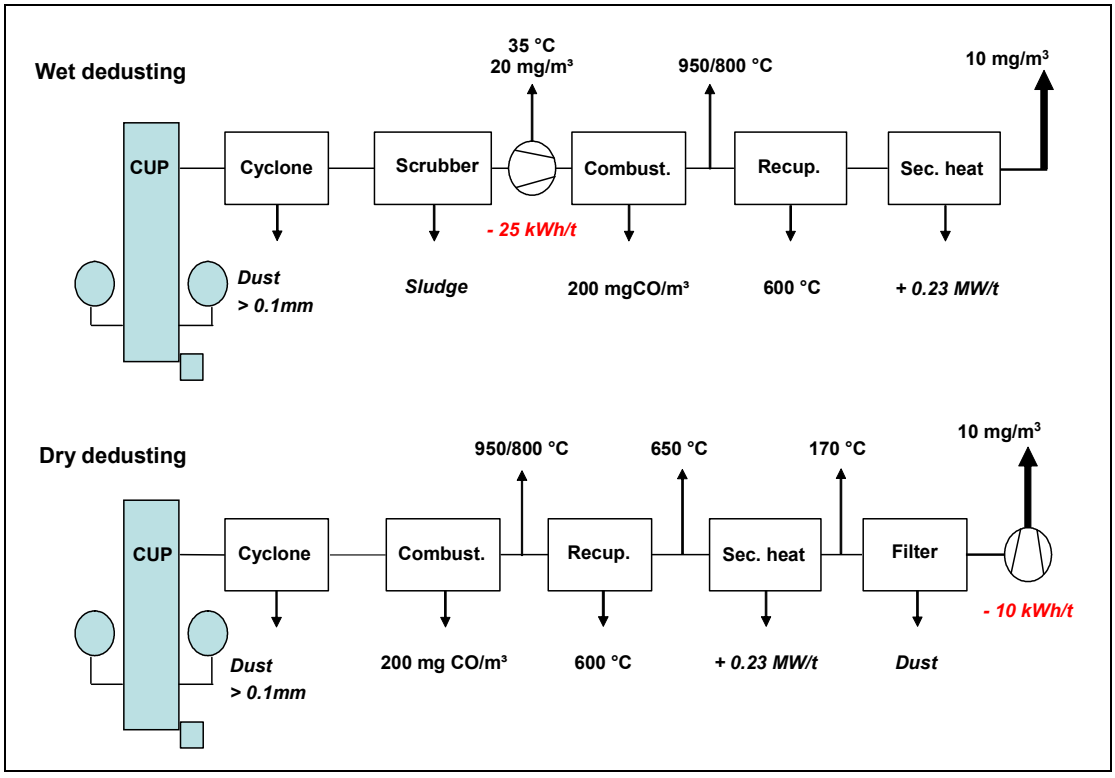


Figure 4.11: Operational conditions for wet and dry dedusting of hot blast cupola off-gas [230, CAEF, 2003]

Applicability
The applicability of the various abatement systems will be discussed in the following sections of this chapter.

Economics
Investment costs and energy usage for bag filters and wet separators are compared in Table 4.33.

Abatement technique	Investment cost* (EUR/Nm³)	Energy consumption (kW/1000 Nm³)
Bag filter	2.5 – 5	1 – 3
Wet separator	1.5 – 5	1 – 3
Biofilter	7.5 – 10	
* Excluding pipes and ducts, but including assembly		

Table 4.33: Investment and energy consumption data for various abatement systems [32, CAEF, 1997], [110, Vito, 2001], [202, TWG, 2002]

Driving force for implementation
Air emission regulations.

Example plants
This technique finds general application in European foundries.

Reference literature
[32, CAEF, 1997], [110, Vito, 2001], [155, European IPPC Bureau, 2001], [202, TWG, 2002]

4.5.1.4 Dioxin prevention and abatement

Description
Dioxins are relevant for thermal processes which have metals present. Dioxins or their precursors may be present in some raw materials and there is a possibility of *de-novo* synthesis in furnaces or abatement systems. Dioxins are easily adsorbed onto solid matter and may be collected by all environmental media as dust, scrubber solids and filter dust. Field tests have shown that the formation of dioxins in cupola furnaces cannot be correlated to one (or a few single) operational parameter(s). A combination of measures is needed to minimise the risk of dioxin formation.

In-process or primary measures to prevent dioxin emissions include:
- post combustion of the furnace off-gas in the CBC shaft or in a HBC combustion chamber. Combustion of cupola off-gas is fully described in Sections 4.5.2.2 and 4.5.2.3
- continuous temperature monitoring and control in the HBC combustion chamber (T >850 ºC) and maximising of the residence time (preferably >2s)
- maintaining the particulate matter concentration in the recuperator at a level <20 mg/m³, this is possible for HBC when using wet dedusting
- providing quick quenching of the dust laden off-gases, through the *de-novo* synthesis temperature range of 250 – 450 ºC
- preventing or minimising the build-up of dust along the cooling trajectory of the flue-gas, especially in the heat-exchanger, e.g. using vertical exchanger tubes, efficient internal cleaning, high temperature de-dusting
- melting clean scrap. This technique is described in Section 4.1.4
- using oxygen injection to ensure complete combustion. This technique is described in Section 4.2.1.6.

Although dioxins are destroyed at high temperature (i.e. above 850 ºC) in the presence of oxygen, the process of *de-novo* synthesis is still possible as the gases are cooled through the

reformation window (250 – 450 ºC). This window can be present in heat-exchangers or abatement systems and in cooler parts of the furnace, e.g. the feed area. Care must be taken in the design of cooling systems to minimise the residence time in the window and to avoid dust build-up, in order to prevent *de-novo* synthesis. An alternative is to dedust the off-gas by quick quenching using a wet system. Sufficient oxygen also needs to be present in the hot gases and for this oxygen injection can be used to ensure complete combustion. Nevertheless, excess oxygen should be prevented since this may support *de-novo* synthesis.

Sulphur has an inhibiting effect on the formation of dioxins, through depletion of molecular chlorine. The use of coal with a higher sulphur content in large combustion plants has been shown to provide lower PCDD/F concentrations. The reducing inhibiting effect is related to the S/Cl ratio, with a critical ratio of 0.64. A further increase does not result in less dioxins and furans. This effect has not been demonstrated in foundries, but may be studied. [231, UNEP, 2003]

The great spreading and big variability in the dioxin emission levels (even for the same installation) show that primary measures alone may not allow a stable and low dioxin emission value. Therefore, besides primary measures, the following abatement measures may be considered:

- *injection of additive powders* into the gas stream, such as activated carbon, open-hearth furnace coke or zeolite, so that dioxins are absorbed onto the surface. High efficiency dust filtration is then used to remove the dust and dioxins. The additive is injected into the off-gas stream before filtration. The adsorption process mainly takes place while the absorbents adhere to the filter bag. The filter dust may be recirculated back to the flue-gas to attain a higher efficiency. When using a carbon-based additive, special measures should be taken to prevent fire and explosion risk. The collected dusts may have high dioxin concentrations and will need to be disposed of or treated carefully
- *catalytic oxidation* systems are available for the destruction of dioxins. Fabric filters that incorporate a catalytic layer are used for the destruction of dioxins. In other sectors (e.g. steel, municipal waste incineration) this technique has been implemented successfully and implementation in the foundry industry is considered feasible. However, in order to prevent deactivation of the catalyst layer, a prior removal of coarse dust particles may be needed.

These are techniques to be considered depending on the application. They can all be incorporated into existing processes. The choice of the most effective and economically viable technique will depend on the specific site, safety aspects, and operational stability, as well as on economic factors.

Although the absence of one of the five dioxin building conditions mentioned above hinders dioxin synthesis, it is currently not possible to precisely foresee dioxin emissions by considering known operational parameters. The building of a new furnace therefore needs the careful consideration of primary measures as well as the option to add secondary measures in case of unexpectedly high values.

Achieved environmental benefits
Reduction of the emission of dioxins and furans to air.

Cross-media effects
The adsorption of dioxins and furans on activated carbon generates a PCDD/F-loaded dust stream. In order to prevent the explosion risk in the bag filter, mixing of the activated carbon with lime may be needed. This will increase the total amount of residue for disposal and will limit the possibility to re-use the filter dust.

Operational data
In-process measurements of dioxins in a hot blast cupola with dry dedusting have shown that high PCDD/F-levels (5 ngTEQ/Nm³) occur in the heat-exchanger. Other parts of the flue-gas system show much lower values. Reduction measures should therefore aim at minimising the

contact between dust and flue-gas in this zone, by minimsing dust or reducing the dust residence time.

A PCDD/F-emission level of 0.5 ng TEQ/Nm^3 can be achieved by using primary measures; and better than 0.5 ng TEQ/Nm³ can be achieved by using one or more of these techniques. A German survey concluded that without secondary measures the level of 0.1 ng TEQ/Nm³ is passed only in a limited number of installations and then only by a limited extent. The operational data as given in 3.8.2, however show that the level should be evaluated on a plant-by-plant basis.

Secondary measures in other sectors have been proven to allow a reduction to below 0.1 ng TEQ/Nm³.

For a flue-gas rate of 8000 m³/h at a blast rate of 3000m³/h, quick quenching of the cupola off-gas from 800 ºC to 150 ºC requires a water consumption of 4 m³/h.

Applicability
These techniques are applied in other industrial sectors, such as steel and non-ferrous metal production and waste incineration. Judging on a technical basis, they may be transposed to foundry furnace types that show a risk of dioxin formation: cupola, rotary and electric arc furnaces melting iron and steel (Section 3.8.2). For new and existing installations primary dioxin reduction measures, such as efficient combustion, furnace design modifications and scrap quality control have to be taken into consideration on a case-by-case basis, before turning to secondary measures.

The application of additive injection involves the installation of an additive silo, an injection system and, in the case of carbon injection control measures to prevent additive build-up. In order to prevent fire risks, activated carbon may be mixed with lime and may be injected, after the first filtration but before a dedicated secondary filter unit.

The application of catalytic filtration involves the least technical modification for existing plants, since only the filter bags need to be replaced by the catalytic type.

Economics
Primary measures do not involve additional investment costs. Operational costs are restricted to the use of oxygen or a higher price for cleaner scrap.

A cost estimation has been made for a hot blast cupola, as given in Table 4.34. Operational costs depend on the coke injection dose used and are given in Table 4.35. Costs for staff, maintenance, spare parts as well as possibly required early bag exchange or the installation of another type of bag quality have not been taken into consideration.

Parameter	Units	Value
Volume flow	Nm³/h	50000
Operating hours	h/yr	6250
Additive powder		Open-heart furnace coke
Additive price	EUR/t	400
Landfill price	EUR/t	300
Energy costs	EUR/kWh	0.09
Particle content		2 g/Nm³ - 100 kg/h
Investment cost: incl. silo, safety equipment, recirculation, integration - total cost - yearly cost	 EUR EUR/yr	 350000 52500
Energy consumption Cost of energy consumption	kW EUR/yr	10 6000

Table 4.34: Investment cost estimation for carbon injection installation, added to HBC [230, CAEF, 2003]

Parameter	Units	Values			
Coke content	g/Nm³ humid	0.2	0.3	0.4	0.5
Coke consumption	t/yr	63	94	126	156
Purchase cost	EUR/yr	25200	37600	50400	62400
Landfill cost	EUR/yr	18900	28200	37800	46800
Abated investment cost	EUR/yr	52500	52500	52500	52500
Energy cost	EUR/yr	6000	6000	6000	6000
Total cost	**EUR/yr**	**102600**	**124300**	**146700**	**167700**

Table 4.35: Total costs for carbon injection installation, added to HBC [230, CAEF, 2003]

Catalytic bag filter systems are used in the waste incinerator sector. Cost data from this application are transposed on basis of the flue-gas volume to be treated, but without taking into account operational parameters such as air-to-cloth ratio. For a depreciation time of 5 years, the investment and operational costs can be estimated at EUR 0.4 – 0.5/tonne molten metal for HBC and EUR 0.9 – 1.3/tonne molten metal for CBC. This price estimation was nor confirmed nor discarded by a catalytic bag filter supplier.

Driving force for implementation
Regulation limiting dioxin and furan emissions from the melting of metals.

Example plants
Reduction by installing oxygen injection: 3 example CBC plants in the Netherlands
Activated carbon injection: 1 example plant in Germany

Reference literature
[155, European IPPC Bureau, 2001], [161, UK Environment Agency, 2002], [202, TWG, 2002], [224, Helber, et al., 2000], [230, CAEF, 2003]

4.5.1.5 Odour abatement

Odour emissions are mainly associated with processes involving sand binders. The actual odorous products of pyrolysis may vary according to the type of system used, but generally the phenolic breakdown products, i.e. cresols and xylenols, are the most common source of odour complaint, due to their very low odour detection thresholds. The dispersion of odours during casting, cooling and shake-out involves mixing with large volumes of air, which makes collection and treatment difficult. The use of inorganic binders, such as sodium silicate, can substantially reduce emissions. No totally effective proven method of eliminating foundry generated smells is known to be currently available. A general approach is to ensure good ventilation and a rate of air change that ensures that emissions are quickly and efficiently dispersed to the atmosphere. Process-integrated measures include the substitution of binders or binder solvents (see Section 4.3.3.7). End-of-pipe techniques aim to abate pyrolysis products (see Section 4.5.8.5) and amines (see Section 4.5.8.4). These include adsorption techniques, post combustion, wet scrubbers and biofilters (see Section 4.5.8.6).

4.5.2 Cupola furnace

4.5.2.1 Gas collection, cleaning and cooling

Description
The design of the collection and gas cleaning system is based on the conditions occuring during blow-down, as these are often the most severe conditions experienced during the system operation. At the end of a melting campaign, the furnace is no longer filled with charge materials. Gas temperatures will increase gradually since they are no longer cooled by a cold charge in the stack. In contact with oxygen, CO will burn automatically. Temperatures can

therefore reach up to 1200 ºC, or even higher. The off-gas collection and treatment system has to be able to cope with these severe conditions.

Collection

Two systems are in use for top gas collection:

- *Above charge-hole offtake*: The exhaust gases are withdrawn at the end of the cupola stack by means of ductwork and a fan placed downstream. The opening above the charge-hole allows an important inflow of air, necessary to prevent cupola gases being emitted from the area. This volume of extra air may be many times the cupola gas flow. This increases the size and cost of the collection and cleaning system. Reducing charge-hole sizes may have some merit but this option may be limited because of the explosion hazard present when too little oxygen is mixed with the CO containing cupola gases (pulsating combustion)
- *Below charge-hole offtake*: The cupola top gases are collected through an annular ring below the charge-hole. No air inflow is required since the gases cannot be emitted out of the hole, provided the control system is sensitive enough to function properly during the variation of the blowing rate of the cupola. Too little offtake rate can result in the emission of uncleaned gases through the cupola stack, too great an offtake flow can result in air ingress, leading to combustion and overheating of the gases (i.e. an explosion hazard).

Cooling

Following collection, the gases may need cooling depending on the dust abatement system used. In the hot blast operation, the heat recovered from cooling may be used for preheating the blast air.

Several options are possible for cooling the collected gases, including:

- *Using tube coolers*: Running the collected gases through long ducts, decreases the temperature by natural convection and radiation. This system is simple but takes up a lot of space and does not offer controlled cooling (therefore there is a risk of condensation)
- *Using a forced air/gas heat-exchanger*: Cold ambient air is forced through an arrangement of tubes or plates to cool down the gases. Dust collection and the subsequent need for cleaning the heat-exchanging surfaces may lead to a complex and expensive design of the system. One advantage of this system is the possible use of the heated air for external heating purposes. Recuperative hot blast cupolas are equipped with a post combustion unit and a heat-exchanger (recuperator) to heat the blast air
- *Using an oil/gas heat-exchanger*: This is similar to the above system but more expensive because of the need for a secondary cooling system. The heat-exchanger is generally cooled with a circulation of mineral oil. Cooling with a water/gas heat-exchanger is not (or only very rarely) practised
- *Saturation with water*: Here the gases are cooled by the evaporation of the water sprayed into the gas stream. Wet scrubbers perform better if the gases are cooled in a saturation chamber prior to cleaning. When using fabric filters only, partial saturation is possible to prevent clogging of the fabric due to the condensation of water. A good control system is necessary to guarantee correct functioning of the system. Quenching the gases has the advantage that rapid cooling reduces the risk of dioxin formation.

Dedusting

Dust capture equipment of various types can be used to remove particulate matter from the waste gases. Generally wet scrubbers have low capital costs and maintenance, but require a high energy input to achieve acceptable collection efficiencies. The removal of the sludge is difficult and the scrubber water has to be treated prior to discharge. Dry collection systems have more expensive capital costs and need better control of the inlet gas conditions (temperature, condensation of water or organic vapours, $CO:O_2$ ratio, sparks) but usually use less energy than that needed for wet scrubbing. Furthermore, dry cupola dust can be recycled into the cupola (see 4.9.4.2).

Both venturi scrubbers and disintegrators are used with cupola systems. Descriptions of these systems are given in Section 4.5.1.3. A separator to remove small particles entrained in water droplets, is located after the wet scrubber.

With regard to dry systems, the following remarks can be made:

- *Multicyclones*: These are often used in conjunction with a fabric filter, acting as coarse dust arrestors. They help to prevent incandescent coke particles reaching the filter cloth. Provided refractory lining and high grade steel are used in the design of the cyclone, they can operate at high temperatures. Note, the collection efficiency from cyclones alone is not sufficient to meet today's regulations, hence they are usually used in combination with other dedustung systems
- *Bag filters*: These are ideal when the gases are burned prior to the dedusting. This avoids problems of the deposition of carbonaceous material or fire hazards. Bag filters can be designed to provide good efficiency for collecting metallurgical fume particles such as ZnO
- *Electrostatic precipitators*: These systems are less common in the European foundry industry. This system is best suited to more or less constant working conditions, such as in long campaign cupolas, because of its sensitivity to variations in gas temperature, flow and humidity. There is an explosion hazard when dedusting unburned gases mixed with air, due to the relatively large volume of the precipitator. The precipitator therefore needs to be flushed before applying electrical power.

A schematic representation of a cold blast cupola with heat recovery and a bag filter is given in Figure 4.12.

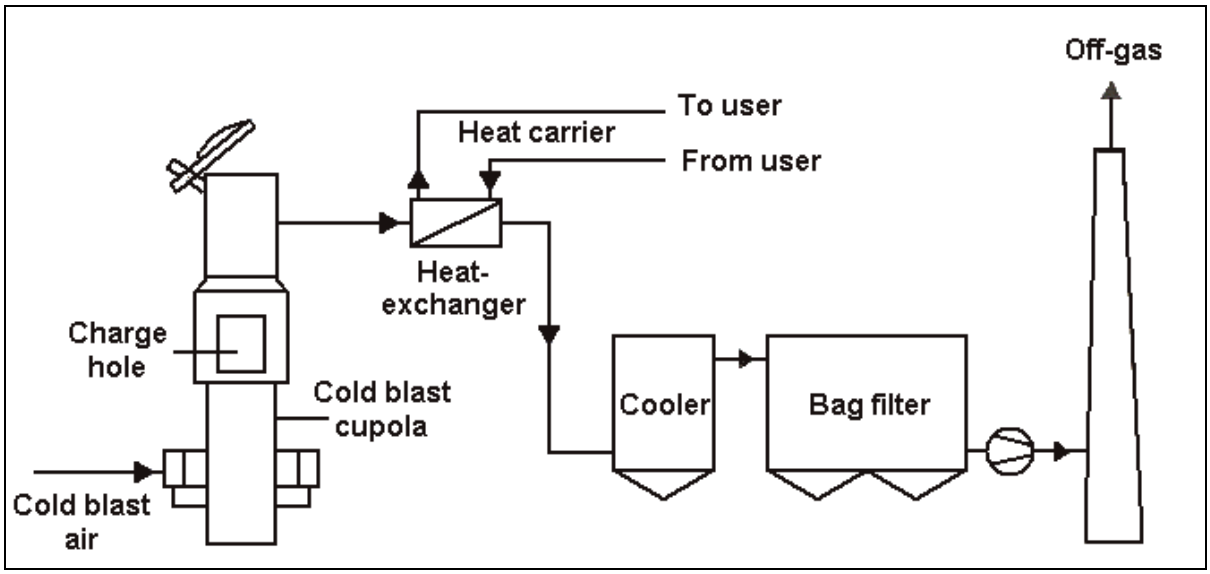


Figure 4.12: Flow sheet of cold blast cupola with heat recovery, cooling and a bag filter [29, Batz, 1986]

Post combustion

Post combustion of the waste gases is used to optimise heat recovery (chemically bonded as CO) and to provide cleaner exhaust gases. In burning CO, any residual carbonaceous material is simultaneously oxidised to CO_2 and H_2O. The generated heat can be recovered using a heat-exchanger and then transported to an internal user (e.g. blast air preheating).

Typical arrangements are:

- a post combustion chamber placed before (bag filter) or after (wet-filter) the dedusting unit (for below charge-hole offtake), this is discussed in Section 4.5.2.2
- (natural gas) burners or controlled air injection in the cupola shaft (for above charge-hole offtake), this is discussed in Section 4.5.2.3.

The design of the system needs to ensure that the waste gases remain at a temperature above 800 ºC and with a suitable residence time, i.e. 2 seconds, to guarantee the complete oxidation of the waste gases. The different systems are fully described and discussed below.

Achieved environmental benefits
Exhaust capture and cleaning is a necessary measure to reduce the emission products from coke combustion such as NO_x, SO_2, HF, PCDD/F, and dust.

The post combustion of CO allows (additional) heat recovery from the cupola off-gas. Additionally, it allows the melting of scrap contaminated with oil and grease without additional environmental effects and thus stimulates the recycling of metals. Post combustion without heat recovery shows a negative environmental balance (See cross-media effects).

Cross-media effects
Dedusting systems produce a residual dust for disposal. 5 – 13 kg of dust are produced per tonne of liquid iron. The dust may be re-circulated into the cupola. This is discussed in Section 4.9.4.2. The characteristics of the dust have already been given in Section 3.2.2.2.

The post combustion of CO without heat recovery has negative impacts on the environment, since powerful burners with a power of tens of kW need to be installed. The burners generate emissions of combustion gases and consume additional oxygen.

Operational data
Fabric filters have an efficiency of over 99 %. Daily average dust emission values stay well below 10 mg/Nm³. The sum of Pb, Zn, Cr, Cu, Mn,V, Sn, Cr, Ni, As, and Cd reaches about 20 % of the total dust content. The data represented in Table 4.36 were gathered within the framework of investigations of the Federal Environmental Agency in Germany of operational plants. Data for 3 example plants are given.

	Units	Plant D		Plant E	Plant F
		Initial	After rebuild		
Melting capacity					
- design value	t/h	7.5 – 8	12.0	6 – 7	4 – 5
- actual value	t/h	7.0	11.0	5.5	3.7
Exhaust gas stream					
- design value	Nm³/h	25000	30000	20000	n.d
- actual value	Nm³/h	19800	22300	17400	14300
Year of construction of the filter		1981	1995	1988	1985
Last filter cloth change		n.d	1995	1988	1993
Date of the measurements		07/1981	11/1997	03/1993	03/1993
Emissions	mg/Nm³				
- dust					
- raw gas		1623 - 2674		n.d	n.d
- clean gas					
• average[1]		21.5	<1	3	3
• min.		18.0	<1	1	2
• max.		25.4	<1	5	4
- gaseous [2]					
• SO_2		288	n.d	174	227
• NO_x		43	n.d	24	31
• C_{total}		n.d	n.d	22	7
• CO		700	n.d	11890	18980
• CO_2	%	7	n.d	4.9	3.9

	Units	Plant D			Plant E	Plant F
		Initial		After rebuild		
Heavy metal emissions - Cd - Cr - Pb - Zn - Ni - As - Mo	mg/Nm^3	Raw 0.0184 0.7287 29.895 16.464 0.2024 0.7665 0.2672	Clean 0.0019 0.0384 0.2952 0.2862 0.0077 0.0149 0.0420	Clean gas 0.00313 (ΣCu, Mn, Cr, V) 0.00057	n.d	n.d
PCDD/F-emissions - clean gas[3] - emission factor	ngTEQ/Nm^3 µg TEQ/t Fe			n.d	0.512 1.620	0.085 0.330
Filter dust - collected amount - PCDD/F-Gehalt	kg/t Fe µg TEQ/kg	6.5 disposal		8.2 re-use	4.850	0.960
Filter material		Polyester cloth with PA coating		Synthetic fibre	Polyester	Needle cloth
Filter cleaning		Pulse jet		Medium pressure counter flow	Pneumatical with pressure drop control	
Capital cost	EUR '000	385 (1981)		370 (1995/96)	n.d	350
Operating cost	EUR/tonne good casting	9.8 (1982) = 3 % of the casting costs		9.04 (1998) = 2.8 % of the casting costs	n.d	n.d

[1] Dust average is calculated on basis of 3 - 5 half-hour measurement data
[2] The concentrations of sulphur dioxide, nitrogen oxide, total carbon, carbon monoxide and carbon dioxide are calculated averages from continuous measurements over several hours during sampling for dust or PCDD/F
[3] Sampling time of 6 hours
n.d: no data

Table 4.36: Operational data of cold blast cupola furnaces with a bag filter for dust abatement data taken from [43, Batz, 1996] and [202, TWG, 2002], [225, TWG, 2003]

Data for hot blast cupolas are given in Section 4.5.2.2.

Applicability
This technique applies to all new and existing cupola furnaces.

Economics
Table 4.36 shows emission values and economic data. The most important operational cost factors are the electrical energy requirements for overcoming the pressure drop and for the filter material.

For a melting installation incorporating two cold blast cupolas with a melting rate of 4.5 t/h, a sales quotation was made with the following details:
- abatement equipment to treat up to 12400 m^3/h blast, with combustion chamber at a temperature of 820 ºC accepting up to:
  - VOC – 1 g/Nm^3
  - CO – 59100 g/Nm^3
- two burners to be used with methane – Power/burner 390 kW

Installation and start-up price: EUR 350000.
Foreseen running cost, considering a 4500 tonne casting production, five year payment period plus 10 % for energy and maintenance per year: EUR 23.3/t.
Driving force for implementation
Regulation of air emissions from foundries.

Example plants
The mentioned techniques are generally applied in European foundries with cupola furnaces.

Reference literature
[29, Batz, 1986], [32, CAEF, 1997], [110, Vito, 2001], [202, TWG, 2002], [225, TWG, 2003]

4.5.2.2 Post combustion in an HBC combustion chamber

Description
A post combustion chamber with a burner is installed after the cupola. Normally a separate post combustion unit has to be preheated with a natural gas burner. Once the cupola is up and running either a smaller burner sustains the combustion of the waste gases or the gases self-ignite.

The type and position of the chamber can vary according to the process composition. Both horizontal and vertical combustion chamber types exist.

- *Hot blast cupola with a recuperator and wet scrubber* (Figure 4.13): In this arrangement, the gases are dedusted prior to combustion. This reduces dust build-up in the recuperator, which improves the rate of heat transfer. One disadvantage is the higher energy consumption in the post combustion unit, caused because the gases are cooled down in the wet scrubber. Early cooling of the offtake gases is continuously carried out to reduce the size of the dedusting unit.

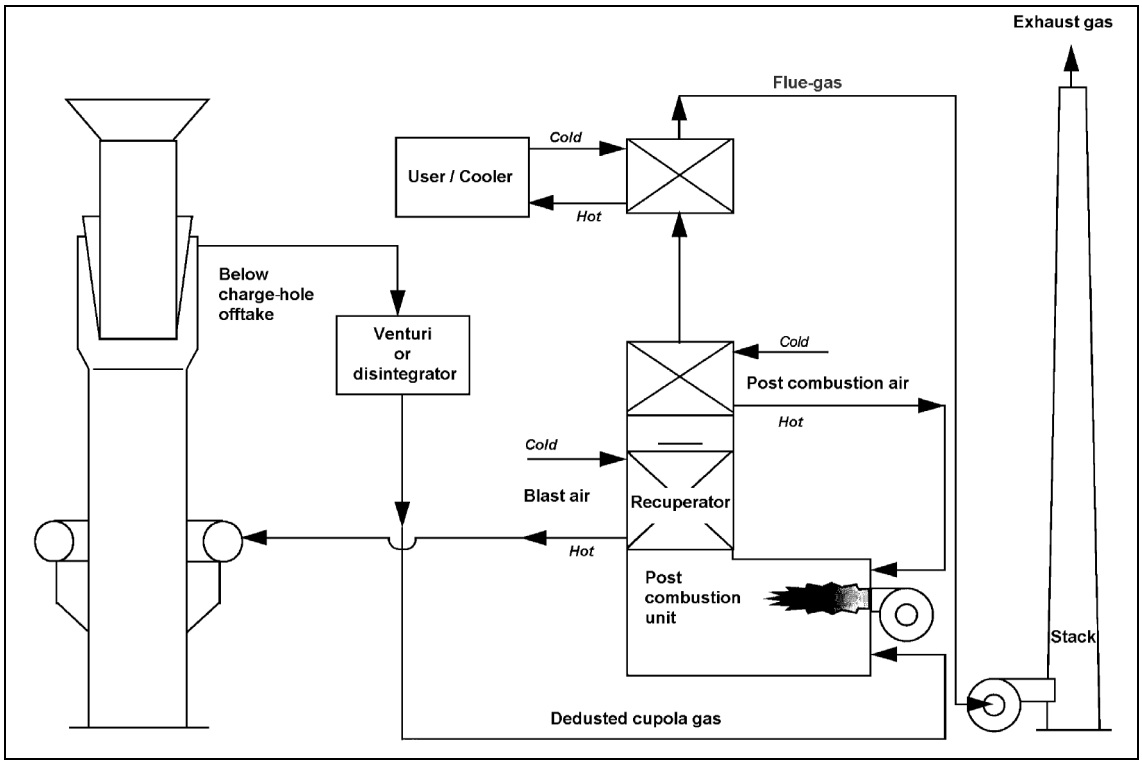


Figure 4.13: Hot blast cupola with a recuperator and wet scrubber
[32, CAEF, 1997]

- *Hot blast cupola with a recuperator and bag filter* (Figure 4.14): The hot, dust laden, top gases are fed directly into the post combustion unit. Close process control is necessary to prevent sintering of the dust particles to the walls of the recuperator, which need to be

cleaned regularly. The gases need further cooling before entering the bag filter since they leave the recuperator at temperatures of 500 to 600 ºC.

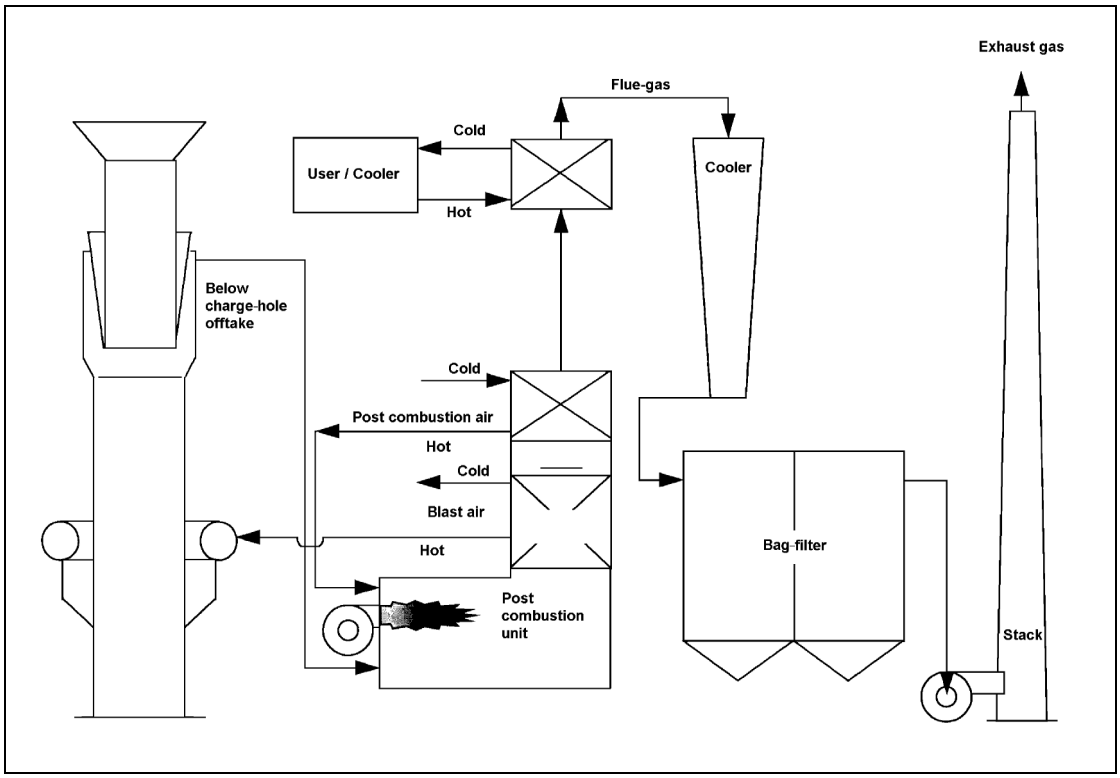


Figure 4.14: Hot blast cupola with a recuperator and bag filter
[32, CAEF, 1997]

Achieved environmental benefits
Post combustion limits the emissions of CO and eliminates the majority of organic compounds. If not combusted, these would be captured in the dust or emitted through the chimney. Furthermore, post combustion reduces the risk of fire in the filter.

Cross-media effects
Dry dedusting techniques produce dust for disposal (4 – 12 kg/t liquid iron). The dust may be re-circulated into the cupola. This is discussed in Section 4.9.4.2. Wet systems produce a sludge fraction.

Operational data
Operational data for hot blast cupolas are given in Table 4.37. Data for two example plants are given:

1. Foundry G is a 3 shifts/days and 5 days/week operated foundry with a melting capacity of 50 t/h. The off-gas is collected below the charge-hole and combusted in a recuperator. The waste gas is then separated: one part goes to hot blast production (T = 600 ºC), another part goes to a steam boiler. The steam is fed into a turbine, which powers a generator or compressor. The residual heat is used for preheating the combustion air of the recuperator. Waste gas is then cleaned in a bag filter. A concept drawing and further discussion of the installation is given in Section 4.7.3. Dust is recycled into the cupola, after mixing with petcokes. This is discussed in Section 4.9.4.2.

2. Foundry H is a 3 shifts/day and 5 days/week operated foundry with a melting capacity of 70 t/h. The off-gas is collected below the charge-hole and washed in a disintegrator, before post combustion in a recuperator. Heat is used for blast air preheating and goes

to a further heat recovery, before leaving through the stack at a temperature of 220 ºC. Further discussion of the heat recovery installation is given in Section 4.7.3. Waste water is re-circulated after settling. The circulating water volume is 440 m³/h. The sludge from the settling tank is dried in a filter press to a 50 % DS content, before disposal. Some 80 m³/day of waste water are disposed to the municipal waste water treatment.

	Units	Plant G	Plant H
Melting capacity	tonne/h	50	50
Waste gas flow	Nm³/h	75000	55000
Hot blast temperature	°C	600	570
Exhaust gas temperature	°C	127	220
Year of construction of the flue-gas treatment		1989	1983
Date of the measurements		10/1990	Control measurement 09/1993
Emissions	mg/Nm³		
- Dust			
• Raw gas		1300 – 4300	8000 – 20000
• Clean gas: average[1]		1.1	6.1
maximum		1.8	7.3
- Gaseous[2]			
• SO_2		33	15.6
• NO_x		44	52.5
• C_{total}		<5	28.6 (FID)
• CO		32	<100
• O_2	%	12.2	6.4
Heavy metal emission	mg/Nm³	Clean gas[3]	Clean gas
- Cr		<0.001	<0.0022
- Cr_{total}		<0.001	n.d
- Pb		<0.001	0.11
- Zn		<0.011	0.36
- Ni		n.d	<0.004
PCDD/F-emissions[1]			
- Clean gas[4]	ng TEQ/Nm³	0.048	0.003
- Emission factor	µg TEQ/tonne Fe	0.089	0.004
Filter dust/sludge		Dust recycling	Filter cakes to disposal
- solitary quantity	kg/tonne Fe	4.5	5.5
- PCDD/F-content	µg TEQ/kg	0.176	1.4
Waste heat utilisation		Hot blast air, steam for electricity production up to 3 MW electric	Hot blast air, thermal oil for the conversion of the waste heat for heating and drying purposes up to 21 MW
Investment cost	DEM '000	26400	22700 in 1980/81
Operational cost	DEM/tonne good casting	See data in the text for foundry G	See data in the text for foundry H

1 Dust average is calculated on basis of 5 - 6 half-hour measurement data and 2x2 hour values for PCDD/F
2 The concentrations of sulphur dioxide, nitrogen oxide, total carbon, carbon monoxide and carbon dioxide are calculated averages from continuous measurements over several hours during sampling for dust or PCDD/F
3 At the time of measurement, the dust recycling was not operational
4 Sampling time of 2 hours
n.d: no data
note: Raw gas sampling was performed before the bag filter in G and before the disintegrator for H; clean gas sampling was performed after the bag filter for G and after the recuperator for H

Table 4.37: Operational data of hot blast cupola furnaces using a bag filter and a disintegrator for dust capture
[17, Strauß, 1983], [27, Kran, et al., 1995], [202, TWG, 2002]

Burning the fumes in the post combustion chamber does not consume much energy, providing there is sufficient carbon monoxide in the fumes, which is generally the case. But the whole system for treating the fumes (combustion chamber + heat-exchanger + filter or wet scrubber +

fans) also needs electrical energy and regular maintenance. Table 4.38 gives some examples of energy consumption for hot blast cupolas.

Hourly rate of the cupola	Type of dedusting	Gas consumption for the combustion chamber (kWh/t charged)	Electricity consumption for the fume treatment system (kWh/t charged)
12	Filter	59	46
12	Filter	124	72
26	Filter	42	n.d
17	Electro filter (wet)	16	38

Table 4.38: Energy consumption of hot blast cupolas

Applicability
During the design stage, considerable care has to be taken to minimise the total flow of the gases to be treated. The combustion air intake has to be kept to a strict minimum. This is the reason why a separate combustion unit is always installed in conjunction with a below charge-hole offtake.
For economic reasons (see below) the post combustion chamber is only used on hot blast cupolas.

Economics
The high energy consumption of the post combustion is only economically reasonable if the released heat of the waste gases can be re-used, as it is in the recuperative hot blast cupola. However, switching from a cold blast to a hot blast cupola for the sole reason of gas combustion might encounter economical limitations in certain situations. Hot blast cupolas, preferably in a long campaign configuration, involve higher investment costs and are only used with production rates of 10 tonne Fe/h or more. In smaller foundries this production method might not be the right choice.

Table 4.37 gives economic data for the example plants. For foundry G, the investment costs for a hot blast cupola with bag filter and extensive heat recovery are given. The operational costs for 1994 (after refurbishment of the melting shop) were 25 % lower than those for 1985, i.e. with the old melting furnace. For foundry H, investment costs for 1980 - 1981 are given. After refurbishment, the operational costs went down by 2 %/tonne of liquid iron.

Driving force for implementation
Emission limit values and continuous monitoring of CO and emission limit values for organic compounds.

Example plants
The technique finds general application in HBCs around Europe.

Reference literature
[17, Strauß, 1983], [27, Kran, et al., 1995], [32, CAEF, 1997], [157, Godinot, et al., 1999], [202, TWG, 2002]

4.5.2.3 Post combustion in the cupola shaft

Description
The gases are combusted by an injection of air into the upper part of the charge or at a position above the charge top level. The airflow is adjusted so that the off-gases ignite spontaneously, due to their CO content and temperature. The injection nozzles can be placed on one or two levels. The partitioning of the airflow over the various levels, the choice of diameter and the position of the nozzles is based on experience. The goal of the optimisation is to burn the CO without ignition of the coke. The draught will also suck in air from the charge door. This air excess allows a more complete burn-out of the CO.

A supporting burner may be provided to maintain the flame. When using very low coke charges (i.e. <6 – 8 %) the precautionary measure is reasonable.

Post combustion of the off-gas must be combined with a gas cooling, if a bag filter is used. For hot blast cupolas, the cooling is combined with a blast air preheating. In cold blast operation, a rapid cooling may be applied using water injection in the furnace shaft. Alternatively, an (off-gas – air) heat-exchanger may be used. This is illustrated in Figure 4.15.

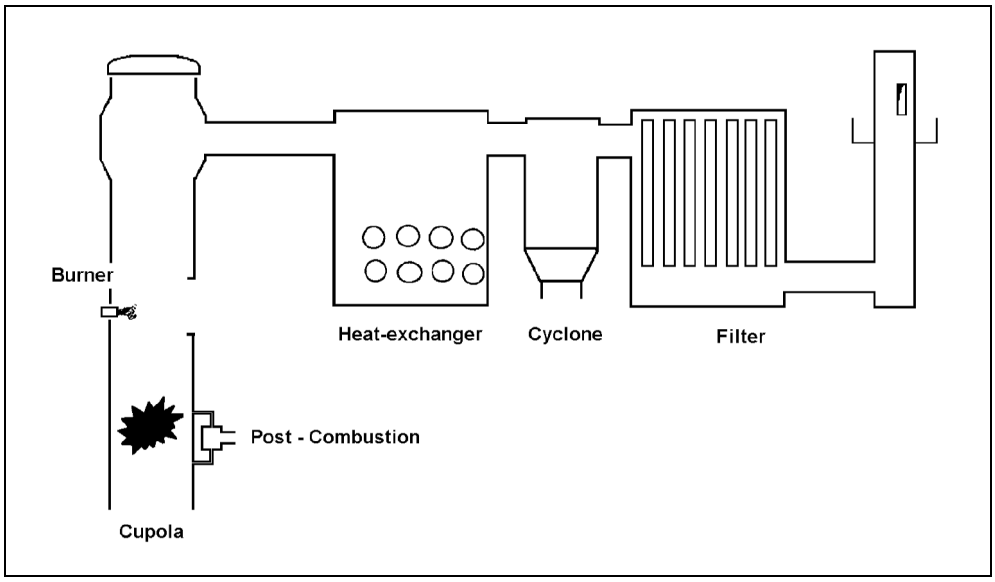


Figure 4.15: Principle of post combustion and off-gas cooling in cold blast cupolas [157, Godinot, et al., 1999]

Installing post combustion on cold blast cupolas can be combined with a full retrofit to hot blast operation. In general, this choice is based on operational considerations. The characteristics of hot blast and long campaign furnaces are discussed in Section 2.4.1.

Achieved environmental benefits

Post combustion limits the emissions of CO and eliminates the majority of organic compounds. If not combusted, these would be captured in the dust or emitted through the chimney. Furthermore, post combustion reduces the risk of fire in the filter.

This technique is known to avoid explosion risks under certain circumstances. The positive environmental effect is limited to those cases when the off-gas is burning autothermally most of the time. Otherwise, the energy consumption will counterbalance the CO reduction.

Cross-media effects

If the cupola off-gas does not ignite spontaneously, the installation of ignition or support burners is necessary. These incur a significant power use and increase the overall flue-gas volume.

Operational data

Two configurations of (in-shaft post combustion and) cooling on cold blast cupolas were studied on an industrial scale and compared by CTIF; cupola I was equipped with a water injection in the cupola shaft, a cyclone and a bag filter, cupola J was equipped with a gas-air heat-exchanger, a cyclone and a bag filter. Operational data are given in Table 4.39. Results of the measurement campaigns and reference to the applicable legislation are given in Table 4.40.

Parameter	Units	Foundry I	Foundry J
Melting capacity	tonne/h	10.3	9.2
Primary + secondary airflow	Nm³/h	7389	6484

Post combustion airflow	Nm³/h	2372	1549
Water flow	l/h	2678	
Flue-gas flow (chimney)	Nm³/h	26780	39179
Residence time combustion to bag filter	s	10.5	12.3
Residence time cooling stage	s	<1.7	6.01
Overall CO combustion efficiency	%	66	96.5

Table 4.39: Operational data of two example configurations using post combustion with water cooling (I), and air cooling (J)
[157, Godinot, et al., 1999]

	Foundry I		Foundry J		Arrêté du 02/02/98	
Compound	**analysis**	**flux**	**analysis**	**flux**	**limit value**	**limit for consideration***
Dust	1.7 – 2.8 mg/Nm³ 3 – 5 g/t	0.04 – 0.07 kg/h	1 mg/Nm³ 34 g/h		100 mg/Nm³ 200 g/t	<1 kg/h melt = 8 tonne/h
CO	450 Nm³/h	560 kg/h	35 Nm³/h	44 kg/h		50 kg/h
HCl	22 mg/Nm³	0.4 kg/h	9.2 mg/Nm³	0.35 kg/h	50 mg/Nm³	1 kg/h
HF	13 mg/Nm³	0.24 kg/h	4.8 mg/Nm³	0.18 kg/h	5 mg/Nm³	0.5 kg/h
HCN	<0.007 mg/Nm³	0.13 g/h	<0.01 mg/Nm³	0.38 kg/h	5 mg/Nm³	50 g/h
NH_3	0.61 mg/Nm³	12 g/h	0.10 mg/Nm³	3.8 g/h	50 mg/Nm³	100 g/h
NO_x	9 mg/Nm³	0.17 kg/h	15 mg/Nm³	0.57 kg/h	500 mg/Nm³	25 kg/h
VOC non-methane	13 mg/Nm³	0.25 kg/h	6 mg/Nm³	0.23 kg/h	110 mg/Nm³	2 kg/h
*: If the flux is below the limit of consideration, the measured value may exceed the limit value						

Table 4.40: Analytical results and applicable (French) legislation, for post combustion in a cold blast cupola with water cooling (I), and the air cooling (J) of flue-gases
[157, Godinot, et al., 1999]

The water spray cooling achieves a CO-destruction efficiency of 66 % and allows compliance with the applicable legislation. Flue-gas cooling over a heat-exchanger provides better efficiency (98 %). For discussion on cooling performance, see also 4.5.2.1.

Applicability
To change the offtake system of an existing cupola from above to below the charge-hole system is in most cases impossible. Post combustion of the waste gases in the furnace shaft therefore is a more viable solution for cupolas with an above charge-hole offtake.

For economic reasons, the application of post combustion has mainly been related to hot blast cupolas. However, recently, a post combustion system for cold blast furnaces, without the complexity of a hot blast installation, has also been developed. This system is currently in operation in France. 'In-shaft' post combustion therefore applies to both hot blast and cold blast cupola operation.

In the Czech Republic, the whole range of cold blast cupola installations was studied for applicability of in-shaft post combustion. The combustion was not spontaneous in any of the set-ups over the whole melting period. In each case, it was necessary to install ignition burners of significant power. The cupola emission volume also increased.

Economics
The high energy consumption of the post combustion needs to be evaluated against its benefits. In hot blast operation, the released heat of the waste gases can be re-used, which makes the investment more viable.

The high energy consumption of the post combustion is only economically reasonable if the released heat of the waste gases can be re-used, as it is in the recuperative hot blast cupola. However, switching from a cold blast to a hot blast cupola for the sole reason of gas combustion is not possible. Hot blast cupolas, preferably in a long campaign configuration, involve higher investment costs and are only used with production rates of 10 tonne Fe/h or more. In smaller foundries, this production method might not be the right choice.

The investment cost for a twin cold blast cupola of 850 mm internal diameter, which produces 4.5 tonnes an hour, 10 hours a day, 5 days a week is in the order of EUR 300000.

Driving force for implementation
Emission limit values and continuous monitoring of CO and emission limit values for organic compounds.

Example plants
The technique is reported in 2 example foundries in France.

Reference literature
hot blast: [150, ETSU, 1998], [202, TWG, 2002]
cold blast: [157, Godinot, et al., 1999], [202, TWG, 2002]

4.5.3 EAF

4.5.3.1 Off-gas collection

Description
Particulate matter from an EAF is very fine and difficult to capture. The capture of smoke and dust is the most difficult problem to solve when installing a dust arrestment system on an electric arc furnace. There are several methods that offer different advantages and disadvantages. Figure 4.16 depicts the principle of roof mounted hoods, side-draught hoods and fourth-hole evacuation.

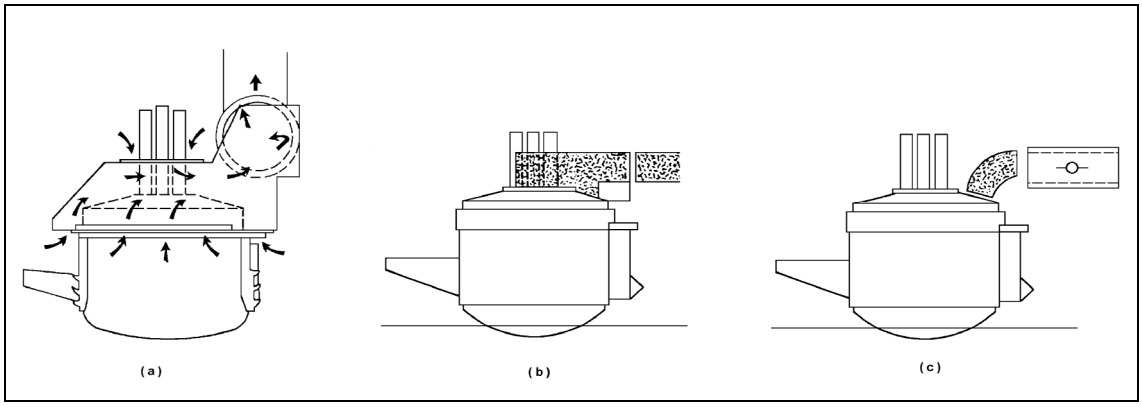


Figure 4.16: Principle drawings of (a) a roof mounted hood, (b) a side-draught hood, and (c) direct evacuation through a fourth-hole
[173, Huelsen, 1985]

- *Roof mounted hoods*: A hood is fixed on the furnace roof and collects fumes through a gap between the furnace shell and the roof. In addition, fumes arising from the working door and the tap-hole are also captured. Roof mounted hoods are heavy and subject to distortion from heat. If fitted to an existing EAF, problems may arise due to increased structural load of the roof lifting and rotating mechanism. Typical extraction rates for this system are 7500 to 15000 Nm^3/tonne
- *Side-draught hoods*: A hood is mounted on the furnace roof and collects the fumes emitted through the electrode ports. Vanes direct the airflow towards the hood. Additional hoods above the working door and the tapping-hole are used to capture emissions at these locations. Higher extraction rates are necessary here, compared to roof mounted hoods, as high air draught velocities are needed to capture the fumes. Some leakage of pollutants to the plant atmosphere can be expected, unless a tight seal is maintained. It has been reported that side-draught hoods increase electrode consumption
- *Canopy hoods*: A large exhaust hood is placed over the complete furnace, and above the charging system. This creates a large gap between the furnace and the extraction system, making it difficult to control the rising smoke and dust, even when using high extraction

rates. Cross-draughts can seriously distort the collection efficiency. These disadvantages make the use of these collection systems unattractive

- *Direct furnace or "fourth-hole" evacuation*: The fumes are collected through a water-cooled or refractory-lined duct connected to a fourth-hole in the furnace roof. Ambient air is aspirated through a joint in the ductwork, thus providing oxygen to burn the CO gas in the undiluted and hot offtake gas. This prevents explosions in the dust collecting system. The dimensions of the combustion chamber are very critical in order to guarantee sufficient combustion at all stages of the melting cycle. The burnt gas (900 ºC) is cooled downstream by dilution with ambient air, water injection, heat-exchangers (water jackets) or by the use of long ducts. This cooling process is needed to protect the dust filter equipment. The use of a pressure control system in the furnace allows a relatively small extraction rate at the furnace at 2000 to 4000 Nm^3/tonne. Electrode consumption is generally higher due to the effect of oxidation
- *Partial furnace enclosure*: Mobile or fixed enclosures are mounted around the furnace and tapping area. The former are retracted in order to accommodate charging and tapping, while the latter are equipped with a mobile roof and side-walls for the same purpose. Exhaust gases are collected through a main exhaust duct at the top of the enclosure, assisted by fans inside the duct to guide the fumes to the exhaust. With these types of system collection, efficiencies of up to 98 % are possible
- *Total furnace enclosure*: This system consists of a large fixed evacuated room completely surrounding the melting furnace and ladle pit. The enclosure is equipped with a movable roof and/or with side panels to accommodate both charging and tapping operations. These may be equipped with air curtains to reduce gas losses. Disadvantages of the technique are the high temperatures and noise levels inside the enclosure. However, the advantages include low outside noise levels and low energy consumption. The energy consumption is estimated to be 30 to 50 % less than that required for a canopy hood.

Achieved environmental benefits
Flue-gas capture allows the controlled evacuation and treatment of the flue-gas stream, and results in a minimisation of both fugitive and guided emissions.

Cross-media effects
Capturing the exhaust increases the energy consumption. As it allows the cleaning of the exhaust gas, it will also generate dust for disposal or re-use.

Operational data
Table 4.41 provides typical exhaust flowrates and removal efficiencies for various capture systems.

	Exhaust flowrate for given furnace capacity			**Particulate removal efficiency (%)**	
	3.9 t/h	**9.1 t/h**	**22.7 t/h**	**Range**	**Typical max.**
Side-draught hood	12.9	19.8	50.00	90 – 100	99
Roof hood	7.7	11.9	30.00	95 – 100	99
Direct evacuation	3.2	5.0	12.5	90 – 100	99
Total enclosure			35 – 42		

Table 4.41: Typical exhaust flowrates (in m^3/s) and particulate removal efficiency of EAF exhaust capture systems
[173, Huelsen, 1985]

In a Polish foundry, the installation of a total enclosure over two EAFs with a capacity of 8.5 tonnes each, resulted in a reduction of the noise level from melting from 91 dBA to less than 85 dBA.

Applicability
The above-mentioned techniques are applicable to all new and existing EAF furnaces, with the following limitations:

- when installing a roof mounted hood on an existing furnace, problems may arise due to the increased structural load from the roof lifting and rotating mechanism
- direct furnace evacuation using a fourth-hole is limited to big electric arc furnaces, as the roof must be big enough to accommodate a fourth-hole without any structural weakening. The technique is not applicable for iron melting, because the in-flow of fresh air generates an excessive oxidation of carbon.

Economics
The construction and assembly of a doghouse over two EAFs with a capacity of 8.5 tonnes each, involved an investment of EUR 275000 (1996 prices), excluding costs for further refurbishment of the ducting and filtration system.

Driving force for implementation
Workers health-related prevention measures. It allows application of a gas cleaning technique by guiding the exhaust gas flow.

Example plants
doghouse: Metalodlew Foundry, Krakow (PL)
off-gas collection: Metso Lokomo Steels and Sulzer Pumps Karhula Foundry (FIN)

Reference literature
[29, Batz, 1986], [32, CAEF, 1997], [173, Huelsen, 1985], [199, Metalodlew s.a., 2002]

4.5.3.2 Exhaust gas cleaning

Description
Gas cleaning systems for EAF flue-gas need to be highly efficient since the particle size is small. Fabric filters are widely used to dedust the exhaust gases. Venturi scrubbers or disintegrators are applied less due to their higher energy consumption, the necessity for water treatment prior to discharge, and due to the need to dispose or recycle wet filter sludge. Fabric filters are widely used in favour of electrostatic filters, due to the wide fluctuations in gas temperature and the particulate concentration of the exhaust gases.

If a fabric filter is used, several precautions need to be taken in order to protect the filter medium as discussed in Section 4.5.1.3. These include:
- using a high temperature cyclone or multicyclone
- using gas cooling equipment. Here the exhaust gases are cooled by dilution with ambient air, water injection (quenching), heat-exchangers or by the use of long ducts. Water injection, in particular, has an additional advantage, in that the quick cooling down of the exhaust gases prevents the recombination of any partially burned organic substances, thereby leading to a cleaner emission. The cooling system needs an effective control system to prevent gases which are too hot from entering the fabric filters.

Achieved environmental benefits
Reduction of particulate emissions from EAF.

Cross-media effects
The application of wet dedusting techniques causes a higher energy consumption, the necessity for water treatment prior to discharge, and the need to dispose or recycle wet filter sludge.

Operational data
Operational data are given in Section 3.2.3.4. Current bag filters have air to cloth ratios between 2:1 and 3:1. The air to cloth ratio is the ratio of volumetric airflow through the filter to the media area and is expressed in $(m^3/s)/m^2$, which yields the same result as the air speed through the filter media.

Applicability
These techniques can be applied to all new and existing installations.

Economics
The costs for installing a new dust capture and filtration unit in an existing Polish EAF foundry using two 8.5 t/h melting furnaces are summarised in Table 4.42. Dust emissions have been reduced from 10 – 13 kg/h and 145 – 150 mg/Nm³ to 0.2 – 0.25 kg/h and 2.8 – 2.9 mg/Nm³. There has also been a major reduction of diffuse emissions from the melting shop.

Investment costs	**EUR***
Foundation and remodelling of old collector	115000
Construction and assembly of doghouse housings over 2 furnaces	275000
Purchase and assembly of filtration unit and electrical devices	560000
Research, implementation and supervision	80000
Operational costs	**EUR/year**
Depreciation cost	100000
Electric power	88000
Repairs and service	1500
* Prices converted from zlotys 1999	

Table 4.42: Cost data for EAF flue-gas capture and cleaning equipment [199, Metalodlew s.a., 2002]

Driving force for implementation
Regulation limiting the dust emissions from the melting of metals.

Example plants
doghouse with bag filter unit: Metalodlew Foundry, Krakow (PL)
Metso Lokomo Steels and Sulzer Pumps Karhula Foundry (FIN)

Reference literature
[173, Huelsen, 1985], [32, CAEF, 1997], [29, Batz, 1986], [199, Metalodlew s.a., 2002]

4.5.4 Induction furnace

4.5.4.1 Off-gas collection

Description
The capture of smoke and dust is the most difficult problem to solve when installing an off-gas collection system on a coreless induction furnace, since there is no exhaust shaft. Several methods have been developed in the past decade, each with advantages and disadvantages.

- *General ventilation of the workplace*: A combination of wall mounted louvres and roof mounted ventilators situated over the furnace platform are used to increase the natural convection of smoke and fumes and to direct them outside. Even with baffles suspended from the roof and using high extraction rates the efficiency is often poor and easily disturbed by draughts.
- *Canopy hood extraction*: Since lower placed hoods will interfere with crane charging systems, larger hoods have to be installed above the charger. This creates a large gap between the furnace and the extraction system, making it difficult to control the rising smoke and dust, even when using high extraction rates. Cross-draughts can seriously distort the collection efficiency of the system. These disadvantages make the use of these collection systems unattractive.
- *Swing aside hoods:* These hoods are more efficient when used in conjunction with vibrating feeders. Cut-outs in the hood can facilitate charging. During tapping, the hood is swung over the ladle, allowing efficient fume extraction.

- *Side-draught hoods*: Placing the extraction hood beside the furnace offers the advantage of good furnace accessibility and no interference with the charging systems. Due to the high buoyancy of the exhaust gases, large extraction rates are achieved, therefore giving good efficiency, especially when the hood is placed outside the furnace platform. In this case extraction control is poor during tapping. Attachment to the furnace platform overcomes this problem but may interfere with charging operations. The efficiency can be improved by installing airjets at the opposite side of the hood to blow the dust and fumes into the hood. Unfortunately, this facility does not work if there are any interferences in the airstream, which is the case during charging.
- *Lip extraction*: A suction ring is placed on top of the furnace and arranged so that it moves with the furnace during deslagging or tapping operations. This system does not interfere with the charging operations. With the lid closed, lip extraction offers very good control, since it is as near to the emission source as possible and involves the lowest extraction rates. The fumes do not pass through the breathing zone of the furnace operators. However, the extraction control decreases significantly when the furnace lid is opened, for instance during charging.
  The design of this extraction equipment has been subjected to many studies. Suppliers offer solutions to overcome some of the disadvantages.
- *Cover extraction*: The gas is exhausted through the furnace cover. This method is very effective. It is used by the majority of furnace producers. Exhaustion is managed according to furnace regime: melting, charging, pouring.

Attention has to be paid to the material used for hoods and ducts since the gases may be at high temperatures when the intake of the collection system is positioned close to the furnace. The heating required by radiation or convection from the molten metal bath needs to be taken into account in the design stage. Proper maintenance in combination with heat-sensors reduces the risk of fire.

Again scrap cleanliness plays an important role. When the scrap contains organic matter, collected gas temperatures may rise due to the combustion of the material, thus requiring the use of heat resistant steel or even refractory linings. Oily deposits, formed by condensation of oil vapour in the ductwork, accumulate dust and can present a fire hazard if not removed regularly. When using clean scrap, a mild steel construction is adequate and does not need accessibility for cleaning.

Achieved environmental benefits
Flue-gas capture allows controlled evacuation and treatment of the flue-gas stream, and results in a minimisation of both fugitive and guided emissions.

Cross-media effects
Applying exhaust capture increases the energy consumption. In addition, as it allows the cleaning of the exhaust gas, it will also generate dust for disposal or re-use.

Operational data
Through the use of specific capture systems, such as side-draught hoods, movable extraction hoods and partial housing of the furnace, a capture efficiency of more than 95 % is possible.

Operational experience in a German cast iron foundry showed that the furnace lid is open on average during 25 % of the working time of the furnace. During the opening periods, dust-generating process steps such as the feeding of additives, deslagging and pouring are performed. The lip extraction system installed on the furnace lid, does not allow extraction of the generated fumes. Installation of a telescopic canopy hood allowed an efficient exhaust capture during the opening of the furnace lid.

Applicability
The installation of exhaust capture equipment is applicable to all new and existing induction furnace installations, both in ferrous and non-ferrous foundries.

Driving force for implementation
Regulations concerning emissions to air.

Example plants
These techniques are commonly used on induction furnaces in Europe. A specific example is Walter Hundhausen GmbH & co KG (D)

Reference literature
[29, Batz, 1986], [18, Rademacher, 1993], [32, CAEF, 1997]

4.5.4.2 Exhaust gas cleaning

Description
Gas cleaning systems for induction furnace flue-gas need to be highly efficient as the particle sizes need to trap are small. Fabric filters are widely used to dedust the exhaust gases. Fabric filters are used in favour of electrostatic filters, as they are more suited to the wide fluctuations in gas temperature and particulate concentration of the exhaust gases.

When using fabric filters care has to be taken with respect to the presence of oil in the scrap, as oily vapour could condense on the filter cloth, where it could block the pores and make the removal of adhering dust impossible. There is also a possible fire hazard. The rapid increase in the pressure loss of the system when pores get blocked quickly reduces the extraction rate of the system. Therefore, in order to prevent workplace pollution the filter media have to be changed or regenerated (cleaned) much quicker than when using clean scrap. The use of coated fabrics or an injection of lime in the ductwork may be a solution to this problem. Furthermore, if the oil vapour is likely to burn in the ductwork, the process must allow enough time for combustion to be completed before the vapour enters the filter housing. The gas temperature may not exceed the design temperature of the fabric, in which case cooling of the gases may therefore be needed.

The wet scrubbers used generally need to be of the high energy type (venturi), because carbonaceous and metallurgical smoke consists of very small particles. These require considerable fan power to create sufficient turbulence in the scrubber to collect the particles. Exhaust flowrates are therefore kept to a minimum by using exhaust capture systems with the least entrainment of ambient air. Under normal conditions, corrosion is not a problem. If borings containing cutting fluids are charged into the furnace, it should be noted that some of these fluids might contain sulphur, which could lead to the formation of SO_2. This could cause problems in the equipment, as the absorption of SO_2 in the scrubber leads to an acidification of the water and eventually to corrosion of the equipment if water treatment is not applied.

Some aluminium foundries melt material recovered from the electrolysis of aluminium. In this instance, inorganic pollutants such as hydrogen fluoride may be formed. These can be cleaned from the flue-gas using a chemisorption step, which can be added onto the dust abatement system. In this treatment calcium hydrate or aluminium oxide can be used as the adsorbant.

Achieved environmental benefits
To reduce particulate and acidifying emissions from induction melting furnaces.

Cross-media effects
Exhaust gas cleaning increases the energy consumption. The dedusting of the exhaust gas, generates dust for disposal or re-use. The application of wet dedusting techniques lead to a higher energy consumption, the necessity of water treatment prior to discharge, and the need to dispose of or recycle wet filter sludge.

Operational data

Cleaning of the captured gases is generally performed using filters. Daily average dust emission values stay well below 10 mg/Nm³. Operational data are given in Section 3.2.4.1.

Table 4.43 gives the operational data for a German cast iron foundry in which a centralised flue-gas capture system is installed, with dedusting carried out using a bag filter. The system collects exhaust gas from the various parts of the foundry, including: the four induction furnaces (each with lip extraction and canopy hood), the scrap storage and preheating, the metal treatment, the sand regeneration, and the casting areas. Data are given for the raw melting of the furnace off-gas, the raw combined gas flow and the cleaned gas flow.

Compound	Melting off-gas	Combined exhaust gas	Cleaned gas*
Dust	89.3	237	<1
NO_x	1.6	8.3	7.9
CO	2.2	4.2	3.8
SO_2	3.5	3.9	3.7
Total C	21.8	34.7	34.9
PCDD/-F		0.036×10^{-6}	0.0027×10^{-6}

* NO_x, CO, SO_2 and total C are not captured in the bag filter. The difference between raw and cleaned gases are due to the slightly changed gas mix after the ID fan
Melting capacity 14 tonne/h, total flue-gas flow 240000 m³/h
All data in mg/Nm³

Table 4.43: Emission data for a cast iron foundry, using induction melting and a centralised exhaust system with a bag filter
[18, Rademacher, 1993]

Applicability
This technique is applicable to all new and existing induction furnace installations, both in ferrous and non-ferrous foundries.

Economics
The cost and consumption data for a bag filter installation on a melting unit of crucible induction furnaces, melting 15 t/h, able to treat 120000 Nm³/h are given in Table 4.44.

Dust emission level (mg/Nm³)	Investment cost (EUR)	Power consumption (kW)
<5	350000	250
<20	200000	150

Table 4.44: Investment cost and power consumption for a bag filter unit on induction furnaces, with varying final dust emission levels
data for Portugal 2003
[225, TWG, 2003]

Driving force for implementation
Regulation limiting the dust emissions from the melting of metals.

Example plants
Flue-gas cleaning is applied in most ferrous foundries using an induction furnace and in a limited number of non-ferrous foundries.

Reference literature
[18, Rademacher, 1993], [32, CAEF, 1997], [29, Batz, 1986]

4.5.5 Rotary furnace

4.5.5.1 Off-gas collection and waste gas cleaning

Description
In most cases, dedusting equipment is needed to meet the applicable regulations. Generally, bag filters are installed for this purpose, but it is also technically possible to use wet dedusting techniques.
In order to lower the temperature of the exhaust gases, they are diluted with ambient air. This is achieved by the intake of air through a gap between the furnace exhaust and the elbow shaped exhaust pipe. This gap is always present as it allows the furnace body to be able to rotate and tilt. Often the exhaust pipe is retractable. In general, dilution for emission reduction is unacceptable. If dilution is used (and is necessary) for cooling, the end-of-pipe technology should have the right dimension for the larger gas flow. Sometimes the diluted waste gases are then fed through an air-gas heat-exchanger for further cooling. This way the gas temperature is reduced from the initial 1500 ºC to 200 ºC, or lower. At this temperature, the gases can be introduced into a bag filter for dedusting.

The application of an afterburner allows the reduction of organic carbon emissions and combustible particles. This technique may also be effective in reducing the risk of dioxin formation upon cooling of the gases. The afterburner is installed after the furnace and before the heat-exchanger. One of the following afterburner types may be used:
- thermal incinerator: combustion in an open flame
- catalytic incinerator: combustion at lower temperatures through the use of a catalyst, resulting in a higher efficiency and lower NO_x emissions
- recuperative incinerator: combustion with a heat recovery for preheating the combustion air, resulting in a higher thermal efficiency and lower fuel consumption
- catalytic recuperative incinerator: a combination of the previous two types.

Achieved environmental benefits
Reduction of particulate emissions from rotary furnaces.

Cross-media effects
Exhaust gas cleaning increases the energy consumption. The dedusting of the exhaust gas generates a dust for disposal or re-use.

Operational data
Operational emission data are given in Section 3.2.5.3.

An afterburner can be expected to achieve between 80 % and 98 % efficiency for burning the combustible particulates emitted from the rotary furnace. Hot gases from the afterburner can be ducted through a recuperator and can assist in preheating the combustion air to the main furnace burner. Recuperators offer an energy saving of up to 15 %.

Applicability
This technique is applicable to all new and existing rotary furnace installations, both in ferrous and non-ferrous foundries.

Driving force for implementation
Regulations limiting the dust emissions from the melting of metals.

Example plants
This technique is commonly applied in foundries using a rotary furnace.

Reference literature
[23, Brettschneider and Vennebusch, 1992], [32, CAEF, 1997], [163, UK Environment Agency, 2002], [202, TWG, 2002]

4.5.6 Crucible, hearth type and radiant roof furnaces

4.5.6.1 Prevention of visible and fugitive emissions during melting and metal treatment

Description
Under normal operating conditions, melting processes using pure metal melts do not emit visible smoke. However, during charging of the furnace it is possible that a visible smoke may be produced. This can be either due to the burning of contaminants in the charge, such as oil or paint, or due to the burner flame being extinguished and unburned fuel being emitted, as may be the case with solid or liquid fuels. In these circumstances, an afterburner may be installed.

Hoods may also be installed to capture visible smoke and fugitive emissions. The melting of clean scrap prevents or minimises these types of emissions.

Achieved environmental benefits
A reduction of the emission to air of the products from incomplete combustion.

Cross-media effects
Smoke capture will involve a usage of electrical energy.

Applicability
This technique applies to new and existing crucible and hearth type furnaces.

For implementation, any constraints due to the current furnace design and operation need to be considered. These include physical constraints, for example due to crane tracks, the existing structural elements of the building, or due to the furnace itself. To be effective the extraction need to be fitted in such a way that it moves with the furnace body when it is tilted to pour, as tapping-out is one of the peak emission operations. This is not always easy to achieve with existing furnace bodies. There can also be physical problems related to the location of associated ducting. In some cases, major modifications to the furnace platform and surrounding area may be necessary to enable the ducting to be installed.

Economics
A cost estimate for an extreme (worst case) scenario, i.e. needing to capture all the dusts from charging and tapping, was made by CTI. Table 4.45 summarises this financial data for an 'average foundry' with the costs depreciated over a presumed 10 year lifespan of the extraction and abatement equipment. This estimation however, can broadly vary, depending on the foundry layout and the techniques used.

Extraction rate m^3/minute	Production rate tonnes/hr	Costs EUR		Power kW	Costs EUR/tonne of iron melted		
		Capital	Civil		Running	Financial	Total
142	0.5	117573	15676	40	15.24	18.81	34.05
	(1150 tonnes per year)						

Note:
- Civil costs are taken as 12 % of capital costs
- Running costs are based on maintenance and waste disposal costs and are equivalent to 10 % of the capital costs and power at EUR 0.06/kWh
- Financial costs are based on the plant being amortised over ten years with interest charges of 10 %

Table 4.45: A cost estimate for installation of an abatement system for visible fumes during charging and tapping
[161, UK Environment Agency, 2002]

In this example, under the pre-conditions used, the costs for abatement of these visible emissions would be about EUR 34.05 per tonne of metal melted.

Driving force for implementation
Regulations limiting the occurrence of visible emissions.

Example plants
This technique is commonly applied in foundries around Europe.

Reference literature
[161, UK Environment Agency, 2002]

4.5.7 Metal treatment

4.5.7.1 AOD Converter: exhaust gas capture and treatment

Description
Pollution control equipment need to be designed to be able to handle the peak effluent condition, even though the peak may only persist for a relatively short period.

Fume control hoods for AOD vessels come in a great variety of shapes and sizes. The alternative to the direct extraction hood is the roof canopy. Roof canopies are in use in several AOD plants and efficiently capture both AOD process fumes and smoke from other operations such as charging and tapping. These roof canopies may be used in conjunction with accelerator stacks over the AOD mouth. The accelerator stack performs several useful functions, including forming a more coherent plume out of the AOD, reducing the size of canopy required, and shielding the surrounding equipment and personnel from the sometimes intense radiation of the AOD flame. The main advantage of the roof canopy is the capture of both process and fugitive effluents in the same hood.

Achieved environmental benefits
Flue-gas capture allows controlled evacuation and treatment of the flue-gas stream, and results in a minimisation of both fugitive and guided emissions.

Cross-media effects
Exhaust gas cleaning increases the energy consumption. The dedusting of the exhaust gas generates dust for disposal or re-use.

Applicability
This technique is applicable to all new and existing AOD installations.

Driving force for implementation
Regulations limiting the dust emissions from the melting of metals.

Example plants
Example plants are reported in Italy and Finland.

Reference literature
[202, TWG, 2002]

4.5.7.2 Nodularisation: off-gas collection and dedusting

Description
The type of exhaust collection applied depends on the technique used for nodularisation (see 2.4.12.4). Depending on the technique, significant amounts of MgO can be released as a white smoke. Properties of the various nodularisation techniques are given in Table 3.20. In general techniques with a higher take-up efficiency result in lower emissions. This is the case for the ‘in-mould’ process, where the nodularisation takes place during pouring.
For ‘in-crucible’ nodularisation, techniques using a lid or cover result in a significant reduction of the emission.

If the nodularisation off-gas is not captured, this could result in the melting shop filling-up with a white smoke, and MgO dust drop out. Exhausting without filtration can result in a visible emission from the foundry. A large volume of visible particulate can be generated in a relatively short period of time, but usually only lasts for a short duration (5 to 10 minutes for each batch treated).

In-crucible nodularisation may be performed at a specific stand or location in the melting shop. The crucible with the molten metal is brought to this point after pouring, but before taking it to the casting furnace or station. This allows the installation of a fixed hood for exhaust capture.

The collection of the MgO fume is hampered by the fact that the gases are very hot and that the intensive Mg reaction causes sparks. Due to the high upward velocity and temperature large quantities of surrounding air need to be extracted as well. This requires a large sized, and high cost, installation.

Dry filtration (using bag filters) of the exhaust gas, results in a MgO powder that may be re-used in pigments or for refractory material production.

Achieved environmental benefits
Mg has no harmful effect on the environment and is an essential nutrient for animals and plants in small concentrations. UK occupational exposure limits give a long-term exposure limit (8-hour TWA) of 4 mg/m³ for MgO dust and respirable fume (expressed as Mg).

Cross-media effects
Capture of the magnesium oxide fume requires an increased energy use and therefore results in increased emissions from energy production. External re-use of the MgO powder leads to a reduced need for primary material.

Operational data
A typical addition rate for magnesium to the melt is around 0.1 % of the melt weight, measured as magnesium (the actual addition of magnesium containing alloy, such as magnesium ferrosilicon, could be up to 2 % of the melt weight according to the alloy used).

This addition provides about 0.05 % of the magnesium in the melt, most of the remainder oxidises and escapes to atmosphere as MgO, where it will agglomerate fairly rapidly in the air. Where there is no fume capture, the fumes can spread through the foundry and a proportion will drop out in the foundry as dust. There is no accurate information available on this amount but a reasonable figure may be 50 % of the fume released. Therefore, for each tonne of metal treated there would be around 500 g of magnesium released to air at the ladle as MgO (i.e. 833 g of MgO released per tonne of metal treated) and about 400 g of MgO released to the external atmosphere.

Applicability
The technique of exhaust capture and filtration applies for foundries using in-crucible nodularisation techniques. No information on applicability to the in-mould nor ductilator was provided.

Economics
In applying this technique, the extraction required to successfully capture most of the MgO emissions from the treatment ladle would be around 280 m³/min. The combined capital and installation costs per foundry would be around EUR 180000.

The table below summarises the financial data for an 'average foundry', with the costs amortised over the presumed 10 year lifespan of the extraction and abatement equipment.

Extraction rate	Production rate	Costs EUR	Power kW	Costs EUR/tonne of iron treated

m³/min	tonne/h	Capital	Civil		Running	Financial	Total
280	0.5	180280	23514	50	21.95	29.35	51.30
	(1000 tonnes per year)						
Note: Civil costs are taken as 15 % of capital costs. Running costs are based on maintenance and waste disposal costs and are equivalent to 10 % of capital costs and power at EUR 0.06/kWh. Financial costs are based on the plant being amortised over ten years with interest charges of 10 %							

Table 4.46: Cost calculation for MgO fume abatement
[161, UK Environment Agency, 2002]

The costs for abatement of the magnesium oxide fume emissions are estimated at about EUR 51.30 per tonne of metal treated.

Driving force for implementation
Regulations limiting visible emissions and workplace atmosphere quality measures.

Example plants
- Römheld & Moelle – Mainz (D)
- Fuchosa – Atxondo (E).

Reference literature
[161, UK Environment Agency, 2002], [110, Vito, 2001]

4.5.8 Mould and core-making

4.5.8.1 Exhaust capture of dust from green sand preparation (sand plant) and dedusting

Description
Only a few of the different green sand preparation stages cause significant dust generation, namely the vibrating screen, dedusting and cooling process stages. These stages are equipped with dust capture and treatment. The units are enclosed and connected to a centralised dedusting unit. The set-up of the dedusting system has to take account of the dew point of the exhaust air and the type of dust.

The exhaust air from the green sand preparation is saturated with water. Therefore, wet systems (often of the low pressure type) seem to be most suitable for exhaust capture. However, the wet system is widely being replaced by dry dust abatement. The latter has the advantage that part of the dust may be recirculated and that no waste water stream is generated. Additionally, the wet systems are prone to internal corrosion and the build-up of dust and oxidation products. The wet separation of exhausted air impurities can result in problems for the waste water cleaning. Dust contains bentonite which is difficult to dispose of due to its anti-sedimentable effects. [225, TWG, 2003]

When applying fabric filters, condensation problems need to be prevented. Condensation may cause a deposition of dust, clogging and/or a tearing of the filter. The addition of cooling water to the sand needs to be done in a controlled way in order to minimise steam formation. The dew point of the airflow may be increased through heating with gas burners.

One benefit is that the collected dust is dry and so can be easily transported. After size separation, the coarse fraction and part of the fine fraction may be recirculated into the sand mixing.
Achieved environmental benefits
Reduction of dust emissions to air.

Cross-media effects
The use of wet systems cause the production of a waste water flow. Which needs to be treated, a sludge fraction, which needs to be a disposed of. Some systems work without producing waste water. The sludge is thickened and, if it contains a sufficient amount of bentonite, is re-used in the moulding-sand cycle.

Operational data
Using fabric filter equipment, a residual concentration well below 10 mg dust/Nm^3 in the exhaust air can be achieved. For wet scrubbers, the efficiency is slightly less, normally resulting in emission levels of 50 – 100 mg dust/Nm^3, though lower values have also been reported (see also Table 4.47)

Equipment	Exhaust gas flow (m³/h)	Abatement technique	Emission level (mg/m³)
Sand preparation 160 tonne/hour	64000	Venturi	4
Sand preparation 11 tonne/hour	48080	Wet scrubber	7
Sand preparation	57400	Bag filter	6
Shake-out unit	51070	Wet scrubber	7
Shake-out unit	50000	Bag filter	2
Grinding	54000	Bag filter	5
Shot blasting	17000	Bag filter	4

Table 4.47: Dust emission values from moulding and post casting shops [29, Batz, 1986]

Continuous monitoring data for a large-scale automotive foundry are given in Annex 2. These data show dust monitoring for sand preparation, sand transport and shot blasting.

Applicability
This technique is applicable to new and existing green sand preparation plants.

Driving force for implementation
Regulation of dust emissions.

Example plants
Generally applied throughout Europe.

Reference literature
[29, Batz, 1986], [32, CAEF, 1997], [110, Vito, 2001], [225, TWG, 2003]

4.5.8.2 Exhaust capture of dust from the green sand moulding shop work area and from dedusting

4.5.8.3 Exhaust capture from core-making – general considerations

The type of binder and hardener used will determine the type of emissions that occur. The exhaust gas from core-making with chemical binders consists mainly of a mixture of organic solvents. Emissions of phenol, formaldehyde, or ammoniac etc. are much smaller and depend on the binder type. Mixing, core shooting and drying can be enclosed to varying degrees, depending on the emissions occurring. Various binder-specific techniques apply, and these are discussed in the subsequent sections. Volatile organic carbon emissions occur with all chemically-bonded sand types, except for water glass sands. For self-setting and cold-setting binders, the emissions during mixing are low, given the low resin usage (1 – 2 % resin:sand

ratio). The emissions during hardening, coating and drying can be considered for capture and treatment.

Upon regeneration of the chemically-bonded sand, dust generation occurs in the shake-out drum. Sand cooling and dedusting is generally performed in a dry unit, since there are no problems with water condensation. It is not possible to recirculate the dust. [110, Vito, 2001]

4.5.8.4 Cold-box: capture of amine vapour and exhaust treatment

Description
The gassing of cold-box cores produces off-gases that need cleaning before emission into the atmosphere. In order to safeguard the working atmosphere, the core shooting machines are enclosed and cores are flushed with air to remove all the gas residues before the machine is opened up to take out the freshly made core.

Exhaust capture systems may be installed to secure good working conditions during the checking, handling and storage of the freshly made cores. For this, hoods or evacuation systems are installed, for example at the checking table, above the handling area and above the temporary storage area (the waiting area for the tray of ready cores).

The exhausted amine vapour requires treatment to prevent an odour nuisance. One of the following methods may be used:
- *Adsorption on activated carbon*: This process is very efficient, but the operational costs are excessive, so it may only be feasible if the exhausted volume is small
- *Combustion*: For this process to be efficient, the afterburner chamber must be correctly designed, to ensure a temperature of at least 800 ºC, with a minimum dwell time of 2 seconds. Energy consumption is high and the process is therefore expensive to operate. In foundries operating a cupola furnace, the exhaust gas may be fed to the cupola for combustion
- *Chemical scrubbing*: Amines are strong bases, and react with sulphuric or phosphoric acid. The pH of the solution is normally controlled to below 3. As a consequence, the scrubbing solution is replaced from time to time to remove concentrated salts, which subsequently require disposal as a hazardous waste. It is technically possible to process the scrubbing solution to reclaim the amine for re-use. This is discussed in Section 4.6.5
- *Biofilter:* See Section 4.5.8.6.

In winter, it may be necessary to heat the exhaust air in order to prevent amine condensation inside the ductwork. This may be done using waste heat from compressors or from other nearby devices.

Achieved environmental benefits
Exhaust capture allowing a reduction in amine emissions and related odour emissions.

Cross-media effects
When using acid scrubbers, the amine is transferred to the scrubbing solution, which then needs further treatment. However, recovery of the amine from the solution is possible. This is discussed in Section 4.6.5.

Operational data
Whatever the treatment method applied, amine emissions can be kept lower than 5 mg/Nm^3.

Emission data for a cold-box core-making shop using an acid scrubber are given in Table 4.48. The scrubber uses a 75 % phospohoric acid solution. In normal operation, 15 kg amine is disposed per day through the scrubber solution. The solution is saturated and stored in a tank for external treatment or disposal. The installation operates at 35.5 kW power and for 2000 h/yr.

Compound	Emission level

	mg/m³
Dust	0.42
Amine	2.4
Phenol	0.53
Oxygen	21 %
Exhaust gas volume	25100 m³/h

Table 4.48: Emission data for a cold-box core-making shop, using an acid scrubber [29, Batz, 1986]

Applicability
The technique applies for all existing and new cold-box core-making shops.

Economics
Operational costs for the installation mentioned in the 'operational data' section are EUR 6.3/tonne good casting.

The investment cost for an example installation, using a wet scrubber is given in Table 4.49.

Property	Value
Exhaust airflow	30000 m^3/h
Crude gas amine concentration	150 mg amine/Nm^3
Cleaned gas amine concentration	<1 mg amine/Nm^3
Power supply	45 kW
Investment cost	EUR 187000

Table 4.49: Specification and investment cost for an amine scrubber on cold-box core-shop exhaust data for Portugal, 2003

Driving force for implementation
To ensure workers health and to prevent odour emissions.

Example plants
The technique is generally applied for foundries using cold-box binders.

Reference literature
[29, Batz, 1986], [32, CAEF, 1997], [15, Gwiasda, 1984]

4.5.8.5 VOC-collection and removal

Description
VOC emissions (mainly solvents, BTEX, and to a lesser extent phenol, formaldehyde, etc.) result from chemically-bonded sand preparation and also, further along the process, from pouring, cooling and shake-out (see Table 3.35 and Table 3.45). These compounds are noxious and generate odour emissions.

The abatement of VOCs is hindered by the fact that large volumes of ambient air are entrained by the collection systems (e.g. canopy hoods) used.

The following techniques are applicable for the removal of VOCs:
- adsorption to activated carbon
- post combustion
- biofilter.

For adsorption to activated carbon, the exhaust gas flows through a carbon bed. Upon saturation, the carbon is thermally regenerated. Activated carbon has a very high adsorption

(and abatement) efficiency. For benzene, the efficiency is >99 %. Nevertheless, it has the following disadvantages:
- the high flue-gas volumes require large amounts of activated carbon
- dust and aerosols need to be filtered out of the off-gas before the carbon adsorption. Since very fine dust particles show a tendency to stick, the filtering is only possible using wet dedusting techniques and this thus generates a waste water flow.

To successfully exploit post combustion to eliminate VOCs from off-gases, specific minimum concentrations are necessary. These limit values are compound specific and depend on the chosen technique. Post combustion is possible for the exhaust gas from shell moulding. Generally, the exhaust gas from the casting shop does not have high enough VOC levels to operate post combustion. One alternative to post combustion is to use exhaust air from the core blowers as combustion air for the cupola.

The use of biofilters is discussed in detail in Section 4.5.8.6.

Achieved environmental benefits
Reduction of VOC-emissions to air.

Cross-media effects
Energy is consumed in the collection of the off-gas flow, which may also involve entraining large volumes of ambient air.

Driving force for implementation
Legislation on the emissions of VOC.

Reference literature
[20, Gapp, 1998], [110, Vito, 2001]

4.5.8.6 Exhaust gas cleaning using biofilter

Description
Biofiltration is based on the ability of microbes living in a fibre-peat filter bed to oxygenate malodorous gases and convert them into odourless compounds. The gas to be purified is blown by a fan through a bed of humid filter material, exiting odourless from the upper side. The odorous compounds are adsorbed in the water phase and are decomposed by micro-organisms living on the filter material. The good performance of the filter depends on the balance between the supply of nutrient (compounds for abatement/decomposition) and the number of micro-organisms.

In foundries, biofilters are applied for the removal of odorous gases, which mainly consist of amines from the off-gas from cold-box core-making processes and for the removal of VOCs (e.g. benzene) from casting shop exhaust gases.

Critical parameters for good functioning of the biofilter are:
- *Permeability of the filter layer*: Gases need to flow through the bed in good contact with the filter bed material. An excess of fine material in the filter bed may cause clogging, pressure build-up and blowout of bed material
- *Wetting of the filter medium*: A water dispersion system may be installed for continuous or intermittent wetting of the bed material
- *Conditioning of the exhaust gas*: The exhaust gases need to be moistened before entering the filter. For optimum operation, a constant temperature (30 ºC) has to be maintained. This may require preheating of the exhaust gas
- *Adequate water treatment*: The biofilter produces residual water, containing phenol and cresol. This is treated in a waste water system before disposal or re-circulation. Re-circulation requires an additional salt removal step.

Introduction of the biofilter technique into a German foundry required a long optimisation period, until it was able to function satisfactory. It was found that the following characteristics appear to be important:

- closure of the biofilter beds with a lid, in order to prevent CO- and condensation problems throughout the installation. The filtered air is evacuated through a centralised chimney
- close control of water quality (e.g. salt content), especially when applying a system not producing waste water
- the addition of nutrient salts to the sprinkling water, to maintain bed activity, and
- control of the pH-value of the bed material and the addition of lime to maintain a neutral pH-value.

Achieved environmental benefits

Reduction of odourous, amine and/or VOC emissions from the core shop and casting shop. The elimination of benzene and other VOCs takes place in biofilters but may not be regarded as reliable. The efficiency varies remarkably according to a wide spectrum of factors, such as weather conditions, age of substrates, etc. The use of biofilters alone is therefore not valid as a stand-alone technique for the reduction of VOCs. Their main purpose consists in the reduction of odour.

Cross-media effects

The biofilter produces a waste water flow. This may be re-circulated internally after treatment, yielding a sludge cake for disposal.

Energy is consumed during the transfer of the off-gas to and through the filter, as well as for the surrounding equipment.

It has been reported that emissions of N_2O, a greenhouse gas, may be a problem.

Operational data

Pilot scale data for amine removal have been provided by Finland. A biofilter unit (diameter 0.8 m, height 1 m) was installed in a core-making off-gas line, after an acid scrubber. The equipment included a fan and a dewing unit, with which the dampness of the biofiltration unit was adjusted to an optimum level. The odour removal was measured using an olfactometer. Results for the odour and total hydrocarbon levels are given in Table 4.50. Variations in the input analysis are due to process variations. The results show that filtration results in a significant odour and hydrocarbon reduction.

Compound	Units	Before biofilter	After biofilter
Odour	OU/m³	410 – 3000	150 – 310
Total hydrocarbons	mg C/m³	20 – 35	5 – 10
OU = Odour units			

Table 4.50: Operational data for the biofiltration of a cold-box core-making off-gas [112, Salminen and Salmi, 1999]

Industrial scale data for VOC removal have been provided by Germany. A biofilter unit (specification: surface 300 m³, height 1 m, in 5 rectangular beds, with a total throughput of 32330 Nm³/h dry gas) was installed for the treatment of exhaust gases from pouring and cooling in a green sand cast-iron foundry, using croning and cold-box cores. The emission data are given in Table 4.51. Olfactometric measurements showed an average reduction of odour emissions by a factor of 94.5 %.

Parameter	Units	Before biofilter	After biofilter	Reduction %
O_2	%	20.74		

CO_2	%	0.17		
NO_x	mg/m³	3.65		
CO	mg/m³	382	299	21.7
Benzene	mg/m³	15.80	1.44	90.9
Toluene	mg/m³	9.37	0.92	90.1
Ethylbenzene	mg/m³	3.00	0.46	84.7
Xylene	mg/m³	4.90	1.54	68.6
Formaldehyde	mg/m³	0.37	0.01	68.6
Dust	mg/m³	13.63	2.03	85.1
Ammonia	mg/m³	8.97	0.16	98.2
Phenol	mg/m³	4.67	<0.02	>99.6
Cresol	mg/m³	3.73	<0.02	>99.5
PCDD/F	ng/m³	0.0056	0.0041	26.8
Benzo(a)pyrene)	mg/m³	0.0001	0.00003	70.0

Table 4.51: Emission data for the biofiltration of exhaust from green sand pouring and a cooling line
[20, Gapp, 1998]

Applicability
This technique finds its application in green sand foundries and cold-box core-making shops. The applicability is limited to 3-shift large series casting foundries, as biofilters need very stable conditions throughout the year. It should be noted in each known case of application great individual efforts of research and development have been required to achieve an acceptable performance.

Economics
Investment costs for the biofilter unit in the German example (specification: surface 300 m³, height 1 m, in 5 rectangular beds, with a total throughput of 32330 Nm³/h dry gas), including a water treatment unit to allow operation without the production of waste water, have been estimated at EUR 3247000. This includes EUR 2333000 for the filter and surrounding equipment and EUR 914000 for the exhaust capture and ductwork. With a design load of 40000 Nm³/h, operational costs are estimated at EUR 170000/yr (costs based on DEM for 1998).

These estimated operational costs are much higher than generally stated investment and operational costs for biofilter units. This is probably due to the large throughput and the extent of the surrounding equipment. In a 1998 paper the cost for an open-bed biofilter, treating 17000 Nm³/h was estimated at USD 70000 – USD 100000 for investment and a yearly operating cost for water, labour and overheads of USD 15000 – USD 25000.

Driving force for implementation
Reduction of nuisance effects (mainly odour) on neighbouring locations.

Example plants
Halberg Guss, Saarbrücken-Brebach (D)

Reference literature
[20, Gapp, 1998], [112, Salminen and Salmi, 1999], [202, TWG, 2002], [208, Devinny, 1998]

4.5.8.7 Permanent moulding: collection of release agent emissions

Description

The spraying of a water-based release agent on HPDC dies generates a mist with low concentrations of decomposition products. The mist is collected using a suction hood and an EP.

Achieved environmental benefits
Reduction in the emission of release agent containing organic compounds. Prevention of diffuse emissions.

Cross-media effects
Capture and collection of the mist requires the consumption of energy.

Operational data
Operational data from an example plant are given in Table 4.52. The data refer to a water miscible release agent (1:40 dilution factor), based on synthetic polymer and polysiloxane. Each die-casting machine is equipped with a separate suction hood and an EP. The hot and cleaned air is blown back into the hall (i.e. for heat recovery).

Compound	Half hour measured values (mg/Nm^3)	Mass – flow (g/h)
Dust	1.5 – 4.3	5.5
Organic substances (values in total carbon) (mg/m^3)	4 -6	9

Table 4.52: Emission data from EP-cleaned HPDC off-gas [202, TWG, 2002]

Applicability
This technique applies to existing installations. It is an end-of-pipe measure, applied in cases where prevention or minimisation of the mist has failed. Prevention and minimisation measures are discussed in Section 4.3.5.1.

Driving force for implementation
Minimisation of diffuse emissions and legislation on the emission of oil mist (e.g. in Sweden).

Example plants
Reference plant: TCG Unitech, Kirchdorf/Krems (A)
General practice for older die-casting machines (D, F, B,...) and for all die-casting machines in Italy.

Reference literature
[202, TWG, 2002], [225, TWG, 2003]

4.5.9 Casting/Cooling/Shake-out

4.5.9.1 Introduction

The emissions during pouring, cooling and shake-out are diverse and differ broadly in quality and quantity from one foundry to another. Basically, dust emissions are produced, as well as inorganic and organic gaseous compounds. These are mainly reaction products, caused by the high temperature and the reducing atmosphere upon pouring and cooling. The composition of pouring fumes is complex. They consist mainly of CO, CO_2, H_2, and methane as the main representatives of the organic decomposition products. Polycyclic aromatic hydrocarbons and benzene occur, depending on the composition of the mould- and core-system.
The capture and treatment of the off-gases of these process stages is generally possible for automated moulding and pouring installations. [29, Batz, 1986]

Relative emissions (as kg/t of molten metal) increase over the pouring-cooling-shake-out sequence. Exhaust capture efforts will need to take this variation into consideration.

4.5.9.2 Pouring and cooling lines encapsulation

Description
The collection of emissions during pouring, cooling, and shake-out is as a rule more extensive as the plant becomes bigger.

The further the pouring process can be restricted to a fixed area or position, the smaller the amount of extracted air will be, and the easier it will be to capture emissions with ventilators and housings, and therefore air-treatment can be carried out more effectively.

In serial pouring, the emissions increase with increasing production capacity. Without extraction, the air at the pouring plant could at some point reach unacceptable concentration levels of noxious substances. To lessen the pollution in the work area, extractor ventilators or extractor surfaces are fitted as close to the moulds as possible, but without hindering the pouring process. The extractor elements are arranged in such a way that all emissions occurring during pouring, are moved away from the work area to the extracting equipment. The air-speed at the free extraction cross-section is kept between 0.5 and 1 m/s.

Achieved environmental benefits
Reduction of diffuse emissions of CO, PAHs and other organic decomposition products.

Cross-media effects
Extraction of exhaust air consumes electrical energy.

Applicability
This technique is applicable to new and existing installations utilising serial pouring and cooling.

Driving force for implementation
Reduction of diffuse emissions. Collection of emissions in order to allow treatment.

Example plants
The technique is commonly applied in large-series foundries.

Reference literature
[32, CAEF, 1997]

4.5.9.3 Exhaust capture and treatment from shake-out

Description
The technique used for the emission collection from shake-out depends on the degree of mechanisation, the emissions to be extracted and the size range of the castings, in particular the smallest and largest item cast on the same machine.

The system of reducing emissions most commonly used is a ventilator panel on the side of the shaker. Usually, panels are installed on both sides of the shaker, regardless of the shaker size. If possible the rear of the shaker is enclosed in this way too. Frequently an extraction point is provided under the shaker in the sand-box, operating through a projecting pipe. This presents the risk of sand being extracted if the box is filled with sand up to the pipe. Moreover the pipe's inlet is often obstructed by sand lumps or adhering steam and dust.
The best way of achieving good emission levels with relatively small ventilation rates is when shake-out is performed in enclosed units. Roof openings, possibly with a moving screen, doors

and entry/exit chutes make it possible to use a crane or other means of transport. In addition, the closed cabins reduce the noise level.

In automatic moulding plants, the casting-mould package is often pressed out of the moulding box by a hydraulic jack with a mounted pressing plate. Afterwards the casting is separated from the sand firstly on a jig-shaker and then to a rotating shake-out drum or tube or a sand cooler. Extraction drums or tube drums, which are now increasingly being used, are much more suited to the collection of emissions than the usual shakers, but they have the disadvantage of possible odour emissions.

The quantity of extracted air is not only determined by the workplace limit values required, but also by processing requirements. Large air volumes may be required for cooling and for protection of the filter bags. This needs to be balanced against the demands of any pollution abatement techniques, that usually need highly charged waste gases with small air volume streams in order to be effective.

Appropriate techniques for dedusting are cyclones combined with wet scrubbers or dry filters. Biofilters are also used and are discussed in Section 4.5.8.6.

For gravity die-casting and centrifugal casting, post combustion, chemical washing and adsorption to activated carbon are used in order to reduce organic emissions and odour. These systems have already been described above.

Achieved environmental benefits
Reduction of the emissions of VOC and dust to air.

Cross-media effects
Dust collection produces a residue for disposal.

Operational data
With free-standing extraction shakers up to 2 m in width, for every m^2 of shaker surface 7000 to 9000 Nm^3/h of air is extracted in the case of a one-sided ventilation screen. With a two-sided screen, 5000 Nm^3/h per m^2 of shaker surface is installed.

If the extraction point is under the shaker in the sand-box, the amount of air extracted per m^2 of shaker surface is designed to be about 700 Nm^3/h.

In a Polish example foundry for large-size cast steel castings, a removable doghouse type cover was constructed over the shake-out grate. The doghouse consists of two sideways moving doors, which are opened and closed hydraulically, as shown in Figure 4.17. The cover reduces dust and noise emissions into the foundry hall. The exhaust is cleaned using dry de-dusting. The noise level for shake-out was reduced from 100 dBA to below 85 dBA.

Figure 4.17: Doghouse cover for a shake-out grate, for large-size batch castings

[209, Metalodlew s.a., 2003]

Applicability
In plants where clay-bonded sand moulds are shaken out, the emission of steam is significant. The combination of dust and steam can lead to huge obstructions in the ductwork if the temperature drops below the dew point or worse, below freezing point. To overcome this problem, hot air must be injected into the ducts and the piping and filter-housing must be insulated, or water (free of dust) must be sprayed into the ventilator piping to prevent these obstructions.

Economics
For the doghouse in the Polish example foundry, as mentioned above, the investment cost was EUR 220000, including some additional equipment.

Driving force for implementation
Regulations on the emission of VOC and dust.

Example plants
Metalodlew s.a., Krakow (PL)

Reference literature
[16, Gerber and Gwiasda, 1981], [32, CAEF, 1997], [209, Metalodlew s.a., 2003]

4.5.9.4 Off-gas cleaning using biofilter

Description
Biofilters are used to treat emissions of VOC and benzene and are therefore used for the treatment of off-gas from pouring, cooling and shake-out. The full description and discussion of the technique is given in Section 4.5.8.6.

Example plants
Several examples in Germany.

Reference literature
[225, TWG, 2003]

4.5.10 Finishing/post-casting operations: off-gas collection and treatment

4.5.10.1 Finishing off-gas collection

Description
Considerable amounts of fume have to be captured and extracted when using thermal separation techniques. The work area may be as enclosed as much as possible, but ensuring the freedom of movement and that the inhaled air supply of the worker can be assisted. Dust collection techniques during abrasive cutting and grinding are differentiated between stationary machines and hand machines. Rigid hoods are customary at stationary machines, partly in connection with partial housings.

For stationary grinding machines, the tightly limited abrasive blast goes into an extracting funnel and is extracted. In the case of abrasive cutting-off stations, it is sensible to additionally

extract emissions from the cabin in the interest of worker's health and safety. Handheld machine emissions are occasionally extracted via the splint protection hood. This is an effective but unpopular method, as it increases the weight of the machine and impairs its manageability. Normally hand grinding and hand cutting-off machines are housed in cabins (i.e. partial housings).

Collection of the dust takes place via extracting walls, roof domes, moveable hoods or extraction work benches. An effective aid when collecting emissions are hot-air curtains which direct additional air into the cabin. The additional air used may be cleaned recycled extraction air, in order to economise on heating energy. However, it should be noted, that a portion of fresh air will still always need to be provided from the outside.

Dust or pollutant collection is in most cases not needed for sawing, rapping, pressing, chiselling, stamping and milling. Screens may sometimes be used to protect the operator against rough particles. Welding is divided into processes with and without additional materials. Work protection regulations requiring extraction exist for most processes.

Achieved environmental benefits
Reduction of diffuse emissions of metallic particles and dust.

Cross-media effects
The collection and extraction of dust-laden off-gas consumes energy.

Operational data
Operational data have been given in Section 3.11 and show that emission from cutting, scarfing and welding (without off-gas cleaning) are low compared to those for fettling and shot blasting.

Applicability
As indicated in Table 4.53, some finishing techniques do not generate dust and consequently do not necessitate an off-gas collection system.

	Roof ventilation	Dome-shaped roof	Rigid hood	Adjustable hood	Housing
Abrasive cutting			x	x	x
Burning	x	x	x	x	x
Chiselling, needling	Off-gas collection seldom necessary				
Fettling		x	x	x	x
Milling	No off-gas collection necessary				
Rapping, pressing	No off-gas collection necessary				
Sawing	No off-gas collection necessary				
Slide grinding	x	x	x	x	x
Shot blasting					x
Stamping	No off-gas collection necessary				
Welding	x		x	x	x

Table 4.53: Applicability of dust capture techniques for various finishing operations [32, CAEF, 1997], [225, TWG, 2003]

Driving force for implementation
Regulations on dust emissions and occupational health and safety.

Example plants
The technique is applied in the vast majority of the European foundries.

Reference literature
[32, CAEF, 1997]

4.5.10.2 Exhaust air cleaning techniques

Description
- *Blasting:* Blasting generates a lot of dust. Off-gas capture is unproblematic due to the total enclosure of the blasting process in a closed cabin. Customary exhaust air decontamination processes are wet washing and dry filters, usually with a cyclone as a pre-filter
- *Slide grinding, drumming:* Both processes do not require emission reduction in normal conditions. Aerosols that can form in quickly moving drums can be neglected
- *Cutting:* All thermal separation processes generate emissions. Exhaust capture is achieved through enclosing the work place and carrying out an intensive extraction of the arising fume. It is important to place the capture elements as close as possible to the emission source, but without hindering the operating process. In some cases it has proven beneficial to combine a mobile arm for direct extraction and additional cabin extraction. By carefully arranging the extraction elements, the dust-filled air can be guided away from the breathing area of the worker. The usual exhaust air decontamination processes are wet washing and dry filters. It should be noted that the systems are set up for the smaller grain sizes of the emitted fumes. Inertia force separators are applied as pre-separators
- *Abrasive cutting*: Stationary abrasive cutting installations are extracted. Customary exhaust air decontamination processes are cyclones, wet washing and dry filters
- *Sawing, rapping, pressing*: These handling processes cause few emissions and do not require reduction measures in normal conditions
- *Chiselling, needling*: In these processes mainly coarse particles are produced which are difficult to remove through extraction. The work is mainly carried out in cabins for safety reasons. In special cases, e.g. when removing burnt-on sand, the generated dust may be extracted by an extraction arm. The exhaust air is decontaminated in cyclones, wet washing and dry filters

- *Grinding*: Emission capture when grinding on stationary machines takes place in a similar way as with abrasive cutting, i.e. via fixed funnels into which the abrasive blast is directed. An enclosed work place is used for manual grinding and abrasive cutting. Extraction walls can then be applied in the housing. Air decontamination processes are cyclones, wet washing and dry filters
- *Stamping, milling*: These handling processes cause few emissions and do not require reduction measures in normal conditions
- *Welding*: More or less emissions occur according to the type of the selected welding process, which is usually be best collected by extraction arms. For exhaust air cleaning, wet washing and dry filters and occasionally electrostatic filters are used.

Achieved environmental benefits
Reduction of dust emissions.

Cross-media effects
The extraction and cleaning of dust-laden off-gas consumes energy.

Operational data
Wet scrubbers and fabric filters have been installed and operated successfully for many years. Fettling cabins with high-efficient dust arrestment units can be run stackless, as their output is cleaner than the usual fettling shop air. They also help to improve workplace conditions.

Operational data is given in Section 3.11 and show that emission factors for cutting, scarfing and welding (without off-gas cleaning) are low, as compared to those for fettling and shot blasting.

Using fabric filter equipment, emission levels below 10 mg dust/Nm^3 can be achieved.
Using wet dust removal systems, emission levels below 20 mg dust/Nm^3 can be achieved.

Applicability
These techniques apply to new and existing foundries. In general, non-ferrous foundries do not apply intensive (dust generating) finishing operations.

Driving force for implementation
Regulations on dust emissions and occupational health and safety.

Example plants
The technique is applied in the vast majority of the European foundries.

Reference literature
[32, CAEF, 1997], [180, Assofond, 2002]

4.5.11 Heat treatment waste gas collection and cleaning

4.5.11.1 Use of clean fuels in burner-heated heat treatment furnaces

Description
A basic process-integrated measure for emission reduction in burner-heated heat treatment furnaces is the use of clean fuels i.e. natural gas or low-level sulphur content fuel.

Additionally, automated furnace operation allows close control of the working regime and temperature and minimises excessive energy consumption.

Achieved environmental benefits
Reduction of combustion-based pollutants, such as CO, SO_2, NO_x.

Cross-media effects
No cross-media effects apply.
Operational data
In an example foundry in Poland, up to 1998 the heat treatment was performed in 3 coal gas furnaces with manually controlled burners. The coal gas came direct from the coke oven and was of a variable quality (e.g. CO-content up to 15%). This resulted in high emissions and the risk of intoxication, together with a poor control of the temperature profile.

In 1998, 2 of the 3 furnaces were newly equipped with computer controlled natural gas burners. Additionally the furnace lining was renewed. The results of these changes on the operation were:
- automated control of the temperature profile
- 40 % reduction of gas consumption (volume)
- reduction in cost due to the use of cheaper natural gas
- reduction of emissions of SO_2, NO_x, CO and aromatics (see Table 4.54).

Compound	Coke oven gas burners	Natural gas burners

	Concentration (g/Nm³)	Emission (kg/h)	Concentration (g/Nm³)	Emission (kg/h)
CO	0.006	0.074	0.000	0.000
SO_2	0.011	0.136	0.003	0.064
NO_x	0.016	0.197	0.004	0.085
Aromatics	0.001	0.012	0.00025	0.0054

Table 4.54: Emission levels from a heat treatment furnace before and after conversion to natural gas burners system

Applicability
This technique applies to burner-fired heat treatment furnaces.

Driving force for implementation
Regulation of emissions of SO_2, NO_x, CO.

Example plants
Metalodlew, Krakow (PL)

Reference literature
[32, CAEF, 1997]

4.5.11.2 Quenching baths

Description
Here, emission capture and reduction essentially involves the capture of fume at the quenching baths, especially at the oil quenching baths. Roof ventilation, extraction domes and edge extractors are used. Here similar difficulties arise as with shake-out grids. The baths must be frequently loaded by a crane, so the extraction hoods need to be installed high above the hall floor.

Abatement systems are not widely applied at this pointin general, but if any abatement is performed, electrostatic filters are mostly used.

Achieved environmental benefits
Reduction of diffuse emissions of oil-mists.

Cross-media effects
Exhaust extraction consumes energy.

Applicability
The applicable techniques for different types of baths are characterised in Table 4.55.

	Roof ventilation	Dome-shaped roof	Dome, rigid	Dome, adjustable	Edge extraction
Water	x				
Emulsion	x	x	x	x	x
Hardening oil	x	x	x	x	x
Note: x : applicable					

Table 4.55: Applicability of fume collection techniques for quenching baths [32, CAEF, 1997]

Edge extractors are only effective up to a certain size and lose their effectiveness almost completely at the time of the highest emissions, i.e. when a hot workpiece is submerged in the

bath. In spite of this, edge extraction is the most sensible capture measure, utilising big baths combined with a blast veil and a roof dome.

Driving force for implementation
Regulations on emissions and occupational health and safety.

Example plants
The technique is used in several foundries around Europe.

Reference literature
[32, CAEF, 1997]

4.6 Waste water prevention and treatment

4.6.1 Measures to prevent the generation of waste water

Description
The following measures result in a marked reduction in waste water:

- *Use of dry dedusting systems:* Dry dedusting systems can be used for most foundry exhaust gas flows. However, in exceptional cases, it may be necessary to use a wet scrubber for removal of iron-containing ultra-fine dust fractions. The applicabilities of dry and wet exhaust cleaning techniques are discussed in Section 4.5
- *Biological waste gas scrubbers or compost filters:* The use of a biological waste gas scrubber can be considered if the gases to be treated contain readily biodegradable substances such as phenols, etc. Biological scrubbers generate less waste water than conventional wet scrubbers because biologically treated waste water can be recirculated more often.
  Note: Compost filters (biofilters) do not generate any waste water, although the compost material must be sufficiently moist. The technique of biofiltration is discussed in Section 4.5.8.6
- *Internal recycling of process water:* An extensive recycling of scrubbing water requires the use of treatment facilities. These include sedimentation tanks, possibly with an integrated flocculation stage, and filtration equipment. Depending on the process, cooling may be necessary. Evaporation losses and substance inputs from gas scrubbing lead to an accumulation of salt in the circulating water. Depending on the salt concentration and the applicable discharge limit values (in the case of indirect discharge), circulating water may have to be drawn off. It may be economically favourable to evaporate this waste water and to use the condensate to make up evaporation losses
- *Multiple use of treated waste water:* Multiple use of treated waste water needs to be considered, e.g. using process water from sand preparation in the moulding sand cycle or in slag granulation. The use of cooling water in wet scrubbing may also be considered
- *Use of waste heat for the evaporation of waste water:* This technique can only be applied when waste heat is available on a continuous basis. A case-by-case evaluation is needed to evaluate its applicability and economic viability
- *Prevention of waste water from scrap storage:* The generation of waste water from the storage of contaminated scrap can be prevented by roofing the storage area. The run-off water is collected as uncontaminated rainwater. All techniques for storage are discussed in Section 4.1
- *Avoidance of AOX formation in waste water:* Careful selection of scrap types can prevent the uptake of chlorinated compounds in the production cycle. Analyses for AOX compounds prior to scrap purchase are a helpful measure. AOX may also be contained in auxiliaries used in waste water treatment, e.g. commercial-grade hydrochloric acid, iron chloride or aluminium chloride

- *Keep water types separate:*Various water flows with distinct pollutant levels are kept separate, in order to minimise the need for waste water treatment and to optimise the water use.

Achieved environmental benefits
Prevention of the production of waste water.

Cross-media effects
Cross-media effects may apply, depending on the chosen technique. Information is given in the specified sections.

Operational data
Operational data are given in the description of the example plant in Section 4.6.3.

The waste water system of an example aluminium foundry consists of 4 separate flows:
- surface run-off: this joins to the central rainwater channel, through an oil separator (2xNG80), and onto a nearby river
- used water = process water (open cooling baths) and sanitary water: this goes through an open air channel on site, into a public channel and then onto the public sewage works of the town
- cooling water: this is initially taken from the nearby river, over a sand filter, and goes through the installation in a closed percolation cooling circuit, and then back to the river, with a temperature limited to 28 ºC. Roof water also enters the cooling water circuit
- water from off-gas scrubbers (green sand, post casting): this is partially evaporated, so that only the remaining sludge leaves the installation.

Applicability
This technique applies to all new and existing installations.

Economics
Economic data are given in the specified sections for alternative techniques and in the 'Example plants' section of Section 4.6.3.

Driving force for implementation
Minimisation of waste water production.

Example plants
Honsel, Meschede (D)

Reference literature
[195, UBA, 2003]

4.6.2 Treatment of scrubbing water and other waste water flows

Description
For furnace gas cleaning, dry filtration systems eliminate potential waste water streams, however with a wet cleaning system there is no need for an aqueous discharge if appropriate measures are taken to clean the water and recycle it. As long as solids are removed to a level acceptable to the scrubbing device, soluble compounds can normally be allowed to reach saturation without any adverse effects. There are a variety of techniques, or combinations thereof, which could adequately separate the solids.

The following treatment techniques are applied:
- sedimentation
- hydroxide precipitation
- multi-stage precipitation
- wet oxidation

- filtration procedures.

The waste water can contain undissolved and dissolved heavy metals, phenols and cyanides. The treatment needs to be adapted to the type of pollutants.

Undissolved heavy metals have to be removed from waste water by physical methods (sedimentation, filtration, possibly flotation). Concentrations well below 0.5 mg/l can be achieved by the use of these methods.

Dissolved heavy metals must first be transformed into poorly soluble compounds using suitable precipitants. Especially strong bases (lime milk, caustic soda solution, soda) are used as precipitants for hydroxide precipitation. If this is not sufficient, sulphide precipitation with organic sulphides or alkali sulphides must be carried out.

Phenols and **cyanides** can be biologically degraded or removed by physical-chemical treatment. Normally they are present in such low concentrations that there is no need for targeted pretreatment. Combined treatment in a sufficiently large biological waste water treatment plant is sufficient.

Achieved environmental benefits
Reduction of the pollutant load in discharged waste water.

Cross-media effects
Waste water treatment generates a sludge fraction for disposal.

Operational data
Waste water from foundries mainly contains zinc, in addition to iron. Hydroxide precipitation in a pH range of 8.5 to 11 can reduce the zinc concentration to values below 2 mg/l. This pH range must be respected, because at a pH in excess of this range amphoteric zinc is re-dissolved, in the form of zincates.

By way of example, Figure 4.18 shows the combined conditioning and precipitation reaction of non-dewatered sludge from wet scrubbers of cupola furnaces. Following removal from the wet scrubber's water treatment system, the sludge is conditioned in a separate treatment stage using caustic lime. This results in an increase in the pH value and the precipitation of heavy metals. Organic pollutants are also adsorbed. The sludge is subsequently dewatered in a chamber filter press. Following turbidity measurements, the filtrate is passed to a storage tank incorporating a monitoring of pH and conductivity. Depending on its condition and actual needs, the filtrate is returned to the sludge silo, sent to slag granulation or sent for dry dust humidification via equalising tanks, or discharged to drain as surplus (following the requirements for discharge to a municipal waste water treatment plant).

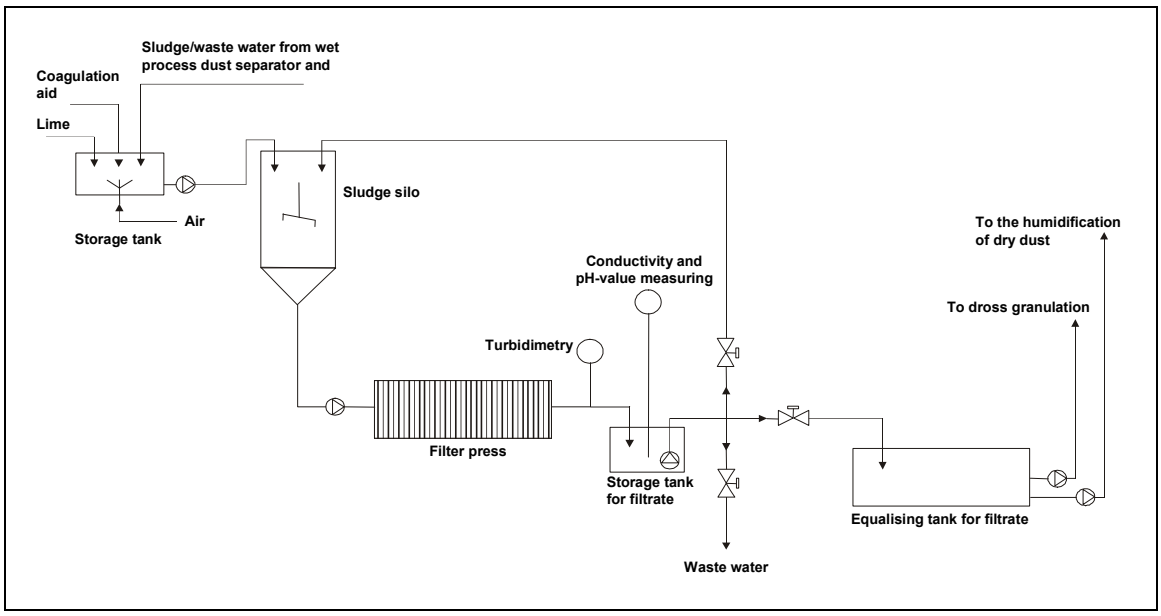


Figure 4.18: Treatment of waste water and sludge from the wet de-dusting system of a cupola furnace
[195, UBA, 2003]

Additional operational data are given in the description of the example plant in Section 4.6.3.

Applicability
The type of waste water treatment to be applied needs to be selected on the basis of the waste water composition and the local conditions for disposal of water from the plant into the receiving water medium.

Economics
Economic data are given in the description of the example plant in Section 4.6.3.

Driving force for implementation
Regulations for pollutants discharge into water.

Example plants
See Section 4.6.3

Reference literature
[195, UBA, 2003], [160, UK Environment Agency, 2002]

4.6.3 Example plant for waste water prevention and reduction

Description
A German example plant produces parts from cast iron (grey and nodular cast iron) and die-cast aluminium.
The following operations are carried out:
- *Melting:* Gas-fired melting furnaces and flue-gas treatment plant (dry filter)
- *Manufacture of diecast parts:* Automated casting-punching cells for aluminium diecasting
- *Sand casting:* Manufacture of special alloys
- *Iron casting (core production):* For core production, the cold-box and Croning processes are used. Scrubbing concentrates are generated in amine scrubbing
- *Iron casting (melting):* The melting shop consists of a mixing plant, a hot blast cupola furnace, several electric furnaces, a converter and a holding furnace
- *Iron casting (moulding):* Use of lost moulds made of bentonite-bonded sand.

Production data and water consumption are given in Table 4.56.

Production	
Good iron castings, total	46710 t
Good non-ferrous metal castings, total	2355 t
Water consumption	
Drinking water (town water)	59630 m^3
Surface water/groundwater	64998 m^3

Table 4.56: Production and water consumption data (on yearly basis) for example foundry [195, UBA, 2003]

Wet scrubbers are applied where large volumes of waste gas containing relatively high concentrations of organic substances are generated (waste gas from core-making) or where high flue-gas temperatures occur (flue-gas from hot-blast cupola furnaces).

A schematic representation of the water circuit of the wet dedusting system is given in Figure 4.19. The waste gas from under-charge cupola flue-gas extraction is fed to a cyclone separator and a venturi scrubber for dedusting. The subsequent removal of gaseous pollutants is achieved in a packed bed scrubber. The waste water from the venturi scrubber is pretreated in a float and sink separator and then passed to a settling tank for secondary treatment. The scrubbing liquid from the packed tower is fed directly into the settling tank. The settled sludge from the settling tank can be pumped discontinuously to the float and sink separator. The sludge from the float and sink separator is pumped to a scraper conveyor, agglomerated by the addition of flocculants, and passed into a storage tank. From there, the sludge is fed to the sludge silo and is subsequently solidified in a mixing plant by the addition of dry dust.

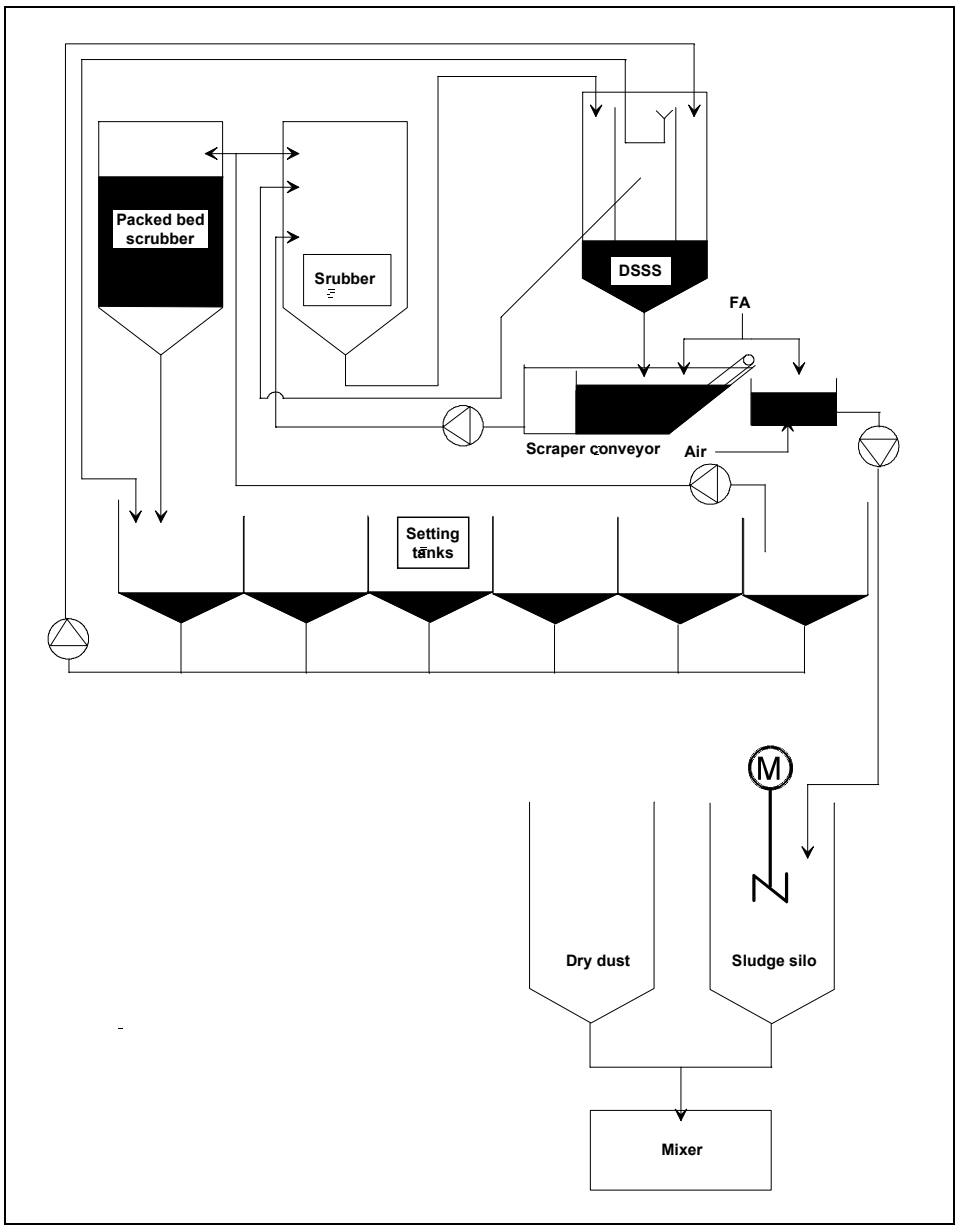


Figure 4.19: Water circuit for the wet dedusting system of a cupola furnace
DSSS: double shell sinking separator; FA: flocculant, M: motor
[195, UBA, 2003]

In this basic layout, the plant experienced some operational problems, due to salt accumulation and the low final water quality. An extension was made to the plant, with the aims of:

- increasing the settling velocity, by the use of other flocculants
- reducing the pollutant content in the scrubbing medium
- improving sludge dewatering
- re-using the scrubbing medium from the gas scrubbing cycle.

For this purpose, a chamber filter press with a volume of 2 m^3 and a sludge collection tank (30 m^3 in volume) with an agitator were installed. The sludge was passed from the scraper conveyor directly into the storage tank and preconditioned with lime.

During the trial phase, which lasted several months, it was found that approximately 25 kg of lime per batch were needed to achieve the best result in terms of dewatering and heavy metal removal. The average dry matter content was 70%. Analysis of the filtrate for heavy metals showed values in the range of detection limits. However, the relatively high sulphate concentrations of about 1 g/l posed a problem for re-use of the filtrate in the scrubbing cycle.

As a practicable alternative, the sludge treatment was further extended with other compounds as shown in Figure 4.20. The water/solids mixtures from wet scrubbing were pre-conditioned by the addition of flocculant and the resulting sludge was fed to a mixing tank by a scraper. Lime is added to the mixing tank in a quantity which needs to be determined previously through tests, and the sludge is fed to the sludge silo by a pump (pump P1 in Figure 4.20). Pump P2 pumps it to the filter press.

The filtrate is passed via a turbidity meter into a storage tank in which pH and conductivity are monitored. There are three possibilities for where it goes from there:
- via an equalising tank to slag granulation or dry dust humidification
- back to the sludge silo (if the turbidity limit is exceeded)
- to drain (emergency measure only).

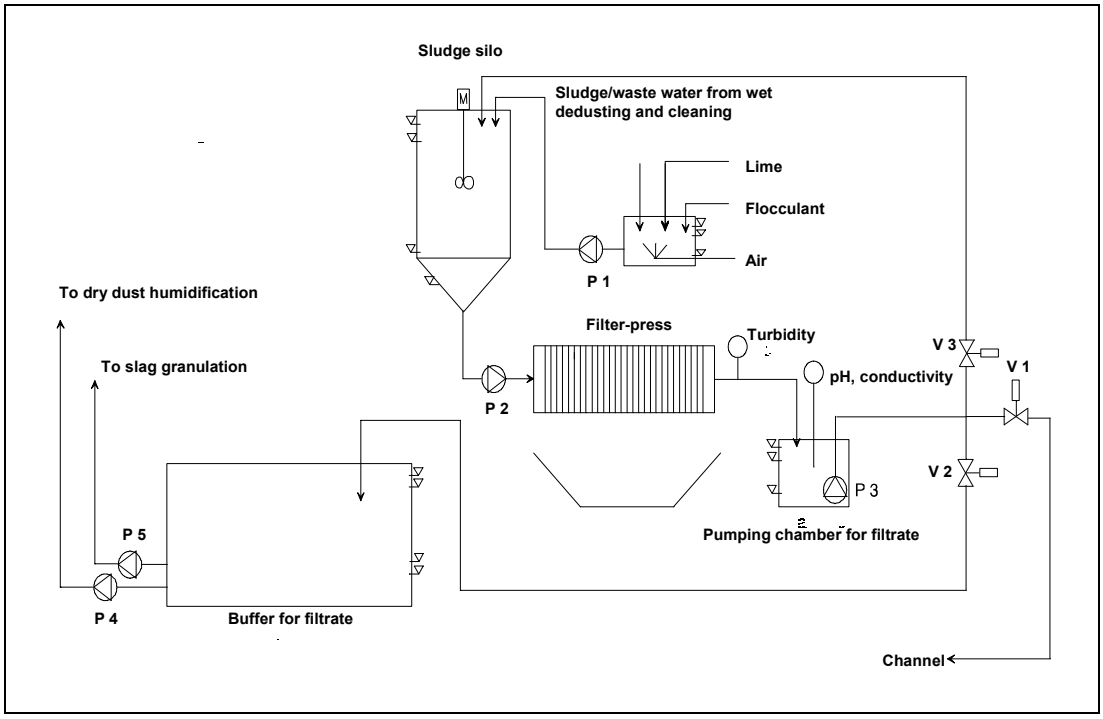


Figure 4.20: Treatment system for sludge from the wet dedusting of cupola flue-gas [195, UBA, 2003]

Economics

Economic data concerning the extension of the system with the sludge treatment are given in Table 4.57.

Before extension		After extension	
Generated sludge with a dry matter content of 30%	2000 t/yr	Generated sludge with a dry matter content of 70%	850 t/yr
Dry dust for sludge solidication	1100 t/yr	Dry dust for sludge solidication	0 t/yr
Landfill price	EUR 100/t	Landfill price	EUR 100/t
Disposal costs per year	**EUR 310000**		**EUR 85000**

Table 4.57: Disposal costs for the extension of a waste water system with sludge treatment [195, UBA, 2003]

The sludge with 70 % dry matter content does not need further stabilisation before disposal. For the wet sludge, a solidification with dry dust is needed. The saving in disposal costs is EUR 310000 – EUR 85000 = EUR 225000. This compares to an investment cost for the extension totalling EUR 175000 and an additional annual operating costs of about EUR 50000.

The total cost saving therefore amounts to EUR 175000/yr, giving a 1-year payback period. The calculation does not include the cost savings from the re-use of the filtrate.

Example plants
Sach Giesserei GmbH, Kitzingen (D).

Reference literature
[195, UBA, 2003]

4.6.4 Oil interceptors

Description
Run-off from all open areas, but particularly from raw materials stocking areas, contain suspended solids, which can be removed by settlement or other techniques. Oil interceptors are used in draining scrap handling areas. Drainage sumps are designed with a sufficient size to handle storm-water and to accommodate any storm surge, in order to prevent carry-over of unsettled material.

Oil interceptors are used on waste water from permanent mould casting foundries. The hydraulic systems of die casting automates can potentially leak oil. The water collection system is thus designed in such a way that any oil from leakage is collected and the resulting waste water flow is treated using an oil interceptor.

Achieved environmental benefits
Prevention of water pollution.

Cross-media effects
Oil interception generates a residue for disposal.

Applicability
This technique applies to new and existing die-casting (permanent mould) foundries and to all other foundries with a waste water discharge directly to surface water.

Driving force for implementation
Regulations for pollutants discharge into water.

Example plants
Honsel, Meschede (D).

Reference literature
[160, UK Environment Agency, 2002]

4.6.5 Recovery of amine from scrubbing water

Description
When acid washing the cold-box exhaust gas, amine sulphate is formed (see Section 4.5.8.4). This amine may be recovered through neutralisation with sodium hydroxide, followed by distillation.

As shown in Figure 4.21, the salt that is formed from tertiary amine (e.g. DMEA, DMIA and triethanolamine (TEA)) in the acid scrubber, and the scrubbing acid (e.g. sulphuric acid) are retransformed by reaction with a strong base (e.g. caustic soda solution), thereby forming free amine and e.g. sodium sulphate. The amine is expelled with water vapour and is then cleaned and concentrated in a column, to an extent that allows it to be re-used. The sodium sulphate solution (together with polluted scrubbing solution) can be recovered or may be disposed of.

If the amine is not recycled, the scrubbing concentrates can be treated in a biological waste water treatment plant with nitrogen elimination.

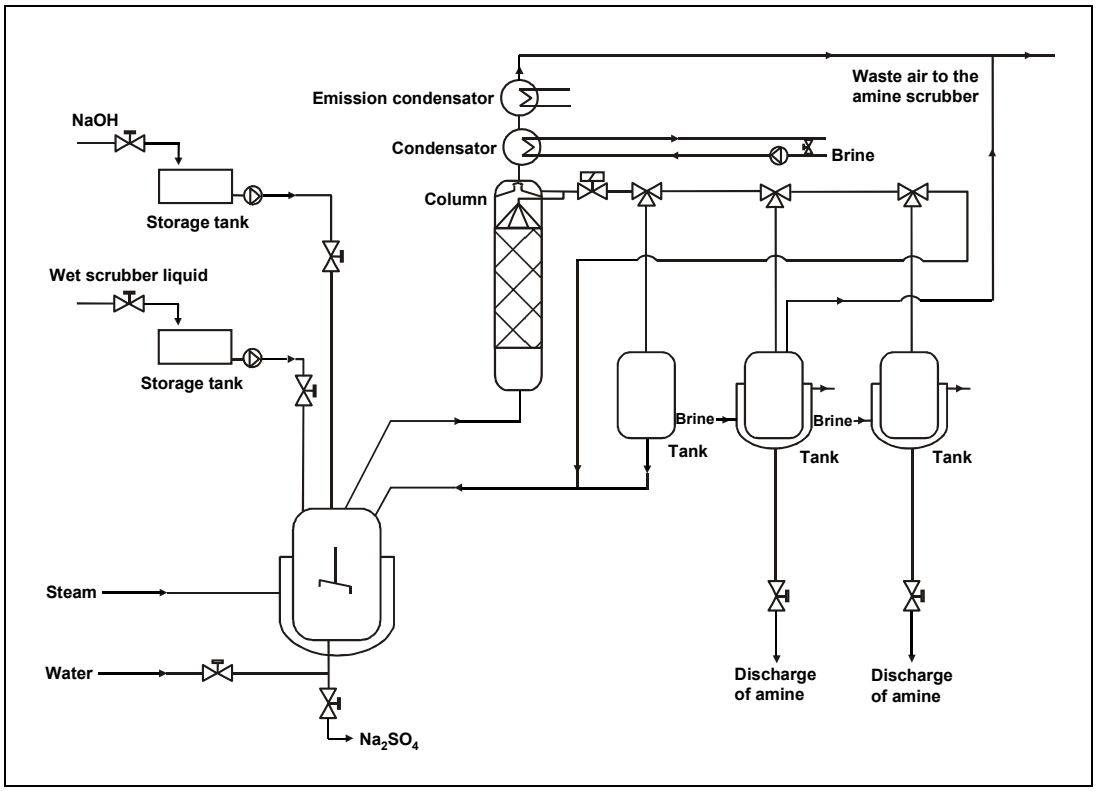


Figure 4.21: Amine recycling plant
[195, UBA, 2003]

Achieved environmental benefits
Recovery of a chemical compound, which may be re-used.

Cross-media effects
If the operation is performed in a centralised plant, it involves transport of the scrubber liquid to the treatment unit.

Applicability
This technique is applicable to all amine-containing scrubber liquors from core-making exhaust. The implementation is limited by economic factors (e.g. transport costs), since sufficient quantities of amine scrubber liquid need to be available. In general, the treatment is applied in a centralised location, treating the effluents of several foundries. Since the operation is subject to an explosion hazard, any necessary measures to prevent explosion risks should be taken.

Driving force for implementation
Recovery of chemical compounds. Disposal costs for industrial waste.

Example plants
- Centralised recycling plants Voerde (D)
- Centralised plant for group of automotive foundries: Poitou (F).

Reference literature
[195, UBA, 2003]

4.6.6 Reduction of glycols in die-casting waste water streams

Description
Hydraulic systems for die-casting use water-glycol mixtures, such as hydraulic liquid. Leaks in the hydraulic system and consequent transport of the leaked liquid into the water system could lead to the presence of glycols in the foundry waste water. Removal of the glycol is not possible using filtration or flotation techniques.

The applicable treatment techniques are:
- distillation or vacuum evaporation
- biological degradation.

The cleaned waste water may be re-used as a solvent for the release agent.

Achieved environmental benefits
Reduction of water pollution.

Cross-media effects
In the waste water treatment, a sludge cake is produced and needs disposal.

Operational data
In an example Belgian foundry, process water is treated in a vacuum evaporation unit (capacity 3 m^3/day). Three sources feed the unit: excess release agent (collected under the HPDC units), leakage hydraulic fluid from casting automates (water + glycol), and water from E-filter cleaning. The vacuum evaporation produces a sludge cake for disposal and an effluent. The effluent has a high COD and a low hardness (alkalinity). This makes it well suited for re-use as a solvent for the release agent.

Applicability
This technique applies to all new and existing die-casting foundries.

Driving force for implementation
Regulation for pollutant discharge into water.

Example plants
Metaalgieterij Giessen, Hoboken (B): aluminium foundry using HPDC and gravity die-casting.

Reference literature
[202, TWG, 2002]

4.7 Energy efficiency

4.7.1 Introduction

Metal melting and the holding of molten metal in the molten state generally take up a significant part of a foundry's energy consumption. In many foundries more energy is used in holding the metal in the molten state than in the actual melting process. Furthermore, considerable energy is expended in areas other than that of metal supply. For example, foundries are generally large users of compressed air. Other large users of energy are likely to be items such as high-pressure die-casting machines, whose mainly hydraulic power units are also driven by electricity. Sand and gravity die foundries may employ hot core-making processes, such as shell or hot-box, using gas or electricity to heat the boxes. The heating of dies and ladle and furnace linings can amount to an appreciable fraction of the total energy used. The typical relative distribution of energy use in two foundry types is given in Table 4.58.
[64, ETSU, 1997]

Activity	Non-ferrous foundry (%)	EAF steel foundry (10000 t/yr good casting) (%)
Melting	30	44
Holding	30	
Plant actuation	15	
Air compression	14	10
Tool heating	3	
Heat treatment (gas)		7
Others *	8	39
(*) Includes all activities for which no values are given in the same column and activities which are not mentioned		

Table 4.58: Typical energy use in a non-ferrous and EAF steel foundry [64, ETSU, 1997], [202, TWG, 2002]

These data show that foundry services (i.e. all but melting and holding) are responsible for up to half of foundry energy consumption. This includes activities using items such as motors and drives, compressed air, lighting, space heating and boiler plant. Energy efficiency measures should have regards to both the melting and the services field. [46, ETSU, 1995]

Energy efficient operation is brought about by applying good practice measures to reduce energy use in all of the mentioned steps. Improved energy efficiency is one of the main environmental benefits mentioned throughout the techniques discussions this chapter. The following sections focus on specific techniques aimed at heat recovery and heat transfer to other parts of the foundry.

4.7.2 Induction furnace: waste heat utilisation

Description

A significant proportion of the electrical energy which is supplied to an induction-melting furnace is converted into waste heat. About 20 to 30 % of the total energy input to the plant is dissipated through the cooling system. The furnace cooling circuit not only deals with the electrical losses in the induction coil, but also protects the coil from heat conducted through the furnace lining from the hot metal in the crucible. The heat in the furnace cooling system is used in some installations for space-heating, the heating of shower water and for drying raw materials.

- *Drying of raw materials:* Where metallic charge materials are added to a molten heel in an induction-melting furnace, the presence of water in the scrap can potentially be very dangerous. Although scrap may be stored under cover at the foundry, it is possible that it may be wet when delivered by the scrap dealer. The heat in the furnace cooling water can be extracted in an air/water heat-exchanger and a fan can be used to convey the warmed air to the bases of the stockyard bunkers. A diagrammatic layout of such an installation is shown in Figure 4.22.

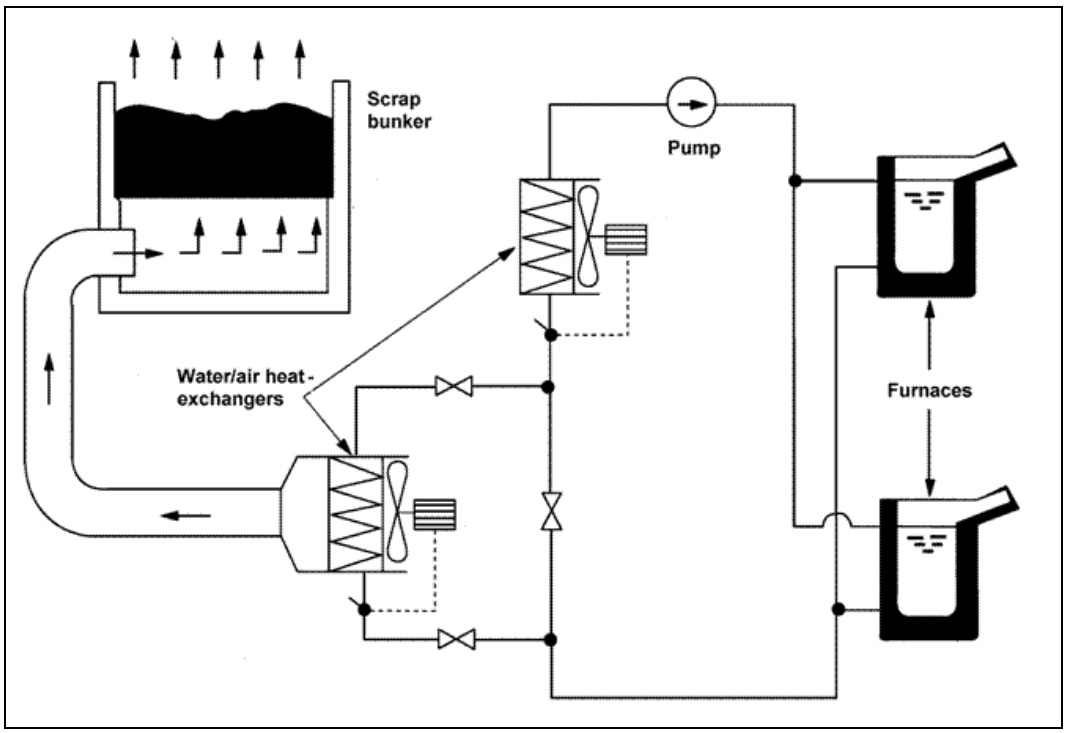


Figure 4.22: Use of waste heat for scrap drying
[47, ETSU, 1992]

- *Space heating and hot water supply:* A similar system to the one discussed above may be used to blow hot air into the foundry hall for space heating. Alternatively, a water-water heat-exchange is used to heat a water circuit for radiators or for hot water supply.

  Since the temperature of the cooling water in an unpressurised system is normally unlikely to exceed 60 – 70 ºC, radiators will need extra large surface areas are necessary in order to transfer heat efficiently. Alternatively, the temperature of the water can be boosted by some other heat source, such as supplementary gas or oil burners or an electrical heater. Some alternative heating system may be necessary to take over when the furnaces are not operating; for example, early in the morning, to raise the temperature of the work areas to a comfortable level.

  The normal furnace cooling facilities must be kept operating during the summer period and at other times when the space-heating facilities are not extracting an appropriate quantity of heat from the furnace cooling system. It is essential to ensure the integrity of the furnace cooling system. The whole installation must be designed to be fail-safe, to protect the integrity of the furnaces at all times. Also water returning to the furnaces must not be too cold (i.e. not below 30 ºC). Temperature operated alarms should be provided and emergency bypass pipework with easily accessible manual control valves, should be installed, to ensure that the heat recovery facilities can be isolated quickly from the primary cooling circuit in the event of any problems.

Achieved environmental benefits
Increased energy efficiency.

Cross-media effects
No cross-media effects have been reported.

Operational data
A heat recovery system using the cooling oil of induction furnaces was installed in a Belgian foundry. The foundry operates two induction holding furnaces in duplex with a cupola furnace.

The inductors of the electrical furnaces are cooled using thermal oil. The thermal oil gets heated up to 200 – 300 ºC and looses its heat over an outside oil-air heat-exchanger. Before installation of the heat recovery system, 1 MW of heat was dissipated into the air. An alternative system was installed to use the waste heat for space heating. The heated air is introduced into the core shop. This allows the recuperation of 1/3 of the dissipated heat and replaces the original gas-fired heating system. The implementation was possible at low cost because the oil-air heat-exchanger is installed next to the core shop. Space heating in other parts of the foundry may be considered later, but will require more piping (and will subsequent thus involve further losses).

Applicability
Before heat recovery can be applied, a number of criteria must be met:

- a worthwhile application for the waste heat must be reasonably nearby and the times at which this recovered heat can be utilised must match the times at which the furnace is operating. However, typically the heat available is fairly low grade. The temperature for the cooling water must not exceed 70 ºC
- the relatively low temperatures involved mean that heat-exchangers need to be much larger than those which are normally encountered
- the furnace water must not be returned to the furnaces at a temperature lower than about 30 ºC, otherwise this may give rise to condensation problems
- maintaining the integrity of the cooling circuits is absolutely essential. The cooling circuit is provided to protect the coil - if it fails in its task the results can be disastrous.

The above aspects, particularly the question of furnace integrity, discourage most furnace operators from even contemplating the utilisation of heat from the cooling circuit.

Economics
A foundry attempting to make use of the heat from the cooling circuit needs to fully evaluate the benefits and then compare them with the cost of the additional equipment and the safety of the furnace and operators.

Driving force for implementation
Increasing energy efficiency at the foundry.

Example plants
Space heating using hot air: Proferro, Oudenaarde (B).
Metso Paper Jyväskylä Foundry (F).

Reference literature
[47, ETSU, 1992]

4.7.3 Cupola furnace: waste heat utilisation

Description
The need to cool cupola off-gases before they enter the bag filter leads to the possibility of attaching to a secondary user and applying waste heat utilisation. The secondary user may be e.g.:
- a steam boiler
- a thermal oil circuit
- a heating circuit
- a hot water circuit.

Achieved environmental benefits
Recovery of waste heat, which otherwise would be lost to the outside, allowing a reduction in fuel (or other sources of energy) consumption.

Cross-media effects
No cross-media effects apply.

Operational data
The two example plants described in Section 4.5.2.2, are equipped with a waste heat utilisation system. Plant data have been given in Table 4.37.

Plant G uses cupola waste heat for electricity production. Part of the off-gas flow is fed to a steam boiler, which drives a turbine, coupled to a generator or compressor. A schematic representation of the installation is given in Figure 4.23. In total 29 % of the introduced cokes heat is converted into additional utilisation. Around 2.9 MW of electrical energy are generated. This means that the plant generates an electrical power of 75 kWh/tonne liquid iron.

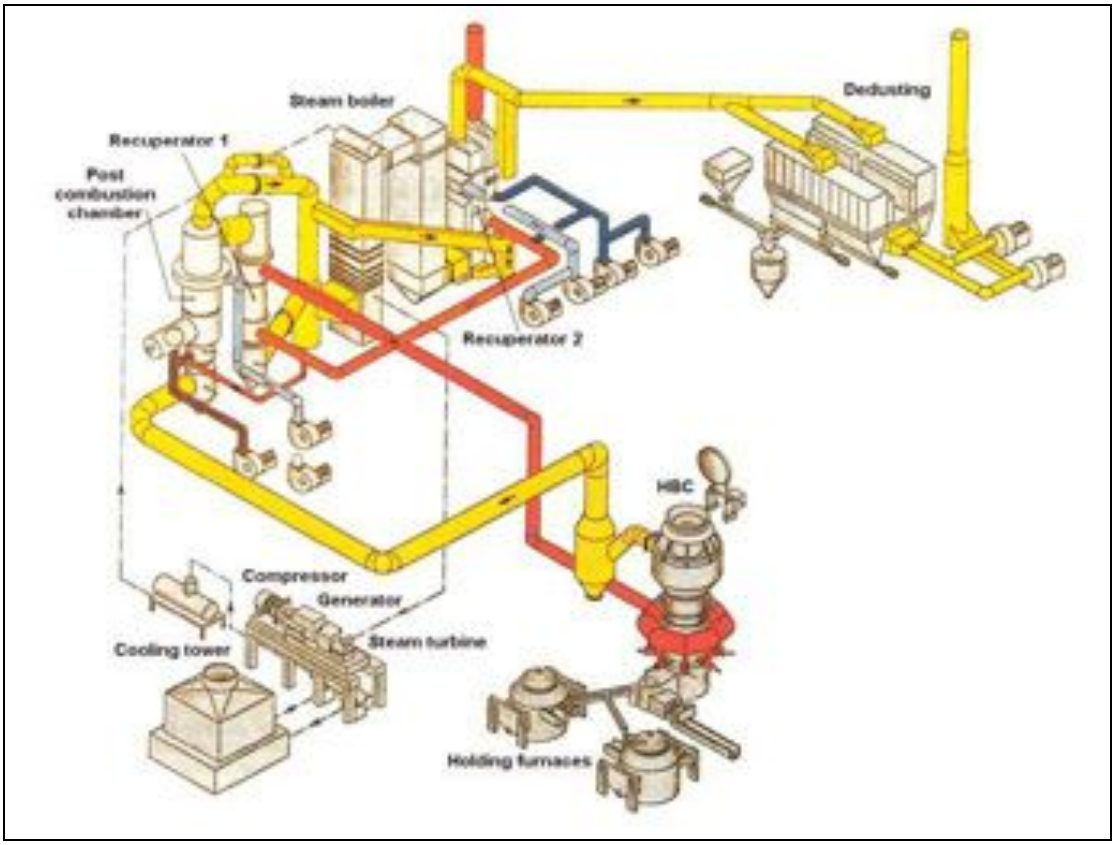


Figure 4.23: Schematic representation of a hot blast cupola with a steam boiler, turbine and generator
[27, Kran, et al., 1995]

Plant H uses cupola waste heat in a thermal oil circuit. After heat exchange for blast preheating, the off-gas passes a gasoil heat-exchanger. The heated oil is used for core drying. A maximum heat recovery of 21 MW can be attained. A process flow diagram is given in Figure 4.24.

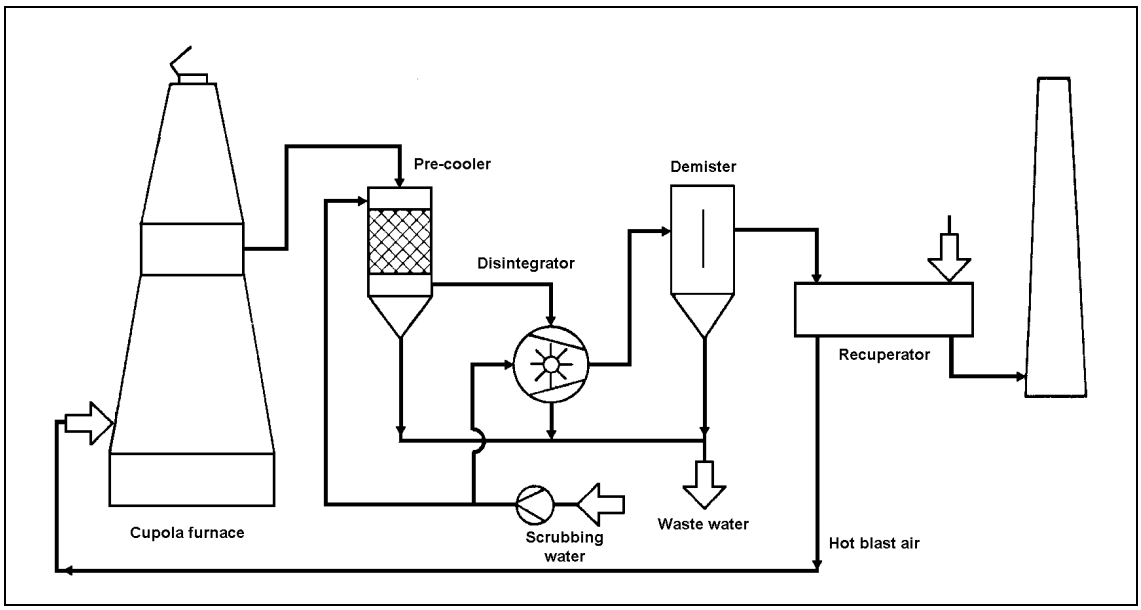


Figure 4.24: Process flow diagram of a hot blast cupola with heat recovery [17, Strauß, 1983]

Applicability
This technique applies to new installations and should be taken into account when designing the process. For existing plants, the technique can be applied during major refurbishment of the plant, however, small add-on units can generally be accomodated in existing plants.

Economics
The stated examples were installed as part of a major rebuilding of the considered installation. It is therefore not possible to extract specific cost data.

Driving force for implementation
Increasing energy efficiency of industrial processes.

Example plants
The two mentioned example plants are located in Germany.

Reference literature
[17, Strauß, 1983], [27, Kran, et al., 1995], [202, TWG, 2002]

4.7.4 Reduce energy loss/improve preheating practice of ladles

Description
Energy is wasted if the molten metal transfer system allows an excessive loss of metal temperature between furnace tapping and mould pouring. Losses can be prevented by using good practice measures. These imply the following:

- the utilisation of clean ladles, preheated to bright red heat
- the utilisation of distribution and pouring ladles, which are as large as is practicable and are fitted with heat-retaining covers
- keeping the covers on ladles which are standing empty or putting ladles upside down when not in use
- minimising the need to transfer metal from one ladle to another
- always conveying the metal as quickly as possible, while still complying with safety requirements.

Achieved environmental benefits
To reduce energy losses.

Cross-media effects
No cross-media effects occur.

Applicability
Since this technique involves measures related to good practice, it is applicable to all new and existing foundries.

Economics
No economic data can be given.

Driving force for implementation
Energy efficient foundry management.

Example plants
These measures are used to a varying extent in European foundries.

Reference literature
[44, ETSU, 1993]

4.8 Sand: regeneration, recycling, re-use and disposal

4.8.1 Introduction

Since foundries make intensive use of sand as an inert primary material, the regeneration of this sand is a major point of consideration as part of its environmental performance. A clear distinction must be made between green sand and chemically-bonded sand. Green sand can be easily reconditioned after use. Indeed, recirculated green sand shows a better technical quality than new sand. Most green sand foundries perform primary regeneration.

Primary regeneration, also known as attrition or particulation, involves breaking down the sand from moulds or cores back to its original grain size. This includes screening the sand, removing tramp metal, and separating and removing fines and over-sized agglomerates. The sand is then cooled before being sent for storage, returned to the sand system or blended with new sand. At this stage, the sand grains are likely to retain a partial coating of spent binder. This affects the amount of reclaimed sand that can be used to make moulds and, more particularly, cores. New sand therefore has to be added to ensure that the sand mix produces adequate mould and core strength and subsequenty aids good casting quality. Primary reclaimed sand is not generally of sufficient quality to be used for core-making, without further processing to remove residual binder materials, and is therefore used principally for moulds. The main primary regeneration techniques are vibration, rotating drum or shot blasting.

Secondary regeneration involves the further processing of the previously particulated sand to remove residual binder. The sand is returned to a quality similar to, or better than, that of new sand. Foundries using secondary regeneration have, in some cases, virtually eliminated the need for new sand. To remove residual binder, more aggressive techniques are needed than for primary regeneration. The main secondary regeneration techniques are:

- cold mechanical treatment:
  - low energy attrition: friction, impact (for cold-setting resins)
  - high energy attrition: pneumatic chafing, grinding, centrifugal friction
- thermal treatment (usually in a fluidised bed)
- wet scrubbing.

Sands bonded with cold-setting resins may be regenerated using simple treatment techniques, due to the fragility of the binder layer. Mechanical regeneration systems (e.g. fluidised bed systems) are based on interparticle friction or impact.

Sands bonded with gas-hardened and thermosetting resins need more intensive treatment to remove the binder layer. These include grinding, pneumatical chafing and centrifugal friction. Silicate sands can only be regenerated mechanically using pneumatical treatment.

Thermal treatment involves the burning of the organic binder. Bentonite is inactivated by the high treatment temperature. For sand flows containing green sand, any thermal treatment should therefore be combined with a mechanical treatment.

Wet regeneration involves binder removal through interparticle grinding. This technique applies only for green sand and silicate or CO_2-bonded sands and is not widely applied.

Secondary regeneration of green sand as a monosand flow finds limited implementation. For chemically-bonded sands, mechanical regeneration is most widely applied (>200 units in Germany in 1999) [80, ERM Lahmeyer International GmbH, 1999]. The applicability of the various regeneration techniques and of the regenerated sand are summarised in Table 4.59 (monosands) and Table 4.60 (mixed sand). Each of the presented techniques will be discussed in more detail in the sections below.

The most important **monosand** flows for secondary regeneration are the core sands in non-ferrous foundries. Due to the low thermal load they are easily separated from the green sand. Furthermore monosands are produced from mould and core-making with purely organic systems such as croning, furan resin and urethane cold-box. A smaller monosand stream is non-cured core sand, arising from broken or rejected cores in the core-making shop and the residual sand of core-making machines.

Mixed sands generally contain bentonite-bonded sand as well as chemically-bonded sand. They are mainly generated in iron foundries and represent some 75 % of the total waste sand production.

Type of sand	Regeneration technique	Regeneration equipment	Utilisation	Borderline conditions	Minimal quantity (tonne/h)
Organic monosystems					
Cold-setting resins	Mechanical or thermal	Mechanical: friction, impact, pneumatic chafing Thermal: turbulent bed, fluidised bed or rotary furnace	- for mould-making using cold-setting resins - 20 – 25 % substitution of new sand for cold-setting core-making	- mechanical: only if binder shells have become fragile enough upon pouring - the target values for regenerate quality must be met	1.5
Cold-Box, SO_2, Hot-Box and Croning sand	Mechanical or thermal	Mechanical: pneumatic chafing, centrifugal friction, fluidised bed chafing Thermal: turbulent bed, fluidised bed or rotary furnace	In core-making, as new sand substitute	- mechanical: only if binder shells have become fragile enough upon pouring - the orientative values for regenerate quality must be met - re-use of fines	0.75
Resol- ester methyl formate hardened sand	Mechanical	Mechanical: friction, impact, pneumatic chafing	With limitations, in mould-making with methyl formate sands	- regeneration as resol-ester cold setting but with lower yield - embrittlement of binder components	
Inorganic monosystems					
Green sand	Mechanical	pneumatic chafing, grinding	Renewal sand for green sand circuit	- requires predrying - re-use of fines	0.75
Sodium silicate sand	Mechanical		Only for making moulds and cores using sodium silicate sand	Embrittlement of binder components at 200 ºC	0.5

Table 4.59: Fields of application of different regeneration systems for monosands [128, IHOBE, 1998], [225, TWG, 2003]

Type of sand	Regeneration technique	Regeneration equipment	Utilisation	Borderline conditions	Minimal quantity (tonne/h)
Mixed organic systems	Mechanical or thermal	Mechanical: pneumatic chafing, centrifugal friction, fluidised bed chafing Thermal: turbulent bed, fluidised bed or rotary furnace	- core-making substituting new sand	- mechanical: only if binder shells have become fragile enough upon pouring - the orientative values for regenerate quality must be met - re-use of fines	0.75
Mixed sands containing bentonite	Mechanical or mechanical-thermal-mechanical	Mechanical: grinding, pneumatic chafing, fluidised bed chafing Thermal: turbulent bed, fluidised bed or rotary furnace	- core-making substituting new sand - renewal sand for the green sand circuit	- require pre-drying - combined thermal regeneration requires efficient mechanical regeneration to remove active bentonite - re-use of fines	0.75

Table 4.60: Fields of application of different regeneration systems for mixed sands [128, IHOBE, 1998]

The applicability of the various treatment systems is summarised in Table 4.61 and will be discussed further in the specific applicability sections.

	Simple mechanical systems	Cold mechanical			Wet regeneration	Thermal	Mechanical – thermal – mechanical
		Grinding	Impact drum	Pneumatic chafing			
Monosands							
Cold setting	x	x	x	x	x	x	0
Cold-box, SO_2, Hot-box, Croning	0	x	x	x	0	x	0
Silicate (CO_2 or ester)	0	0	0	x	x	0	0
Green sand (primary)	x	0	0	0	0	0	0
Green sand (secondary)	0	x	0	x	x	0	0
Mixed sands							
Mixed organic	0	x	x	x	0	x	0
Mixed green + organic	0	x	0	x	x	0	x
x: Applicable; 0: Not applicable							

Table 4.61: Applicability of various sand regeneration techniques to various sand types

The application of both primary and secondary regeneration in a mixed sand foundry in order to achieve a total regeneration of 92 % is shown in Figure 4.25. This simplified scheme does not take into account the various losses in the processing steps. The addition of new sand can be reduced to a minimum by integrating (the coarse fraction of) the filter dust sands (from the exhaust of hand forming lines, de-coring lines, storage silos, etc).

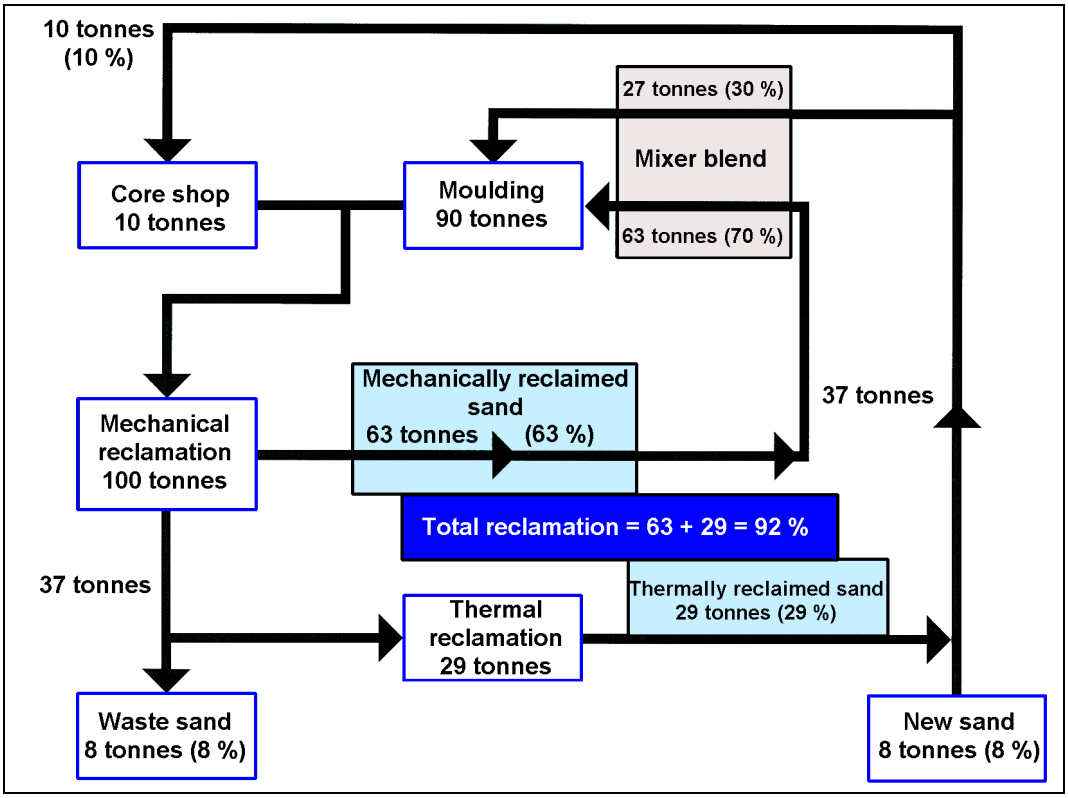


Figure 4.25: Sand balance diagram for a thermal/mechanical regeneration system [70, ETSU, 1998]

An overall reclamation ratio of 92 %, as given above, is a normal value for mixed green sand – chemically bonded sand systems. Regeneration ratios of up to 98 % have been reported. The actual ratio depends on the volume and chemical composition of the used cores. For furan cold setting monosands, values around 78 % are reported.

Generally the mixing of different types of sands has a negative effect on the strength of the cores and subsequently the moulds made with the regenerated sand, although there are a few exceptions to this general principle. In order to produce a good quality regenerated sand it is therefore of great importance to keep non-compatible sand types separate. Optimisation of the regeneration potential may therefore imply changing to compatible binder systems, if mixed sands are used, or the application of (shake-out) techniques that allow the separation of various sand types. Table 4.62 provides a cross-compatibility table.

Source system \ Goal system		Bentonite	Silicate	Cold-setting	Hot-box	Croning	Cold-box		
							Methyl-formate	Amine	SO_2
Bentonite		+	0	0	-	0	0	0	0
Silicate		0	+	-	-	-	-	-	-
Cold-setting		+	-	+	-	0	-	0	+
Hot-box		0	-	+	+	+	-	0	+
Croning		+	+	+	+	+	+	+	+
Cold-box	Methyl-formate	0	+	0/-	-	-	0	0	-
	Amine	+	+	+	+	+	0	+	+
	SO_2	+	-	+	-	0	0	+	+
+: Compatible, 0: Limited compatibility, -: Incompatible									

Table 4.62: Compatibility of regenerated sources sands with various binders [37, Winterhalter, et al., 1992], [225, TWG, 2003]

[37, Winterhalter, et al., 1992], [70, ETSU, 1998], [128, IHOBE, 1998], [138, Metaalgieterij Giesen B.V., 1996], [153, Umweltbundesamt, 2002], [202, TWG, 2002], [225, TWG, 2003]

4.8.2 Regeneration of green sand under optimised conditions (primary regeneration)

Description

One of the major advantages in using green sand moulding is that the sand from the moulds can be reconditioned after pouring for multiple re-use. The addition of a minimum percentage of new sand is performed in order to maintain the quality of the moulding-sand. The amount of new sand added is determined by the input of core sand and the losses in the process. For coreless moulding, the average sand renewal ratio is 2 – 5 %. In casting processes using cores, sand renewal occurs through the introduction of the core sand into the loop. In any case, surplus sand is removed from the sand circuit after the shake-out screen or from the storage silos. The general treatment is depicted in Figure 2.28. This internal recirculation of green sand with minimal treatment is referred to as primary regeneration. This regeneration basically has three aims: (1) to break the sand into its original grain size or small particles, (2) to remove the fines, and (3) to cool the sand before blending with new sand.

Various techniques are applied for the breaking and separation:

- *Vibration*: The vibratory grid, or screen equipment, is the most widely used technique for primary reclamation purposes. The sieved sand is removed for subsequent treatment, e.g. for cooling, size classification, and thermal reclamation, and the residual material is collected for disposal

- *Drum*: Sand from the knock-out operation is loaded into a rotating drum fitted with both lifting and travelling bars. As the sand travels along the drum, the rotating and lifting action causes the sand particles to grind against each other and break down to individual grains. The sand grains fall through screens at the end of the drum, while oversize and tramp materials are removed for landfill disposal
- *Shot blast*: The mould and casting is loaded directly into the shot blast machine. The action of the shot blast results in the complete disintegration of the mould and also cleans the surface of the casting. The sand and shot are subsequently separated. However, this technique is not very common.

During cooling of the castings, the sand gets heated-up. In order to reach good sand mixing conditions, the sand needs to be cooled down to 40 – 45 ºC. Evaporative coolers are used with turbulent and fluidised beds, as well as heat-exchangers. If shake-out is done using the vibrating transporters of revolving drums, the cooling can occur at the same time.

If a fluidised bed cooler is used, the drying air may be heated using gas or electricity. The average treatment time in the bed is 10 minutes. In general, the sand enters the fluidised bed with a humidity of 2 – 3 % and a temperature of 250 – 300 ºC. Temperature and humidity control may be performed before the fluidised bed cooler with a subsequent addition of controlled amounts of water. This allows minimisation of the amount of fines that are removed during the fluidised bed drying. The fines contain bentonite that may be re-activated. The level of humidity of the return sand needs to be kept between 2 and 2.2 % at 35 ºC. Consequently, during storage, the bentonite contained in the cooled and wet sand starts to activate and, during the mixing, the water and bentonite that need to be added are reduced, as is the cycle time.

A good homogenisation of the sand allows a constant sand quality and better and easier sand preparation. Homogenisation systems consist of the use of a few small silos instead of one big one, or in the re-circulation of the sand in the silo.

In systems using chemically-bonded cores, the mixing of the core sand may have a negative effect on the sand quality, depending on the binder type and the amount of core sand mixed. The negative effects are more significant with acidic and alkaline cores, than compared to neutral systems (SO_2-epoxy, PUR-cold-box). During shake-out, core sand and moulding sand will inevitably get mixed. Uncured cores and non-broken cores, however, may be left out or taken out of the sand before feeding back to the primary regeneration.

Achieved environmental benefits
Reduced usage of primary materials (sand and bentonite), reduced amount of material for disposal.

Cross-media effects
Sand regeneration uses electricity, therefore it increases the overall electric energy consumption of the installation. Since mechanical techniques are mainly applied, this increase is low.
Sand cooling and the separation of fines leads to dust-laden exhaust gas. The exhaust needs to be filtered to prevent dust emissions. The collected dust is sent to disposal or re-used (see Section 4.8.12).

Operational data
While the level of new sand addition is governed by a number of factors, the usual range is 10 - 20 % of the poured metal weight. However, it is more convenient to consider new sand additions as a percentage of sand throughput. For most foundry processes, a 5 % addition is considered sufficient, but many foundries work at lower rates.

For a green sand monosystem, regeneration ratios of 98 % may be achieved. Systems with a high degree of incompatible cores, may achieve a regeneration ratio of 90 – 94 %.

Applicability
This technique is applicable to all green sand foundries, in new and existing installations.

Economics
The potential cost benefit of reclamation for a foundry that does not currently reclaim its sand is summarised in Table 4.63.

Description	Cost (EUR/tonne of sand)
Average price of silica sand	32.64
Average cost of waste sand disposal	14.56
Total cost of sand purchase and disposal	**47.2**
Estimated depreciation cost to recoup equipment expenditure in one year	18.24
Average operating cost	7.76
Anticipated cost saving in first year	**21.2**
Anticipated cost saving in subsequent years	**39.44**

Table 4.63: Cost benefits from primary reclamation (UK estimation 1995)

The investment for a mixer, dosing unit and process control unit is in the range of EUR 0.05 - 1 million. The investment for the size reduction of core-breaks is EUR 0.1 million, although this is only applied if the size reduction cannot be done in an available mechanical or pneumatic regeneration unit. Operational costs (on a yearly basis) can be estimated at 5 – 10 % of the investment cost.

Driving force for implementation
Many foundry operators state the reduction in costs as the sole reason for starting various sand reclamation programmes. Regulations encourage a reduction in the amount of dumped material, through an increase in disposal costs.

Example plants
Primary reclamation is used by virtually all green sand foundries, though the degree of sophistication of the reclamation plant varies widely; from a simple manual operation to one fully automated with computer-controlled equipment.

Reference literature
[72, ETSU, 1995], [73, ETSU, 1995], [108, FEAF, 1999], [110, Vito, 2001], [128, IHOBE, 1998], [140, EU Thematic Network Foundry Wastes, 2001], [143, Inasmet and CTIF, 2002]

4.8.3 Simple mechanical regeneration of cold-setting sand

Description
Simple mechanical techniques are used for the regeneration of cold setting monosands (e.g. furan sand) and uncured core sand. These techniques include the breaking of lumps, segregation of the sand grains and cleaning by intergranular friction, with consequent dedusting and cooling down to operational temperature. Various types of crushers and mills are used, e.g. impact crusher, jaw crusher, ball mill.

Achieved environmental benefits
A reduction of the amount of sand for disposal and of the consumption of new primary sand.

Cross-media effects
The regeneration of sand requires additional energy and causes additional dust emissions and residual dust for disposal.

Operational data
For furan cold setting monosands regeneration ratios around 78 % are reported.

Applicability
The technique can be used for all cold-setting sand, excluding silicate sand. The regenerated sand can be re-used in the same moulding cycle, with small additions of new sand to level-off quality losses.

The technique can be used for uncured coresand with organic binders. The regenerated sand may be re-used for core-making using the same binder type, after mixing with new sand. It may also be used, within certain limits, for the renewal of moulding-sand.

Driving force for implementation
Legislation using high disposal fees to reduce the amount of residues for disposal.

Example plants
Simple mechanical regeneration of furan sand is applied in many foundries around Europe, and is specifically widespread in Germany and Finland.

Reference literature
[153, Umweltbundesamt, 2002], [202, TWG, 2002]

4.8.4 Cold mechanical regeneration using a grinding wheel unit

Description
This is a widely applied commercial grinding system (see Figure 4.26). The system was originally developed to regenerate mixed bentonite-organic sands. In this system, a horizontally rotating grinding wheel is used to remove the hard oolitic bentonite layer from the sand. The grinding can also remove chemical binders from sand grains. Around the grinding wheel is a slowly rotating paddle wheel, which continuously moves the sand onto the grinding wheel. Above this, a dedusting unit extracts the dusts and the fines. To be fit for processing, the sand must be dry. A pre-drying step, using a fluid bed or other dryer, is required to bring the moisture content down to below 0.2 %.

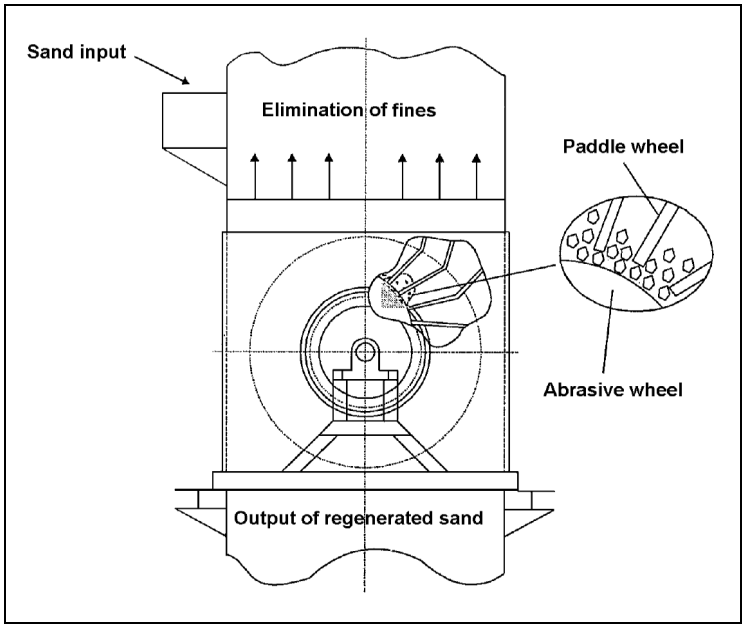


Figure 4.26: Cold mechanical regeneration using grinding
[128, IHOBE, 1998]

The off-gas stream of the regenerator is dedusted using a cyclone and a bag filter. The filter dust contains residual active bentonite and coal dust. It may be recirculated into the core-making, thereby allowing a reduction in the use of lustrous carbon. Furthermore, the moulds demonstrate better technical quality (wet tensile strength, flowability), due to the remaining bentonite content, which furthermore leads to a reduction in the amount of scrap moulds and a reduction in finning on the castings.

Achieved environmental benefits
A reduction of the amount of sand for disposal and of the consumption of new primary sand.
A reduction in the consumption of lustrous carbon, in the case of green sand.
An increase in moulding sand properties, resulting in a reduction in the number of scrap moulds and in the number of rejects in finished castings.

Cross-media effects
The regeneration of sand requires additional energy and causes additional dust emissions and residual dust for disposal. However, the use of regenerated sand in the moulding process allows a reduction in the amounts of lustrous carbon used.

Operational data
For clay-bonded sand, the maximum regeneration rate is 65 - 75 %. This corresponds to the quartz grain content of the material. For a chemically-bonded sand, the amount of recyclable quartz sand is 90 – 95 %.

The total sand circuit flow and the need for new sand depends on the amount of cores (and core sand) used. Therefore, data on the sand circuit are very process-specific. Figure 4.27 gives data for a plant in the Netherlands.

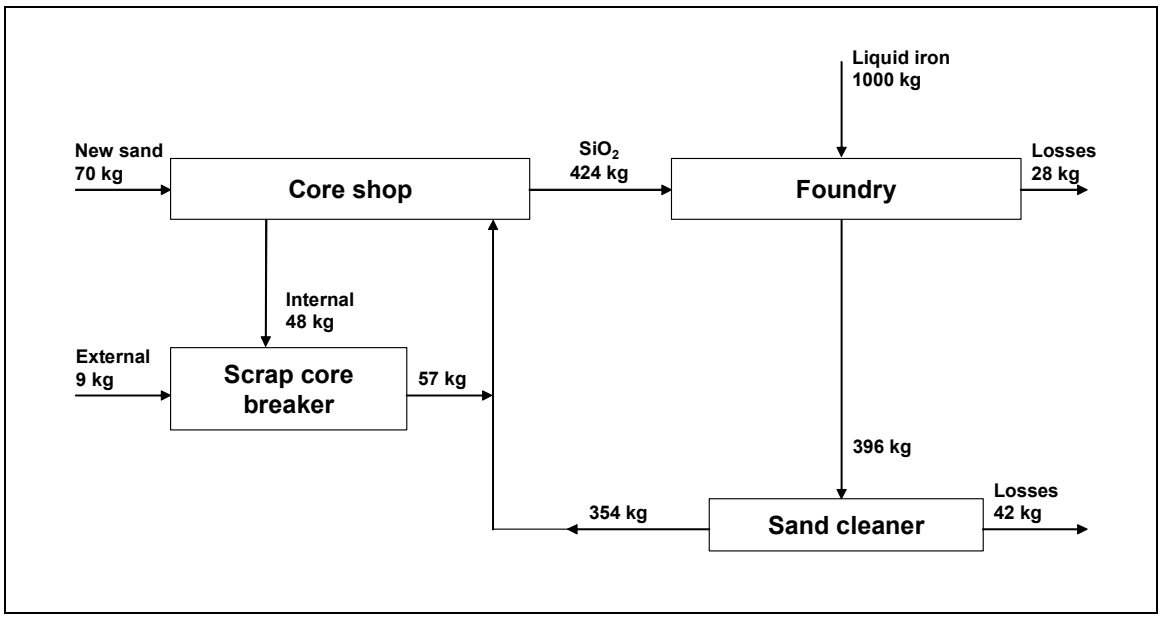


Figure 4.27: Operational data on the sand circuit of a Dutch green sand foundry [140, EU Thematic Network Foundry Wastes, 2001]

In general, waste green sand consists of about 80 % quartz sand grains and about 20 % fines (bentonite, coal dust, etc,). Out of 100 % waste sand, about 70 % is transferred back to the core-making as reclaimed sand. The degree of efficiency with regard to quartz is about 88 %.

The filter dust contains approximately 40 % active bentonite, which has a loss of ignition (LOI) of 17 % and contains 43 % fines. Re-use of the dust in the sand plant results in a reduced requirement for lustrous carbon by up to 30 %. Results of the improved sand quality at the example foundry show the amount of scrap moulds were practically halved.

The cyclone dust (20 % of regenerated green sand weight) contains 25 – 30 % bentonite and high levels of organics, but its chemical composition falls outside the required specification to allow its re-use as a secondary construction material. In the Netherlands, a specific application in cover layers on disposal sites is allowed. In other regions, this fraction will need disposal of. However, legislation limiting the organic content of material for disposal, may limit the disposal options.

The grinding of the sand causes accelerated wearing of the sand grains. This and the recirculation of the filter dust cause shifts in the grain size distribution of the sand. The overall sand composition therefore needs good control and follow-up.

Applicability
Cold mechanical regeneration is mainly applied for removing bentonite layers from green sand and for removing chemical binders in no-bake systems. The grinding technique is the most widely applied cold mechanical treatment. Vibration- and impact systems are also used for chemically-bonded sands but produce sand of only low or average quality. These techniques are more appropriate for the conventional sand loop (primary regeneration). The secondary regeneration of green sand has limited implementation.

Economics
The investment cost for a 50 tonne/day unit, including drying, cooling, regeneration unit, cyclone and bag filter is around EUR 1135000. Data from Germany, state an investment cost of EUR 600000 for a 1.5 tonne/h unit.

The consumption levels are as follows (based on yearly average figures):

Electricity:	39	kWh/tonne
Natural gas:	3	Nm^3/tonne (depending on the moist input of the sand)
Compressed air:	36	Nm^3/tonne
Wear parts:	1.18	EUR/tonne
Manning level:	0 %	
Maintenance:	routine.	

Cost curves for the mechanical regeneration of organic bounded sand are given in Figure 4.28. Fixed costs vary according to the total capacity and investment. Variable costs can be up to around EUR 11/tonne, although the actual costs depend on the specific installation and local conditions. The total costs (fixed plus variables) range from EUR 12 - 40/tonne of regenerated sand, depending on the size and type of equipment.

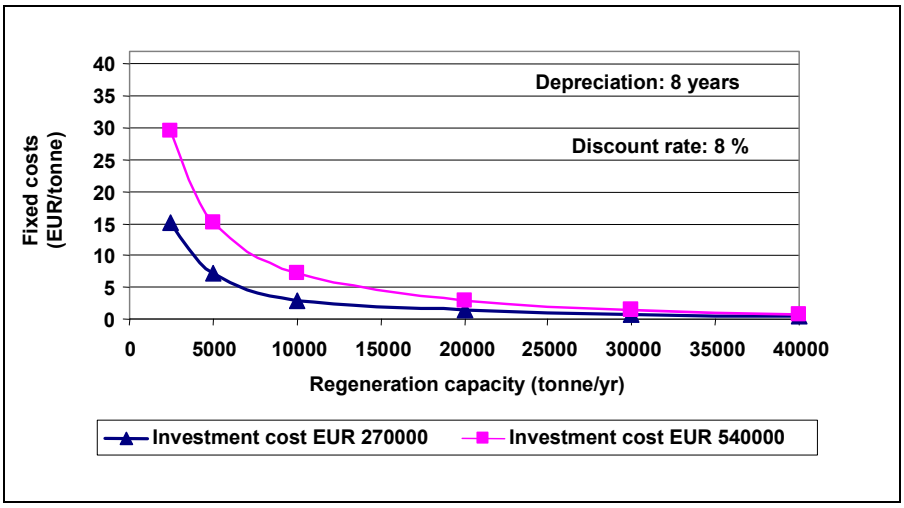


Figure 4.28: Fixed costs in euros per tonne of regenerated sand, for the mechanical regeneration of sand with cold-setting binders
[82, IfG - Institut für Gießereitechnik, 1996]

Driving force for implementation
Legislation using high disposal fees to reduce the amount of residues for disposal.

Example plants
- De Globe, Weert, the Netherlands, 60 tonnes per day plant using two lines, in operation since 1995
- Eisenwerk Brühl, Brühl; D (1.5 tonne/h), 1999
- Giesserei Fritz Winter GmbH & Co KG, Stadtallendorf, D (9.5 tonne/h)
- Mercedez-Benz AG, Mannheim, D (9 tonne/h).

Reference literature
[82, IfG - Institut für Gießereitechnik, 1996], [110, Vito, 2001], [128, IHOBE, 1998], [133, De Globe B.V., 1999], [140, EU Thematic Network Foundry Wastes, 2001], [151, Gemco, 1999]

4.8.5 Cold mechanical regeneration using an impact drum

Description
This mechanical regeneration technique is based on intergranular grinding of the sand and gives the best results for chemically bonded monosand. The sand is fed into a drum with a spinning internal axis, equipped with small blades. Sand grains are impacted against the drum wall and against each other. This impact produces a mechanical abrasive cleaning action. Fines are removed with the exhaust gas. The impact drum operates in a batch wise regime. The installation of two units allows continuous operation.

When applied on a mixed bentonite-organic sand, the regeneration is preceded by a magnetic separator, to remove green sand. Due to the presence of unreacted bentonite, the green sand shows a very weak magnetism, which allows a magnetic separation to be carried out. The regeneration system allows the introduction of a limited amount (15 %) of uncured core sand (core breaks from production). The combination of magnetic separation and impact drum cleaning allows an optimised chemically bonded sand regeneration from a mixed sand flow, with re-use of the regenerated sand in core-making.

Achieved environmental benefits
Internal re-use of core sand, therefore limiting the amount of material for disposal and the need for raw materials.

Cross-media effects
The regeneration of sand requires additional energy, and causes additional dust emissions and residual dust for disposal.

Operational data
The regeneration drum has a batch wise regime, with a 20 minute treatment time for each 1.5 tonne sand charge. The energy consumption of the full installation (including magnetic separation, exhaust treatment, sand transport) is 55 kWh/tonne of treated sand, of which 35 % may be attributed to sand transport and feeding. The installation uses compressed air at 48 Nm^3/tonne sand.

The regenerated sand is of the following quality:
- average grain size: 0.30 – 0.33 mm
- share of fines: 0.4 – 1 %
- pH: 8.7
- loss on ignition: 0.25 – 0.5 %.

Cores made with 100 % regenerated sand have acceptable properties. In practice, 10 – 70 % of regenerated sand is used for new cores, the actual amount depending on the core type.

Dust generation in the installation is 10 % of the regenerator input. This dust is collected using a cyclone (90 %) and a bag filter (10 %).

Applicability
The combined separation-regeneration technique can be applied for the treatment of mixed green sand and chemically bonded sand. Regeneration is performed on the chemically-bonded sand flow and may include uncured core sand. The technique may be applied in new and existing installations.

Economics
Investment costs for a 3 tonne/h unit with 1 impact drum, magnetic separation, exhaust gas dedusting and transport and a feeding system are EUR 1.3 million. Operational costs for this unit are EUR 10/tonne. These include energy consumption, wear and tear of parts, maintenance and disposal of residues. This represents a net benefit of EUR 37/tonne, compared to the costs of new sand purchase and used sand disposal (both incl. transport).

For a 380 tonne/day unit in France, an operational cost of EUR 15/tonne was quoted. For this plant this represents a net benefit of EUR 18/tonne, compared to the costs of new sand purchase and used sand disposal (both incl. transport).

Driving force for implementation
Legislation using high disposal fees to reduce the amount of residues for disposal.

Example plants
This technique is used in the following plants:
- PSA, Sept-Fons (F): 6 magnetic separators and 2 grinders, working alternatively
- GF, Leipzig (D): 2 magnetic separators and 1 grinder
- Döktas – Turkey: 5 magnetic separators and 2 grinders.

Reference literature
[185, Spitz, 2002], [122, Kirst, 1999], [153, Umweltbundesamt, 2002]

4.8.6 Cold regeneration using a pneumatic system

Description
In a pneumatic system, binders are removed from the sand grains using abrasion and impact. The kinetic energy is provided by a compressed air stream. This results in a simultaneous dedusting. The advantage of this type of system is that the direction and velocity of the sand can be controlled. Due to the low energetic efficiency of air compression, the energy consumption is higher compared to the purely mechanical treatment. The principle of the reactor is depicted in Figure 4.29.

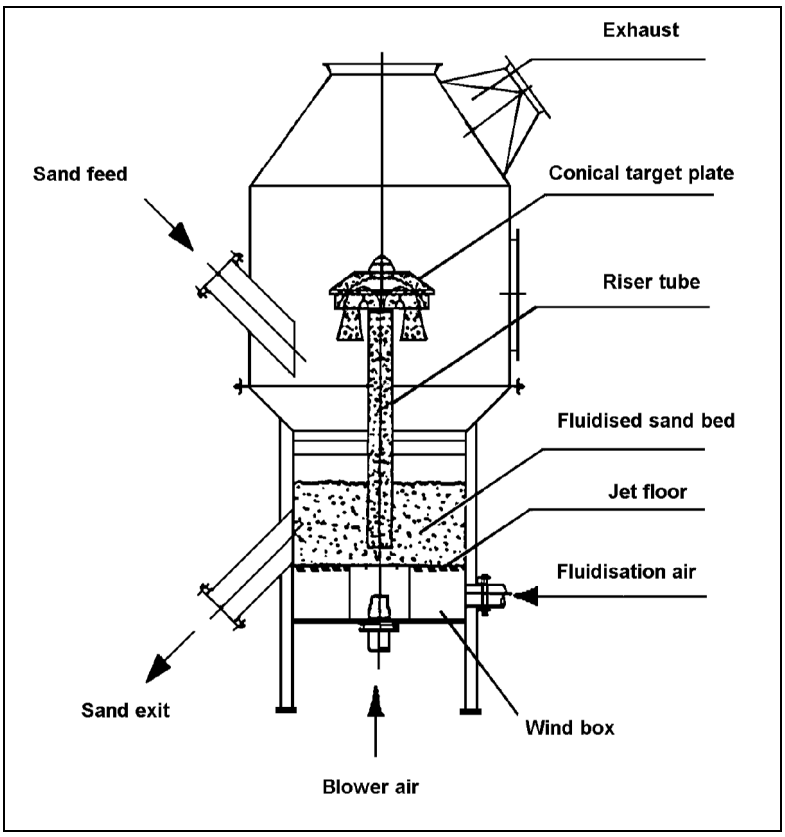


Figure 4.29: Cold mechanical regeneration using a pneumatic system [122, Kirst, 1999]

The reactor uses a fluidised bed with a central raiser tube. The sand is blown into the tube using compressed air and impacts on either a rubber deflector plate or a conical target plate. From there, the sand falls down again and the cycle starts over again. The cleaning happens through intergranular abrasion, abrasion against the impact plate and through 'pure' impact. The shape of the plate determines the main cleaning mechanism: impact (bell-shape) or abrasion (conus). The generated dust is removed with the airflow over a bag filter. Treatment is performed as a batch system or through a series of coupled pneumatic units. In this case, the cleaned sand is sucked out of the reactor through a deflector below the impact plate.

Achieved environmental benefits
Reduction of the amount of sand for disposal and of the consumption of new primary sand.

Cross-media effects
The regeneration of sand requires additional energy and causes additional dust emissions and residual dust for disposal.
The general evaluation of internal regeneration versus external re-use and the corresponding cross-media effects are discussed separately below.

Operational data
A waste sand mix of green sand with chemically-bound core sand having the following characteristics: 8 – 12 % fines content, 3 – 5 % LOI, <2 % humidity; produces a regenerate with the following characteristics:

- regenerate yield, based on SiO_2 content of waste sand: 70 – 80 %
- ultra fines content (<0.063 mm): max. 2 %
- fines content: <2 %
- loss on ignition: <0.5 %
- average grain size: unaltered.

The technique uses a modular installation build-up, using 0.8 – 1.2 t/h basic units. The supplier mentions an electric energy consumption of 15 – 20 kWh/t (excluding dedusting equipment). German operational data give an electric energy consumption of 41 kWh/t for a 8 t/h unit and 62 kWh/t for a 0.75 t/h unit. Reported sand regeneration efficiencies based on sand input range from 65 % to 85 %. Spanish data give a total energy consumption of 120 kWh/t of regenerated sand for a 1.2 t/h unit.

Applicability
The pneumatic system can be used for the regeneration of organic mixed and monosands and mixed sand containing bentonite. It also finds application as a pre- or post-treatment in combined mechanical-thermal-mechanical treatment Here, the main use is the removal of residual dust from the sand grains and cooling. The regenerated sand from simple mechanical regeneration may be used in mould making (using 100 % regenerated sand) or mixed with new sand in core-making (using 40 - 60 % regenerated sand).

Furthermore, the technique may be applied for the regeneration of core sand of the CO_2-water glass type from aluminium foundries. This is discussed separately below.

Economics
Investment costs for a single 0.8 – 1.2 tonne/h unit are EUR 330000. Operational costs are estimated at EUR 22/tonne, which gives a total regeneration cost of EUR 36.5/tonne of sand.

Driving force for implementation
Legislation using high disposal fees to reduce the amount of residues for disposal.

Example plants
This type of equipment is built by various suppliers: e.g. KGT Jet Reclaimer, Künkel-Wagner GmbH Turbo Dry, Kernfest Webac AB. The technique is used in several plants in Western Europe and China.

Reference literature
[32, CAEF, 1997], [82, IfG - Institut für Gießereitechnik, 1996], [108, FEAF, 1999], [110, Vito, 2001], [122, Kirst, 1999], [128, IHOBE, 1998]

4.8.7 Thermal regeneration

Description
Thermal regeneration uses heat to combust binders and contaminants. All thermal processes need an initial mechanical step in order to bring the sand to the correct grain size and to screen out any metallic contaminants. This pretreatment may also involve a (partial) abrasion of bentonite and dust removal. The heating of the sand is usually achieved by means of a fluidised bed furnace, operating at temperatures mostly between 700 to 800 ºC. Rotary kilns or multiple-hearth furnaces are also used. Heat may be provided by gas combustion, electric heaters or by short wave infra-red emitters. The throughput of these systems ranges from 250 kg/h to more than 5 t/h.

The emerging gases are combusted in order to eliminate carbon monoxide and any VOCs that may be present. This may be done in the freeboard of the furnace, if it is large enough, by adding complementary air or by gas-fired afterburners. If the temperature of the combustion gases is not high enough or if the time during which the gases are at a high temperature is not sufficient, a separate afterburning device is added. In all cases, emissions can be considered as insignificant.

The exhaust gases are filtered, mostly by means of fabric filters. Therefore cooling is needed, which may be done using water injection, heat exchange/recovery or by mixing with air naturally entering through openings/slits etc. The cooling may incorporate a preheating of the fluidisation air.

Achieved environmental benefits
Reduction of the amount of sand for disposal and a reduction in the consumption of new primary sand.

Cross-media effects
Thermal regeneration requires fuel and generates emissions of dust and combustion related compounds (NO_x, CO; and in the case of oil:SO_2).
The high energy consumption and complexity of the installation are balanced by a low wearing of the sand grains and the recovery of the dust in a thermally inert form.

Thermal regeneration of furan bonded sand with paratoluenesulphonic acid as a hardener, requires flue-gas cleaning: i.e. a, post-combustion of CO and the adsorption of SO_2.

Operational data
The sand is usually heated to temperatures of 700 – 850 ºC. Theoretically, this requires 200 kWh/t. In practice, energy uses of 150 – 350 kWh/t are reported, depending on the energy recuperation and the calorific value of the sand.

Operational data from 3 thermal regeneration plants, treating various types of sand and of various capacities are given in Table 4.64.

Property	Units	Plant		
Reference plants		**Foundry K**	**Foundry L**	**Foundry M**
Type of sand		Cold-box core units	Green sand moulding, Cold-box cores	Handforming in furan bonded sand
Regeneration unit supplier		CEC/VAW	Richards	Siempelkamp
Technique		Multiple hearth furnace (500 ºC) with sieving and classification	Fluidised bed furnace (780 ºC), mechanical size reduction and dedusting	Fluidising combustion chamber with magnetic pre-separation, simultaneous processing of sand and dust from mechanical furan sand regeneration
Sand throughput	t/h	12 – 16	1.0	2.0 used sand, 0.5 dust
Capacity	t/yr	28600	3840	5000
Regeneration ratio, based on used sand throughput	%	95	95 (99 (1))	95
Application of regenerated sand		Core-making	Core-making	Mould and core-making
Quality criteria for regenerated sand		Dust <1 % AFS 60 – 70 LOI <0.1 %	Identical to new sand F33	LOI <0.5 % pH 6.0 – 6.5 Mould strength upon addition of 1 % binder and 0.3 % harder: 350 N/cm² after 24 h
Consumption of electrical energy	kWh/t	119	65	
Consumption of natural gas	m³/t	24.5	38	
Residue production	t/year	660	Dust: 10 Bentonite sand: 1700	200
Final destination of residues		Mining cavities	Cement production	Construction industry/disposal site
Waste gas flow	Nm³/h	7000	16509	6560
Waste gas temperature	ºC	75	60	35
Type of filter		Post combustion and fabric filter	Fabric filter	Lime injection + fabric filter
Emission levels (2) - dust - C_{total} - CO - O_2 - PCDD/F	 mg/Nm³ % ng TEQ/Nm³	 0.1 2.2 2.3 14 0.006	 4.9 5.7 1.6 n.d n.d	 0.4 10 0 20.95 n.d.

(1) The higher recuperation rate (99%) is reached if only in-house core sand is regenerated. A rate of 95 % applies for mixed internal and external core sand
(2) Emission levels are calculated average values from continuous monitoring data over a period of several hours, during sampling for dust or PCDD/F

Table 4.64: Operational data of 3 German reference foundries applying thermal sand regeneration [153, Umweltbundesamt, 2002]

The performance of the regeneration technique and the quality requirements for the regenerated sand are evaluated on a location-specific basis. Specific data may be found in the references: [186, Stephan, 1996], [187, Stephan, 1997], [188, Stephan, 2000].

Applicability

Thermal systems are normally used for chemically bonded sand systems and mixed sand systems, providing the share of chemically bonded sands (cores) is high enough. Nevertheless, a distinction can be made:

- some binders may leave inorganic salt residues at the grain surface. When the temperature increases above the melting point, these spread out over the sand surface and may cause the sintering of the sand grains upon cooling. Known examples are resol resin and silicate resin-bonded sands
- the thermal recycling of furan resins causes the emission of SO_2 if sulphonic acids are used as a hardening agent. The temperature of the exhaust system must be sufficiently high enough to prevent sulphuric acid condensation. If the emission is high, a wet flue-gas cleaning may be needed. Phosphor (from the phosphoric acid used as a hardener) does not evaporate but remains on the surface in salt form. This may lead to P accumulation upon recycling. If the P-concentration rises above 0.5 – 0.7 %, a metallurgical reaction may occur, causing the rejection of the casting.

The degree of implementation of thermal regeneration is low compared to mechanical regeneration. In Germany, only 10 installations were reported to apply this technique in 1999 (compared to 200 mechanical units).

The Siempelkamp thermal regeneration unit in Krefeld has the ability to treat foundry dust along with the waste sand. Tests have been run on other mineral waste types as well.

Economics

Investment costs vary according to the size and type of equipment and are given in Figure 4.30. The data relate to thermal systems with a mechanical pre- or post-treatment step, as well as for intensive mechanical regeneration (e.g. grinding units). Small scale installations have a capacity of 0.75 t/h or 1500 t/yr. A medium size foundry will be between 2500 and 5000 t/yr. For a small scale unit, the capital cost (with 8 years amortisation and 8 % interest rate) would be EUR 55/t. These costs do not include expenses for energy, personnel nor for the disposal of residues.

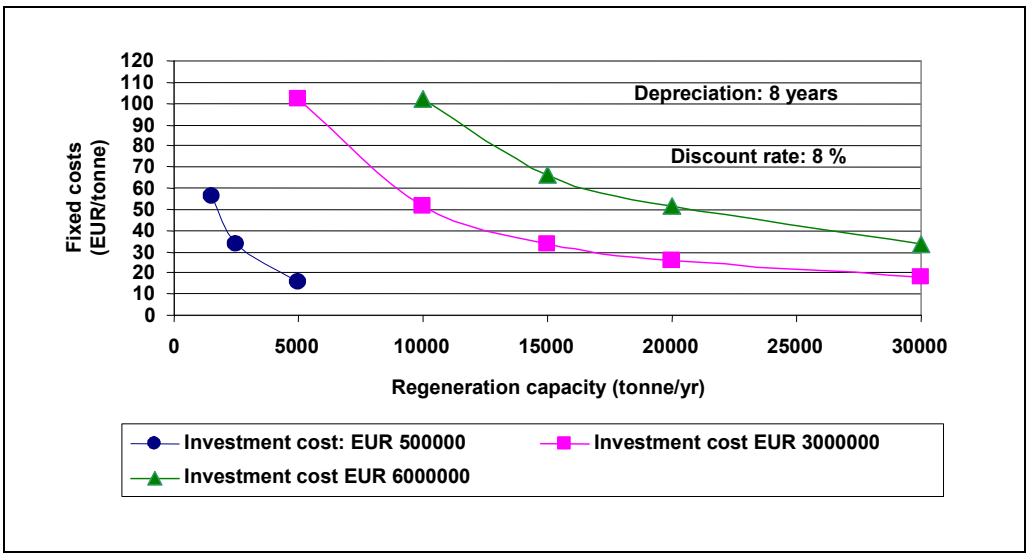


Figure 4.30: Fixed costs in euros per tonne of regenerated sand for thermal regeneration and high level mechanical regeneration of mixed sands
[82, IfG - Institut für Gießereitechnik, 1996]

Driving force for implementation

Legislation using high disposal fees to reduce the amount of residues for disposal.

Example plants
- Fluidised bed, Metaalgieterij Giesen, the Netherlands
- Fluidised bed centralised regeneration plant, Bielefeld, Germany
- VAW Alucast GmbH, Dilingen, Germany, system CEC/VAW
- Werner Rietschle GmbH, Schopfheim, Germany, system Richards
- Siempelkamp Giesserei gmbH & Co, Krefeld, Germany, system Siempelkamp
- Sofogir, Ronchamp (F) system Regetherm 500
- Duranton Sicfond, Vénissieux (F), system Richards
- FOAM, Leumann (I), system Eco-rec
- Fonderie Bréa, Montluçon (F).

Reference literature
[9, Schneider, 1993], [32, CAEF, 1997], [80, ERM Lahmeyer International GmbH, 1999], [128, IHOBE, 1998], [138, Metaalgieterij Giesen B.V., 1996], [186, Stephan, 1996], [187, Stephan, 1997], [188, Stephan, 2000]

4.8.8 Combined regeneration (mechanical–thermal-mechanical) for mixed organic-bentonite sands

Description
In mixed organic-bentonite sands, cured bentonite and organic binders are present on the sand grains. The dust is composed of active and cured bentonite, coal dust (only for iron foundries), quartz fines and organic binder residues. Mixed sands occur mainly in iron foundries and represent some 75 % of the total used sand production. The regeneration can be performed using mechanical, pneumatic, thermal or combined systems.

The sand is pretreated (sieving, magnetic separation) and dried, in order to reduce the water content to <1 %. After this, the sand is mechanically or pneumatically cleaned in order to remove part of the binder. In the thermal step, organic constituents are burned, and inorganic constituents are transferred to the dust or burned onto the grains. In a final mechanical treatment, these layers are removed mechanically or pneumatically and discarded as dust. A typical layout for a system using pneumatic treatment and fluidised bed thermal treatment is depicted in Figure 4.31.

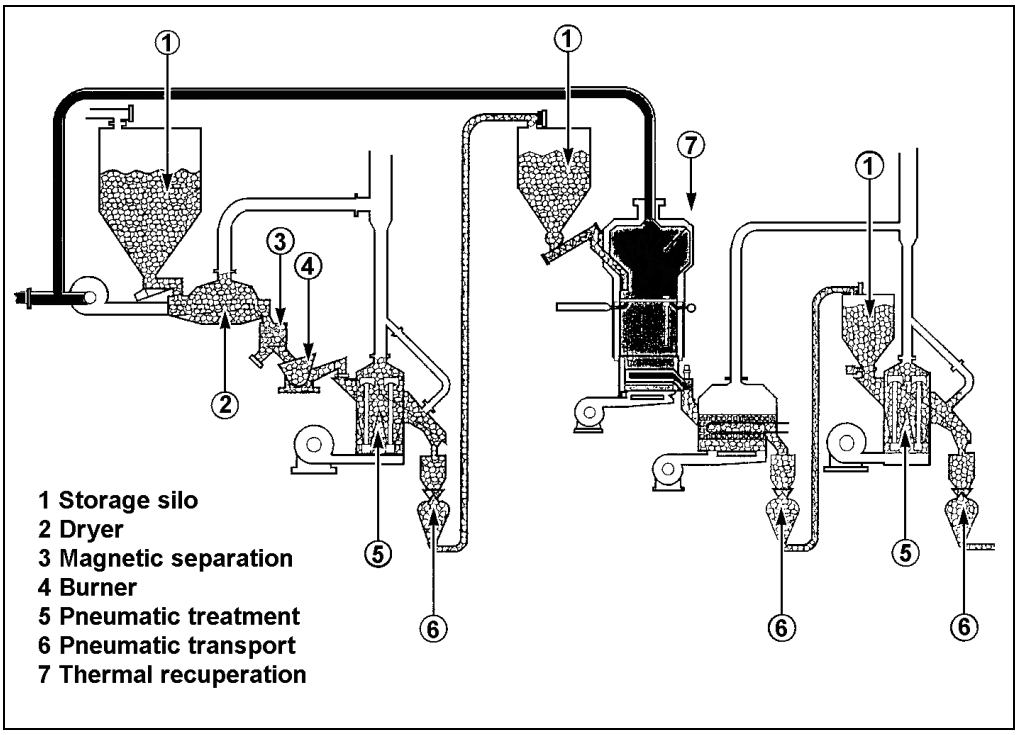


Figure 4.31: Mechanical-thermal-mechanical sand regeneration unit [108, FEAF, 1999]

Achieved environmental benefits
Reduction of the amount of sand for disposal and of the consumption of new primary sand.

Cross-media effects
The regeneration of sand requires additional energy and causes additional dust emissions and residual dust for disposal.
The general evaluation of internal regeneration versus external re-use, and the corresponding cross-media effects, are discussed separately below.

Operational data
Operational data for a mechanical-thermal-mechanical treatment are given in Table 4.65.

Parameter	Units	Foundry N	Foundry O	Foundry P
Sand flow	(tonne/h)	1	2	3
Maximum humidity of the sand input	(%)	1	1	1
Total installed electric power	(kW)	150	215	400
Natural gas	(Nm^3/h)	31	62	155
Thermal treatment - average airflow (fluidisation + combustion)	(Nm^3/h)	700	1200	3000
Treatment temperature	(°C)	800	800	800
Average treatment time	(min)	20	20	20
Flue-gas flow	(Nm^3/h)	200	300	500
Cooling - type - water flow in the circuit	(m^3/h)	Fluidised bed with water circulation 15	30	75
Sand temperature at exit	(°C)	30 – 40		
Total energy consumption: - electric - gas		100 260	90 260	70 260
Compressed airflow	(Nm^3/h)	150	210	330
Efficiency of the installation		70 – 80 %		
Regenerate sand quality: - granulometry - loss on ignition		Unchanged ≤0.1 %		
Re-use of the regenerated sand: - mould making - core-making		100 % 70 – 80 %		

Table 4.65: Operational data of a mechanical-thermal-mechanical treatment system (pneumatic - fluid bed - pneumatic)
[108, FEAF, 1999]

German data for a 85000 tonne/yr (13 – 15 tonne/h) installation provide the following off-gas composition:

- SO_2: 118 mg/Nm³
- NO_x: 150 mg/Nm³
- total C: 10 mg/Nm³
- CO: 30 mg/Nm³

Applicability
This regeneration technique is used for mixed sands containing bentonite. The economical and technical success of the regeneration depends on the selection of the sand to be regenerated. It is not suitable to regenerate the whole sand volume. Sand which is not thermally damaged can be re-used directly for new sand preparation. Its regeneration is not suitable, because active binders and additives would be removed. A selection and separation has to be made during shake-out, before homogenisation. The technique cannot be applied for core sands which disrupt bentonite characteristics (binders of acid nature) or which change green sand characteristics (e.g. water glass sand).

The regenerated sand can be used for core-making in the original process, for cores with low or medium geometrical demands. The applicability for core-making is related to the initial amount of chemically-bonded sand. The applicability in other binder systems must be tested in each case. Furthermore, these sands may be applied without restrictions for the replacement of losses in green sand moulding cycles. Restrictions may apply in processes that use water glass or methyl formate bonded sands.

In recent years, various types of installations have been developed for the treatment of mixed sands, but they have not yet found broad implementation in the sector. Some only work on a pilot scale. Others have been developed for a specific foundry and produce a regenerated sand suitable for re-use only in the same process, and results cannot be transposed to other foundries.

Economics
Costs for a 3-step installation (mechanical-thermal-mechanical) using pneumatic cleaning as the mechanical step (3 tubes in 1 chamber, KGT type Jet Reclaimer) with a capacity of 2.5 tonne/h are as follows: operational costs (consumption, personnel, maintenance) - EUR 21/t, investment costs (8 year amortisation) - EUR 30/t, thus yielding a total regeneration cost of EUR 51/tonne.

The consumption levels are as follows:

- Electricity: 50 kWh/t
- Natural gas: 18 Nm^3/t (depending on the moisture content of the sand)
- Compressed air: 60 Nm^3/t
- Wear parts: 5 EUR/t

Driving force for implementation
Legislation using high disposal fees to reduce the amount of residues for disposal.

Example plants
Halberg Guss GmbH, Saarbrucken (D), thermal-mechanical system. This plant treats 13 – 15 t/h of mixed 30 % organic, 70 % inorganic bonded sand. The organic bounded sand is a 50/50 mixture of Croning and cold-box sand. The regeneration yield on the basis of the amount of used sand treated is 78 %. The regenerated sand is applied for core-making (100 % Croning; 70 – 100 % cold-box).

The mechanical primary regeneration + separation of chromite (from cores) and quartz sand (both chemically-bonded) + thermal/mechanical treatment of quartz sand was demonstrated on a pilot scale in Germany (1993). Separation of both sand types was needed because sintering and eutectics formation occurred in the mixed sand. The plant later closed down due to other economic reasons.

Reference literature
[11, Schachtner and Müller-Späth, 1993], [37, Winterhalter, et al., 1992], [108, FEAF, 1999], [122, Kirst, 1999], [128, IHOBE, 1998], [153, Umweltbundesamt, 2002], [225, TWG, 2003]

4.8.9 Wet sand regeneration

Description
After metal removal, the sand is mixed with water to produce a sludge for easily separating the binder and to allow subsequent wet screening (1.6 mm). The removal of grain-bound binder residues is performed in the wet regeneration unit, through intensive interparticle rubbing of the sand grains. The binders are released into the wash-water. The washed sand is dried to a final moisture content of max. 0.3 %, dry screened (at 1.2 mm), and then cooled. This may be followed by an additional magnetic iron extraction and a final dust collection. The binder residue is separated from the suspension and treated to allow its safe, disposal.

The main advantage of the process over mechanical and thermal processes is that it allows real time process monitoring. Through pH control, continuous follow-up of the process is possible, allowing corrective real-time action if needed and producing a continuous quality regenerated sand. The technique allows removal of the binder layer through wet mechanical action, combined with chemical action when needed, without wearing the sand grains.
The process mainly aims to lower both the oolitisation degree of used sand (LOI max. 1 %) and the acid content.

Achieved environmental benefits
Reduction of the amount of sand for disposal and of the consumption of new primary sand.

Cross-media effects
The wet process generates a sludge for disposal and a waste water stream. A serious problem of this waste water flow is the bad sedimentation of bentonite, and its difficult removal out of waste water. Waste water from water glass sands regeneration shows the presence of alkaline ions. These ions are difficult to separate from the waste water.

Applicability
The wet regeneration system can only be applied to green sand and silicate- or CO_2-bonded sands. Regeneration from these types of processes allows full re-use of the regenerated sand in both moulds and cores. Tests on regenerated green sand showed the possibility of producing good quality cold-box cores with an acceptable binder quantity (1.8 % in total).

Economics
Within the Italian foundry market, a centralised wet regeneration plant can offer regenerated sand at a price lower than that of new sand.

Driving force for implementation
This system is reported to be able to cope with changes in used sand quality better than mechanical or thermal processes. This makes it suitable when considering a centralised sand regeneration plant.

Example plants
Safond centralised green sand wet reclamation plant, which since 1981 has been treating 230000 tonnes/yr of used sand.

One Polish foundry (Odlewnia Zeliwa Srem s.a., Srem (PL)) operates a wet regeneration of furan bonded sand. The operation is governed by site-specific factors and the technique cannot be considered for transposing to other sites.

Reference literature
[37, Winterhalter, et al., 1992], [140, EU Thematic Network Foundry Wastes, 2001], [225, TWG, 2003]

4.8.10 Regeneration of water glass sand using pneumatic systems

Description
Water glass sand has been traditionally difficult to regenerate. The use of a pneumatic system has allowed the setting up of regeneration plants operating of a 60 % regeneration ratio. The system works along the same principle as mentioned above (see Section 4.8.6). For this type of binder however, the sand needs to be heated to 220 ºC before the regeneration, in order to make the silicate layer brittle. The sand should have a humidity below 0.3 % before regeneration. The regenerated sand may be re-used in the same system. In order for the ester to work properly, the regenerated sand must be cooled to below 20 ºC, before feeding back into the moulding cycle.
Water glass sand regeneration systems comprise the following process steps: breaking – drying/heating – (pneumatical) reclamation – cooling - filtration.

This technique has a lower performance than the thermal regeneration of organically bound sands. The following limitations occur:
- lower immediate compressive strength
- shorter applicability times of the core sand mixtures
- stability loss upon storage of cores
- loss of retained compressive strength, especially with the use of binders with high collapsibility.

In order to compensate for these problems, changes to the processing scheme or the binder mixes are needed.

Achieved environmental benefits
The application of water glass sand as a binder has a low environmental impact, compared to the application of organic binders. This technique allows the (partial) regeneration of the water glass bonded sand and thus reduces the need for used sand disposal and primary raw material use.

Cross-media effects
In order to heat up the sand, natural gas is combusted. The corresponding CO_2-emission is estimated to be 18 kg/tonne of used sand. NO_x emissions will also occur.

Operational data
A German example plant operates a pneumatical unit in a step-wise cycle. The sand is first dried by the introduction of heated air (5 min/220 ºC). After this, the pneumatic cleaning is started by injecting of shots of compressed air (70 min.). This is followed by a final dedusting phase, during which only fluidising air is introduced (2 min). There is no need for further cooling, since the sand cools down to a workable temperature.

The yield of regenerated sand for one cycle operation is reported to be 85 % of the initial weight (on the basis of SiO_2). In order to produce stable cores, and taking into account the further reduction of sand quality upon a second regeneration cycle, a maximum regeneration ratio of 62 % may be achieved (leaving 38 % new sand addition).

Specific consumption levels are as follows (for a 1500 tonne/yr; 0.5 tonne/h unit):
- natural gas consumption: 104.4 kWh/t used sand
- electricity consumption: 74.5 kWh/t used sand.

A Polish example plant (in a cast steel foundry) consists of the followig units: vibratory crusher – drier – impact plate regenerator – cascade dedustor – electromagnetic separator. The technical details of the installation are given in Table 4.66. The regenerated sand is re-used in the preparation of silicate-bonded moulding-sand. The silicate-sand is used as backing sand in mould making, with alkaline sand used as contact sand. The total sand balance (on a yearly basis) shows a use of 45 - 47 % regenerated sand.

Characteristic	Value
Capacity	10 tonne/h
Recovery ratio	90 %
Content of regenerated sand in the moulding-sand	50 – 60 %
Working power	76 kW
De-dusting system efficiency (2 bag filters)	99.4 %
Installation area for regeneration site	220 m²

Table 4.66: Operational data of a silicate sand regeneration unit [200, Metalodlew s.a., 2002]

A Spanish example plant (cast steel foundry) reported a re-use of 80 - 88 % (with a yearly average figure of 12.5 % new sand addition) of regenerated silicate-ester sand in a manual moulding line, used for the casting of big pieces. The regeneration system consists of: vibratory crusher – heating in an indirectly heated reactor ('quemador' with gas burner in a side chamber) – cooling in a water-cooled heat-exchange tower – impact cleaning in a rotary mixing chamber.

Italian example plants also use special equipment for heating sand to temperatures of 140 ºC to 150 ºC, to enable the removal of defects and the embritlement of the water glass coating. This is followed by mechanical treatment in a rotary wiper, dedusting and finally cooling. A schematical drawing of the rotary regeneration unit is given in Figure 4.32.

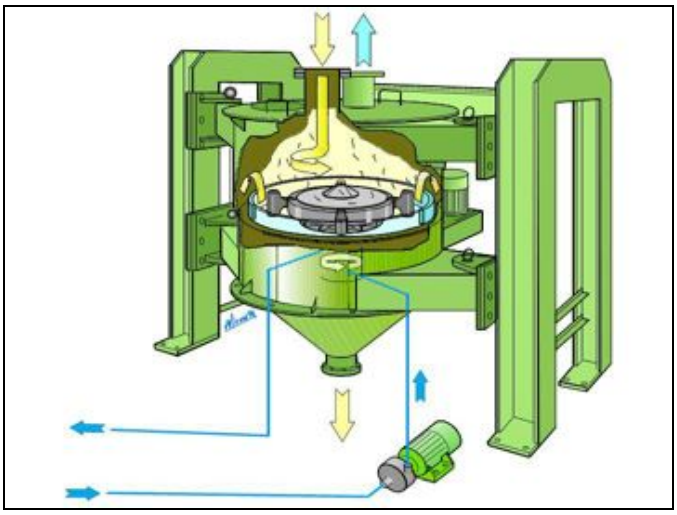


Figure 4.32: Rotary mechanical regeneration unit [225, TWG, 2003]

The equipment has an energy consumption of 35 kW/tonne of regenerated sand. The operational loss of sand is about 5 %. For moulding and core making mixtures, over 90 % of regenerated sand can be used. The achievable regeneration ratio depends on the intensity and time of regeneration and the operational sand loss. Sand losses occur during each part of the whole cycle of mixing, preparation, transportation, mould production and regeneration.

Applicability

The applicability of regeneration for water glass sands depends on the catalyst used. With classic polyacetate glycerol esters, regeneration is no longer possible after a number of cycles. With carbonaceous esters, regeneration is possible and even easier than for silicate-CO_2 sand. If the sand cannot be cooled below 20 ºC before returning to the mixer, esters with a slow reaction need to be used. These cannot be regenerated. This situation may occur during summer in hot climates.

The re-use of the regenerated water glass sand for the preparation of organically bound moulds or cores is problematic. The elevated content of electrolytes (binders) prohibits their use in other

core binder systems. The highly basic water glass residues have a negative effect on bonding and core stability, in both neutral as well as alkaline binder systems. Applications in green sand cycles and acidic core binder systems have not yet been successfully implemented. This may be due to a reduced interest in the development of this application.

Because of the low quality of secondary regenerated sand, it is necessary during de-coring and sand collection to identify the amount of regenerated sand and its origin (e.g. number of cycles), and to then discard any unusable sand.

Due to the high costs and relatively low regeneration ratio, depreciation of the installation in a reasonable time can only be guaranteed for plants with a capacity >2500 tonnes/yr.

Economics
The processing cost of this technique for the German example plant is around EUR 60/tonne. This high cost was the reason one operator closed his plant down and went back to the disposal of the water glass sand, which he could do for the lower cost of EUR 30/tonne.
The reported operational cost by the Spanish example plant is EUR 10/tonne.

Driving force for implementation
To enable the regeneration of water glass sand, which has a good environmental performance in certain applications.

Example plants
- KGT Jet Reclaimer centralised regeneration plant for 4 foundries, constructed 1998 at Fa. Bröer, Schwetzingen (D) but stopped operation in 2001
- Metalodlew s.a., Krakow (PL)
- Lur Sue s.l., Lora Del Rio (E)
- Fonderia Arno Metallurgia, S. Vittore Olona (I)
- Faser Spa, Rogeno (I)
- Talleres De Amurrio S.A. Amurrio (E)
- Daros Piston Rings AB, Partilla (S).

Reference literature
[128, IHOBE, 1998], [152, Notzon and Heil, 1998], [154, Baum, 2002], [200, Metalodlew s.a., 2002], [210, Martínez de Morentin Ronda, 2002], [225, TWG, 2003], [228, Galante, et al., 1997]

4.8.11 Internal re-use of uncured core sand

Description
Core production generates sand residues in the form of broken cores, cores with small mistakes and excess sand from the core-making machines. The excess sand can be hardened in a specific unit. Subsequently the various unused core sand flows are fed to a breaking unit. The resulting sand may be mixed with new sand for the production of new cores.

Achieved environmental benefits
Internal re-circulation of 5 - 10 % of the core sand, which otherwise would be disposed of.

Cross-media effects
No cross-media effects occur.

Applicability
This technique applies for polyurethane (cold-box) and furan resin-bonded sands. Other binders do not allow this technique.

The implementation of the technique necessitates changes in the process control. The optimum ratio of re-circulated and new sand will need to be determined. Additionally changes in binder addition or composition may be needed.

Economics
The technique requires an investment cost of EUR 250000 – 500000 for the combined treatment and breaking unit. Operational costs are about EUR 12/t. These costs are balanced by a reduction in disposal costs and purchasing costs for new sand.
The technique is only viable for core intensive production.

Driving force for implementation
Optimisation of the use of primary materials and reduction of the amount of waste for disposal.

Example plants
The technique was reported by several large-scale foundries.

Reference literature
[82, IfG - Institut für Gießereitechnik, 1996], [110, Vito, 2001]

4.8.12 Re-use of dusts from the green sand circuit in mould making

Description
Dust is collected through the exhaust filtration from the shake-out installation and from the dosing and handling stations for dry green sand. The collected dust contains active binder compounds and may be recycled into the green sand circuit.

Achieved environmental benefits
Reduction in the use of binders (bentonite), and additives (carbon), through internal re-circulation.

Cross-media effects
No cross-media effects exist.

Operational data
An iron automotive foundry, using an automated moulding line with a production of 8000 t/yr castings produces 480 t/yr of dust. This sand is collected, cooled and recycled into the sand mixer. The collected dust contains 23 % active bentonite and 10 % carbon. 50 % of the dust can be re-circulated without any risk of loss of quality due to fine dust.

Applicability
The technique may be applied in new and existing green sand installations.

Economics
The technique requires an investment of EUR 25000 for storage and transport equipment. The amortisation period is 8 years, with a discount rate of 8 %, for a 240 tonne/yr installation, resulting in a capital cost of EUR 17/tonne of treated sand. There are no additional operational costs since the operation of the overall installation does not change.

Driving force for implementation
To optimise the use of primary materials and to reduce the amount of waste for disposal.

Example plants
Iron automotive foundry in Germany.

Reference literature
[82, IfG - Institut für Gießereitechnik, 1996]

4.8.13 External re-use of used sand and the undersize from the sand circuit and regeneration processes

Description
Used sand and undersize sand from the sand circuit or sand regeneration may find some external applications, with the main areas of application being:
- the construction industry (road construction, highway construction)
- the building materials industry (cement, bricks, limestone manufacture)
- in the filling of mining cavities
- in landfill construction (roads on landfills, permanent covers).

The limits of these applications are given by either technical criteria for construction materials and/or environmental criteria for the given application. Environmental criteria are generally based on leaching properties and the content of organic compounds. These differ between various European regions. Used sands generally show a low metal leaching potential. An exceedence of the limit values may occur for materials with a high content of organic binder or with specific additives, such as lustrous carbon.

Due to its high quartz content and appropriate granulometry, used sand may be applied as a virgin sand substitute in road construction. Application in the production of building materials (concrete, bricks, tiles, glass wool, …) are technically feasible but require a higher level of composition control and logistics. Industrial scale trials have been successfully applied in:
- road bases
- filling material
- drainage material
- concrete elements
- cement production (depending on the silicon need of the process. In Germany this application is of major importance)
- filling of mining cavities (due to its good supporting capacities. Used sand is used in this application in Germany)
- final cover on landfills (mixed with water glass and other wastes, examples in the Netherlands)
- construction material for the reinforcement of dikes
- vitrification of hazardous waste.

A survey table which gives more detailed information for the different sand types is given in Section 4.9.

Other fields of application are the fabrication of bricks, secondary copper smelting and zinc recuperation.

It should be stressed that discussions on the (type of) external utilisation fall beyond the scope of the current reference document. However, in general, it can be stated that the sand usually needs no pretreatment and is transported from the foundry after collection and intermediate storage. Usually in order to guarantee a continuous quality of the material, a separate collection and storage system will be developed. Furthermore, the quality of the material needs to be controlled through regular analyses.

Achieved environmental benefits
In external applications, the used sand substitutes, and therefore saves, virgin materials. In general, the external application does not require any treatment of the sand and therefore does not generate any energy expense for the foundry.

Cross-media effects
Residues of organic coatings are possible sources of aromatic hydrocarbons.

Applicability
This technique is applicable for new and existing installations, as long as they can find a buyer for the waste sand.

The use of surplus foundry sand does not reduce the wear resistance of asphalt concrete. The use of surplus foundry sand together with the dust from the same foundry process is possible in Portland cement concrete production. The use of surplus foundry sand together with fly ash and steel slag is possible in mineral wool production. The use of surplus foundry sand in the composting process of biowastes does not negatively affect the environmental or technical features of the final product, i.e. the topsoil. The use of surplus green sand in mineral liners is technically and environmentally possible in the top layers of the landfill.

Economics
Costs for external utilisation depend on the local market and the transport and storage costs needed.

Investment costs for separate collection and storage are minimal. Often these can be realised through organisational measures. Operational costs for analyses and administration may be up to EUR 5000/yr. On the benefit side, there is a reduction in the costs for disposal (up to EUR 125/tonne).

Driving force for implementation
Legislation using high disposal fees to reduce the amount of residues for disposal.

Example plants
Multiple examples have been reported throughout Europe, e.g. by Finland, the Netherlands, Belgium, Germany, UK.

Reference literature
[82, IfG - Institut für Gießereitechnik, 1996], [110, Vito, 2001], [128, IHOBE, 1998], [169, Orkas, 2001], [171, The Castings Development Centre, 1999]

4.9 Dust and solid residues: treatment and re-use

4.9.1 Introduction

A good segregation of materials is essential to facilitate opportunities for recovery, recycling and re-use. Waste should always be recycled or recovered unless a satisfactory justification has been accepted by the regulator that recovery is “technically and economically impossible”.

In general, the waste streams comprise:
- raw material dusts collected in bag or cartridge filters
- slag from desulphurisation
- slag/dross from melting
- melting dust and fume collected in a filter plant
- casting dust and fume collected in a filter plant
- fettling dusts collected in an abatement plant
- chips and turnings from fettling
- used abrasives from shot blasting
- scrubber liquors and sludges and output from the effluent treatment plant
- refractory waste from launders and ladles
- sand
- chemical and oil containers
- general inert industrial waste.

Waste should be recovered wherever practicable. Other than sand, the most significant wastes are:
- slag from the melting and metal treatment processes
- dust collected from abatement plants
- collected sludge
- refractory waste.

[160, UK Environment Agency, 2002]

4.9.2 (Pretreatment for) external re-use of solid residues

Description
In order to allow an external re-use of solid residues, the material may need treatment. Table 4.67 gives the required processing for the various (non-sand) solid residues and possible limitations for their re-use.

For cupola furnace slag, the physical form, and therefore to some extent its options for re-use, depend on the type of de-slagging used. Dry slagging, i.e. pouring of the slag in pots for cooling and solidification, produces a crystalline non-porous mineral. Concerning technological aspects, this slag is comparable to blast furnace slag. Wet slagging generates a granular slag by cooling the slag with a water jet.

Residue type	Treatment	Limitations
Air-cooled cupola slag	Crushing	- generation of glassy dust - handling requirements due to glassy nature
Water quenched cupola slag	None	- generation of glassy dust - handling requirements due to glassy nature
Induction melting slag	Crushing	- generation of glassy dust - handling requirements due to glassy nature - little data available on leachates
EAF slag	Crushing	- generation of glassy dust - handling requirements due to glassy nature - little data available on leachates
Desulphurisation slag	Extraction of metal and other coarse particles	- handling requirements, CaC_2 needs careful handling to avoid injury - run-off - may be a special waste
Dusts and sludges	Sludge pressing, drying and granulation needed for most applications	- health and safety requirements for some dusts - problems with transport of dusty materials - high leaching potential due to nature of product and large surface area

Table 4.67: Necessary treatment and possible limitations for external re-use of solid residues [171, The Castings Development Centre, 1999]

Achieved environmental benefits
In external applications, the re-used material will serve as a secondary construction material and can substitute for virgin materials. The recycling results in a reduction in the amount of material for disposal.

Cross-media effects
Pretreatment requires energy and may generate dust emissions.

Applicability
The technique is applicable for new and existing installations, as long as there is a suitable a local market for the residue.

A survey of external re-use applications for various solid wastes is given in Table 4.68.

SUMMARY OF RE-USE APPLICATIONS	SAND						SLAGS					OTHER	
Construction type uses	Greensand	Alkaline phenolic	Phenolic urethane	Furan	Resin shell	Sodium silicate	Air-cooled cupola	Water quenched cupola	Induction	Electric arc furnace	Desulphurisation	Investment casting shell	Dusts and sludges
Asphalt	x	x	+	+	+	O	x						
Ballast							+			+			
Block making	+	x	+	+	x	+		x					
Brick manufacture	x	x	+	+	+		+	+					
Cement	x	x	+		x	x							
Coarse aggregate substitute							x		x	x		x	
Concrete		x	+	+	+								
Fine aggregate substitute	x	x	+	+	+	+							
Foamed concrete, etc.	x	x	+										
Insulating/mineral/glass wools	+	+	+	+	+	+	+	+					+
Lightweight aggregate production													+
Mortar production						+							
Road base construction		x	+		+	x	x		x	x		x	
Roofing felt				x									
Re-use in another foundry													
As new sand addition to greensand				x									
Soil type uses													
Artificial topsoils	x	+	+	x	+								+
Decorative ground cover							+	+					
Ground cover in riding stables								+					
Fertiliser filler													x
Landfill - capping	x	x	+										+
Landfill - daily cover	x	x	+	x	x	x							
Landfill - liner	+												+
Soil modifier/improver	+	+	+	+	+	+		+			+		+
Miscellaneous													
Abrasives/blasting media		x	+					x	+				
Absorbent media												+	
Blast furnace slag cement manufacture						+					+		
Chemical/industrial applications													x
Slaked lime replacement											+		+
Smelting fluxes		+	+		+	+							
Waste vitrification	+	+	+		+	+							

x Proven re-use application, with successful projects running in the UK
+ Re-use application that has been proven in theory but no re-use project is currently running in the UK
O Unsuitable for re-use in untreated from

Table 4.68: Summary of external re-use applications for solid foundry residues (status 1999) [171, The Castings Development Centre, 1999], [202, TWG, 2002]

Economics
The costs associated with re-use are mainly the processing and transport costs, but these can possibly be reduced by taking into account the income generated from selling the material. However, the latter in general may be low or close to zero, whereas typically mechanical treatment costs are in the range of EUR 8/tonne.

The further the materials have to be transported, the greater the increase in costs. In order to assess the economic viability of the re-use option, the applicable disposal costs should be taken into account. These differ between various regions and depend on the residue type.

Driving force for implementation
Legislation stimulating the recycling of mineral wastes, partly by setting high disposal fees to reduce the amount of residues for disposal.

Example plants
Multiple examples of sand and slag re-use have been reported throughout Europe, e.g. in Finland, the Netherlands, Belgium, Germany, UK

Reference literature
[171, The Castings Development Centre, 1999]

4.9.3 Minimisation of slag forming

Description
The production of slag can be minimised using in-process measures, such as:
- using clean scrap
- using a lower metal temperature
- preventing overshoots (temporary high temperatures)
- preventing long standing times of molten metal in the melting furnace
- making adequate use of fluxes
- making adequate use/choice of refractory lining
- applying water cooling of the furnace wall to avoid usage of refractory lining.

Achieved environmental benefits
Minimisation of residue production and reduction of emissions to air.

Cross-media effects
No cross-media effects occur from these minimisation measures. Concerning the melting of clean scrap, the considerations raised in Section 4.1.4 should be taken into account.

Applicability
This technique applies to all new and existing installations. The applicability of the use of clean scrap has been fully discussed in Section 4.1.4.

Economics
This technique does not involve any investement, since it concerns operational measures.

Driving force for implementation
High disposal costs for residues.

Example plants
This technique is part of existing operational procedures in the majority of European foundries.

Reference literature
[103, Vereniging van Nederlandse Gemeenten, 1998]

4.9.4 Cupola furnace

4.9.4.1 Collection and recycling of coke breeze

Description
The handling, transport and charging of coke results in the production of coke breeze. Specific measures may be adopted for the collection and recycling of this material e.g. collection systems below conveyor belts or, at charging points.

The collected material may be recycled into the process by injection into the cupola or in its utilisation for recarburisation.

Achieved environmental benefits
Minimisation of the production of residues.

Cross-media effects
No cross-media effects apply.

Applicability
This technique applies to new and existing installations.

Driving force for implementation
High disposal fees for solid residues.

Example plants
The technique is reported for several foundries in Europe.

4.9.4.2 Recirculation of filter dust into cupola furnace

Description
Cupola filter dust is re-injected into the cupola furnace. The aim of this technique is to achieve an accumulation of zinc in the dust, up to a level that allows reprocessing with Zn recovery (>18 %). Zn recovery is performed using the Waelz process.

Recirculation of the dust can be done through re-injection at the tuyères or by charging dust pellets through the charging door. Both techniques are applied on an industrial scale. A mass balance analysis can be used to show that the zinc is sublimated and reappears in the recuperated dust. After a number of cycles the dust is rich enough in Zn to allow recovery. Recovery is technically possible above an 18 % Zn level.

There are two limits to recycling dust:
- the zinc essentially appears in the form of Zn_2SO_4, a compound containing 64 % Zn. This therefore sets the maximum level of enrichment
- the dust is also enriched in alkali, which causes flame extinction in the combustion chamber. This effect may be solved by injecting water vapour into the combustion air.

Injection at the tuyères can be based on several principles. There are fifteen (status May 2001) European foundries recycling dust by injection at the tuyères. Eleven use the positive pressure technique, and four use the venturi suction technique. The advantage of the venturi technique is that it consumes less injection air and so cools the melting zone less. With both techniques, the dust becomes sticky after successive cycles. In the case of the venturi technique, the dust must therefore be mixed with petcoke to allow its transport in the pipes.

The recirculation of dust through agglomeration and charging is much less common than tuyère injection. This is because the process is much more difficult to automate. Furthermore, good control and knowledge of the pelletisation process is needed to give the pellets the necessary

consistency. Ferrosilicon can be added to produce pellets with good consistency. In practical tests a mix of 2/3 FeSi with 1/3 of dust was needed to allow good operation. On the other hand the pellet technique can be used to treat large quantities. For cupolas with larger diameters, tuyère injection of the dust into the centre of the fire is difficult, this therefore favours the use of pellets.

The properties of both techniques are compared in Table 4.69.

Re-use of the fines collected in the purification of the cupola off-gas	Injection through nozzles	Introduction as pellets	Observations
Influence of the waste			
Limitation in the introduced amount of fines	7 – 8 kg/tonne metal		Problem of extinction of flame
Reduction in the generated amount of fines	40 %	50 %	Approx.(1)
Increase in the content of zinc in the fines	30 %	20 %	Approx.(1)
Increase in slag production	?	?	
Influence on the operation of the cupolas			
Amount of coke necessary to counteract the temperature loss	0.5 – 0.6 %	0.2 – 0.3 %	Approx.(1)
Variation in the analysis of off-gases	No	No	n.a
Influence in melted metal			
Increase in the metal content (Zn, Pb) in the iron	Limited	No	(in the order of thousandths)
Influence in the losses to fire	10 – 30 %	No	Approx. (1)(2)
Effectiveness to add other products (C, FeSi) with the same method	Yes	No	n.a
Costs			
Reduction in the disposal cost of the fines	60 %	50 %	Approx.(1)
Operations			
Possibility of automating the process	Yes	No	n.a
Additional Problem	No	Yes	Crash-resistance of the pellets
Implementation of technology			
Existing Facilities	Yes	Yes	Preferably cupolas of large size
New facilities	Yes	Yes	

(1) Approximation, real value depending on the initial zinc oxide content the fines, of the degree of necessary enrichment for its re-use, and on the characteristics of the cupola
(2) Function of the amount of steel in the load of the cupola
n.a: not applicable

Table 4.69: Properties of injection techniques for recirculation of cupola furnace dust [108, FEAF, 1999]

Achieved environmental benefits

The main benefit of the technique is a decrease in the net amount of dust sent out by the foundry, for disposal or recovery. The foundry typically sends out a smaller amount of dust, but with a higher load of metals. This allows the recovery of Zn from the cupola dusts. The technique results in an enrichment of the Zn in the cupola dust, while for Pb a larger share ends up with the iron. If the Zn is effectively recuperated from the dust, the technique decreases the heavy metal load of the final dust for disposal, as well as its amount. On the other hand, the amount of slag produced increases.

Cross-media effects

Both techniques consume energy, i.e. coke, to melt the product. An increase in coke use of 0.15 to 0.25 kg cokes/kg dust at a thermal efficiency of 40 % of the furnace is reported.

In addition, the injection of cold dust in the hot melting zone will lower the flame temperature, which accordingly will have to be restored by an injection of oxygen. The total amount of slag produced will also increase.

The loading of sticky dust to several of the internal parts of the system will cause medium-term loss of efficiency and possibly operational problems. These have not been quantified.

Operational data

An analysis of the input and output flows of French cupolas resulted in the mass balance shown in Figure 4.33 and Figure 4.34. The contribution of each flow to the Zn-in/output is given together with the zinc-level (as mass and %). The percentages given are average values over the indicated measuring period.

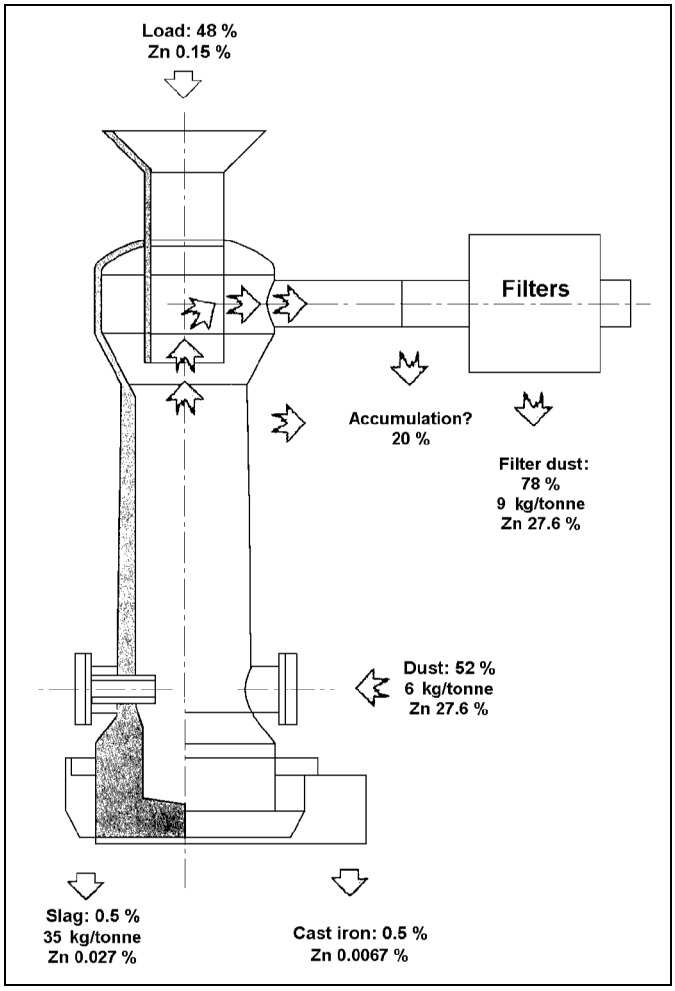


Figure 4.33: Zinc distribution for tuyère injection, upon injection during 20 days [156, Godinot, 2001]

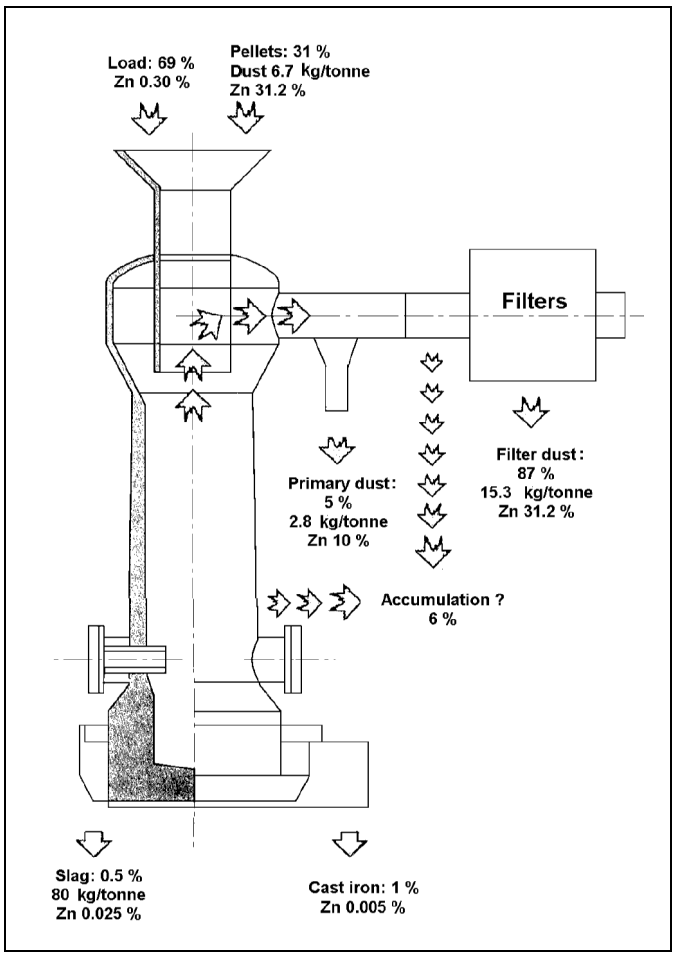


Figure 4.34: Zinc distribution for recirculation through the charge, upon charging during 11 days [156, Godinot, 2001]

The analysis of the input and output flows do not allow a full closure of the zinc balance. This indicates that a considerable part of the zinc (20 % for tuyère injection, 10 % for pellet charging) remains and accumulates in the system. Upon recirculation, the dust gets sticky and deposits in the combustion chamber, heat-exchanger and filters. The recirculation will therefore require increased cleaning efforts and will result in a material for disposal at this cleaning stage.

The recirculation of cupola dust (yearly iron production: 30000 tonnes) in a Dutch iron foundy reduced the net amount of dust by 156 t on a yearly basis, without any significant effect on the environmental and construction qualities of the slag.

Applicability

Recovery is technically possible above an 18 % Zn level. Cupolas with a Zn-rich charge have Zn-levels in the dust >20 %, without recirculation. A minimal content of 40 % Zinc is needed for cost neutral recovery.

It is not possible to re-inject the full dust production of a furnace. Injection of more than 8 kg/tonne metal results in an extinguishing of the flame.

New and existing cupola furnaces with continuous operation can be equipped with these dust recirculation installations.

Economics

Recovery is technically possible above an 18 % Zn level. Operators report profitability of the recirculation and Zn recovery occuring for a Zn-level >40 %.

From the practical data from two foundries in France, additional operational costs were calculated. Tuyère injection showed an additional operational cost of EUR 0.35/tonne cast iron; pellet injection EUR 0.90/tonne cast iron. This calculation does not take into account any extra costs for slag disposal or maintenance works.

In the case of Venturi injection, the following data apply. In a German reference plant over a 5 year period an average of 7.5 kg zinc dust/tonne melted iron could be delivered to the processing industry. Disposal costs were thereby reduced by EUR 1.97/tonne liquid iron. Furthermore, 20 % of the cokes could be replaced by petcokes. This allowed a reduction in the fuel cost of 15 %, which corresponded to a cost reduction of EUR 2.56/tonne liquid iron. This calculation does not take into account any extra costs for slag disposal or maintenance works.

Driving force for implementation
High disposal costs for furnace dusts.

Example plants
Venturi (NPT):
Pont-a-Mousson, Brebach (F)
Positive Pressure (VELCO):
John Deere, Mannheim (D)

Reference literature
[108, FEAF, 1999], [110, Vito, 2001], [140, EU Thematic Network Foundry Wastes, 2001], [156, Godinot, 2001], [181, Ruffin and Godinot, 1998], [198, Georg Fischer,], [202, TWG, 2002]

4.9.5 EAF

4.9.5.1 Recycling of filter dust and sludge (from EAF melting)

Description
Dry collected furnace dust can, under certain circumstances, be recycled in the furnace. The dust will preferably be pretreated, e.g. by pelletising or briquetting, as this will reduce the amount of dust that is just blown through the furnace. The idea is to recover the metallic part of the dust and to melt the inorganic part to slag. In general, the dust is added at the beginning of each melting cycle.

As discussed for cupola furnaces, and for the EAF, in some cases where significant quantities of Zn containing scrap are used, recycling can lead to a Zn enrichment of the furnace dust up to a level where it can be used in the zinc industry for the recovery of Zn if economically viable (up to 30 - 40 %).

Achieved environmental benefits
The main benefit of the technique is a decrease in the net amount of dust sent out by the foundry, for disposal or recovery. The produced dust contains a higher load of metals. This allows the recovery of Zn from the EAF dusts. The technique results in an enrichment of the Zn in the cupola dust, while for Pb a larger share ends up in the iron. If the Zn is effectively recuperated from the dust, the technique decreases the heavy metal load of the final dust for disposal, as well as its amount. On the other hand, the amount of slag produced, increases.

Cross-media effects
Dust recycling possibly reduces furnace efficiency and rises the consumption of electrical energy (approx. 20 - 30 kWh/tonne). The technique results in an increased production of slag.

Operational data
Operational data from EAF steelmaking show a plant which recycles 75 % EAF dust from an original yield of 20 – 22 kg/t, and so only has to take care of about 50 % of the dust, with an average zinc content of 35 %.

Applicability
The technique generally applies for dusts with a high metallic load. The actual applicability though depends on many factors, that may be dissimilar for different plants.

Economics
The technique does not involve any additional investment.

Driving force for implementation
High disposal costs for furnace dusts.

Example plants
This technique is performed in several European foundries.

Reference literature
[32, CAEF, 1997], [211, European IPPC Bureau, 2000]

4.9.5.2 Recycling of Al slags and residues

Description
The possibilities of recycling depend on the product and the generated wastes. Swarfs are mostly recovered for internal remelting while other scrap (containing too much other metal) will usually be sold to secondary aluminium production.

Achieved environmental benefits
Minimisation of the production of residues.

Cross-media effects
No cross-media effects apply.

Applicability
This technique applies to new and existing installations.

Driving force for implementation
High disposal fees for solid residues.

Example plants
The technique is commonly applied in aluminium foundries.

Reference literature
[225, TWG, 2003]

4.10 Noise reduction

Description
The foundry process contains various point sources of noise. These include:
- scrap handling
- furnace charging
- burners
- HPDC automates
- shake-out
- grit-blasting
- core (and mould) shooting
- finishing
- all motors and hydraulic systems
- transport (tipping, loading, etc.).

The overall reduction of noise levels involves developing a noise reduction plan. Here each of the sources needs to be checked and evaluated. Alternative techniques with lower noise levels may be applied and/or point sources may be enclosed. Examples for alternative techniques have been given in Section 4.2.4.2 (oxyburner in RF) and 4.2.2.2 (foamy slag for EAF). Some examples of the enclosure of sources have been given for furnaces (Section 4.5.3.1) and shake-out (4.5.9.3).

General measures include:
- using noise reducing flaps on all outside doors and closing all doors (and keeping them shut as much as possible), especially during the night
- actively blowing air into the foundry hall. This causes a small increase in the indoor pressure and keeps the noise inside
- enclosing fans, insulating of ventilation pipes and using of dampers
- minimising the number of transport activities during the night.

Full enclosure of the foundry building may be considered as well. This will also require setting-up a climate control system, to limit the temperature inside the building.

Achieved environmental benefits
Reduction of noise pollution.

Cross-media effects
Enclosing (parts of) the foundry building may necessitate the installation of a climate control system, the operation of which requires energy.

Operational data
A Belgian aluminium foundry is currently developing a noise reduction plan. The aim is for the general noise level to be reduced from 50 dBA to 40 dBA. This involves the study of 170 sources. Specific measures are taken to reduce the overall noise level between 22.00 h and 6.00 h. Additionally air is blown into the foundry hall, creating a small pressure difference to keep the noise inside. The total inside air volume is refreshed 36 times each hour.

Another Belgian foundry is running a project to reduce noise emissions by fully closing the foundry building. This requires the setting-up of a climate control system, in order to achieve a maximum inside-outside temperature difference of 8 ºC. The system is currently going through subsequent revisions, so tests are still ongoing.

Applicability
This technique applies to all new and existing installations. The level to which measures should be taken depends on the foundry location.

Driving force for implementation
Regulation on noise levels from industrial installations.

Example plants
- MGG, Hoboken (B): noise reduction plan
- Hayes-Lemmertz, Hoboken (B): total building enclosure.

Reference literature
[225, TWG, 2003]

4.11 Decommissioning

Description
Some techniques to consider are:
- considering later de-commissioning at the design stage, thereby minimising risks and excessive costs during later de-commissioning
- for existing installations, where potential problems have been identified, putting in place a programme of improvements. These improvements designs need to ensure that:
  - underground tanks and pipework are avoided where possible (unless protected by secondary containment or a suitable monitoring programme)
  - there is provision for the draining and cleaning-out of vessels and pipework prior to dismantling
  - lagoons and landfills are designed with a view to their eventual clean-up or surrender
  - insulation is used which can be readily dismantled without dust or hazards arising
  - any materials used are recyclable (although bearing in mind they still meet operational or other environmental objectives)

- developing and maintaining a site closure plan, to demonstrate that, in its current state, the installation can be decommissioned to avoid any pollution risk and to return the site of operation to a satisfactory state. The plan should be kept updated as material changes occur. However, even at an early stage, the closure plan can include:
  - either the removal or the flushing out of pipelines and vessels where appropriate and their complete emptying for any potentially harmful contents
  - plans of all underground pipes and vessels
  - the method and resource necessary for the clearing of lagoons
  - the method of ensuring that any on-site landfills can meet the equivalent of surrender conditions
  - the removal of asbestos or other potentially harmful materials unless agreed that it is reasonable to leave such liabilities to future owners
  - methods of dismantling buildings and other structures, for the protection of surface and groundwater at construction and demolition-sites
  - testing of the soil to ascertain the degree of any pollution caused by the activities and the need for any remediation to return the site to a satisfactory state as defined by the initial site report

Achieved environmental benefits
Prevents environmental issues during de-commissioning.

Applicability
Techniques mentioned here are applicable throughout the installation's operational lifetime, during the design and building stage of the site and activities and immediately after the site closure.

Reference literature
[236, UK Environment Agency, 2001]

4.12 Environmental management tools

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

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

Within the European Union, many organisations have decided on a voluntary basis to implement environmental management systems based on EN ISO 14001:1996 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 14001:1996 and EMAS) and non-standardised ("customised") systems in principle take the *organisation* as the entity, this document takes a more narrow approach, not including all activities of the organisation e.g. with regard to their products and services, due to the fact that the regulated entity under the IPPC Directive is the *installation* (as defined in Article 2).

An environmental management system (EMS) for an IPPC installation can contain the following components:

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

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

(a) Definition of an environmental policy

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

- is appropriate to the nature, scale and environmental impacts of the activities
- includes a commitment to pollution prevention and control
- includes a commitment to comply with all relevant applicable environmental legislation and regulations, and with other requirements to which the organisation subscribes
- provides the framework for setting and reviewing environmental objectives and targets
- is documented and communicated to all employees
- is available to the public and all interested parties.

(b) Planning, i.e.:

- procedures to identify the environmental aspects of the installation, in order to determine those activities which have or can have significant impacts on the environment, and to keep this information up-to-date
- procedures to identify and have access to legal and other requirements to which the organisation subscribes and that are applicable to the environmental aspects of its activities
- establishing and reviewing documented environmental objectives and targets, taking into consideration the legal and other requirements and the views of interested parties
- establishing and regularly updating an environmental management programme, including designation of responsibility for achieving objectives and targets at each relevant function and level as well as the means and timeframe by which they are to be achieved.

(c) Implementation and operation of procedures

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

(i) Structure and responsibility
- defining, documenting and communicating roles, responsibilities and authorities, which includes appointing one specific management representative
- providing resources essential to the implementation and control of the environmental management system, including human resources and specialised skills, technology and financial resources.

(ii) Training, awareness and competence

- identifying training needs to ensure that all personnel whose work may significantly affect the environmental impacts of the activity have received appropriate training.

(iii) Communication
- establishing and maintaining procedures for internal communication between the various levels and functions of the installation, as well as procedures that foster a dialogue with external interested parties and procedures for receiving, documenting and, where reasonable, responding to relevant communication from external interested parties.

(iv) Employee involvement
- involving employees in the process aimed at achieving a high level of environmental performance by applying appropriate forms of participation such as the suggestion-book system or project-based group works or environmental committees.

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

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

(vii) Maintenance programme
- establishing a structured programme for maintenance based on technical descriptions of the equipment, norms etc. as well as any equipment failures and consequences
- supporting the maintenance programme by appropriate record keeping systems and diagnostic testing
- clearly allocating responsibility for the planning and execution of maintenance.

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

(d) Checking and corrective action, i.e:

(i) Monitoring and measurement
- establishing and maintaining documented procedures to monitor and measure, on a regular basis, the key characteristics of operations and activities that can have a significant impact on the environment, including the recording of information for tracking performance, relevant operational controls and conformance with the installation's environmental objectives and targets *(see also the Reference document on Monitoring of Emissions)*
- establishing and maintaining a documented procedure for periodically evaluating compliance with relevant environmental legislation and regulations.

(ii) Corrective and preventive action
- establishing and maintaining procedures for defining responsibility and authority for handling and investigating non-conformance with permit conditions, other legal requirements as well as objectives and targets, taking action to mitigate any impacts caused and for initiating and completing corrective and preventive action that are appropriate to the magnitude of the problem and commensurate with the environmental impact encountered.

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

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

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

(e) Management review, i.e.:

- reviewing, by top management, at intervals that it determines, the environmental management system, to ensure its continuing suitability, adequacy and effectiveness
- ensuring that the necessary information is collected to allow management to carry out this evaluation
- documentation of the review.

(f) Preparation of a regular environmental statement

- preparing an environmental statement that pays particular attention to the results achieved by the installation against its environmental objectives and targets. It is regularly produced – from once a year to less frequently depending on the significance of emissions, waste generation etc. It considers the information needs of relevant interested parties and it is publicly available (e.g. in electronic publications, libraries etc.).

When producing a statement, the operator may use relevant existing environmental performance indicators, making sure that the indicators chosen:

i. give an accurate appraisal of the installation's performance
ii. are understandable and unambiguous
iii. allow for year on year comparison to assess the development of the environmental performance of the installation
iv. allow for comparison with sector, national or regional benchmarks as appropriate
v. allow for comparison with regulatory requirements as appropriate.

(g) Validation by certification body or external EMS verifier

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

(h) Design considerations for end-of-life plant decommissioning

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

(i) Development of cleaner technologies

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

(j) Benchmarking, i.e.:

– carrying out systematic and regular comparisons with sector, national or regional benchmarks, including for energy efficiency and energy conservation activities, choice of input materials, emissions to air and discharges to water (using for example the European Pollutant Emission Register, EPER), consumption of water and generation of waste.

Standardised and non-standardised EMSs
An EMS can take the form of a standardised or non-standardised ("customised") system. Implementation and adherence to an internationally accepted standardised system such as EN ISO 14001:1996 can give higher credibility to the EMS, especially when subject to a properly performed external verification. EMAS provides additional credibility due to the interaction with the public through the environmental statement and the mechanism to ensure compliance with the applicable environmental legislation. However, non-standardised systems can in principle be equally effective provided that they are properly designed and implemented.

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

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

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

Operational data
No specific information reported.

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

Economics
It is difficult to accurately determine the costs and economic benefits of introducing and maintaining a good EMS. A number of studies are presented below. However, these are just

examples and their results are not entirely coherent. They might not be representative for all sectors across the EU and should thus be treated with caution.

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

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

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

A number of studies[5] show that there is an inverse relationship between company size and the cost of implementing an EMS. A similar inverse relationship exists for the payback period of invested capital. Both elements imply a less favourable cost-benefit relationship for implementing an EMS in SMEs compared to larger companies.

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

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

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

A recent German study (Schaltegger, Stefan and Wagner, Marcus, *Umweltmanagement in deutschen Unternehmen - der aktuelle Stand der Praxis*, February 2002, p. 106) shows the following costs for EMAS for different branches. It can be noted that these figures are much lower than those of the Swiss study quoted above. This is a confirmation of the difficulty to determine the costs of an EMS.

<u>Costs for building (EUR):</u>
- Minimum: 18750
- Maximum: 75000
- Average: 50000

<u>Costs for validation (EUR):</u>
- Minimum: 5000
- Maximum: 12500
- Average: 6000

[5] E.g. Dyllick and Hamschmidt (2000, 73) quoted in Klemisch H. and R. Holger, *Umweltmanagementsysteme in kleinen und mittleren Unternehmen – Befunde bisheriger Umsetzung,* KNI Papers 01/02, January 2002, p 15; Clausen J., M. Keil and M. Jungwirth, *The State of EMAS in the EU.Eco-Management as a Tool for Sustainable Development – Literature Study,* Institute for Ecological Economy Research (Berlin) and Ecologic – Institute for International and European Environmental Policy (Berlin), 2002, p 15.

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

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

Driving force 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 14001:1996 and the European Community Eco-Management and Audit Scheme (EMAS), whereas the features (f) and (g) are specific to EMAS. These two standardised systems are applied in a number of IPPC installations. As an example, 357 organisations within the EU chemical and chemical products industry (NACE code 24) were EMAS registered in July 2002, most of which operate IPPC installations.

In the UK, the Environment Agency of England and Wales carried out a survey among IPC (the precursor to IPPC) regulated installations in 2001. It showed that 32 % of respondents were certified to ISO 14001 (corresponding to 21 % of all IPC installations) and 7 % were EMAS registered. All cement works in the UK (around 20) are certified to ISO 14001 and the majority are EMAS registered. In Ireland, where the establishment of an EMS (not necessarily of a standardised nature) is required in IPC licenses, an estimated 100 out of approximately 500 licensed installations have established an EMS according to ISO 14001, with the other 400 installations having opted for a non-standardised EMS.

Reference literature
[78, ETSU, 1996]

(Regulation (EC) No 761/2001 of the European parliament and of the council allowing voluntary participation by organisations in a Community eco-management and audit scheme (EMAS), OJ L 114, 24/4/2001, http://europa.eu.int/comm/environment/emas/index_en.htm)

(EN ISO 14001:1996, http://www.iso.ch/iso/en/iso9000-14000/iso14000/iso14000index.html; http://www.tc207.org)

5 BEST AVAILABLE TECHNIQUES FOR FOUNDRIES

In understanding this chapter 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 chapter have been assessed through an iterative process involving the following steps:

- identification of the key environmental issues for the foundries sector
- examination of the techniques most relevant to address these key issues
- identification of the best environmental performance levels, on the basis of the available data in the European Union and worldwide
- examination of the conditions under which these performance levels were achieved; such as costs, cross-media effects, main driving forces involved in implementation of the 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(11) and Annex IV of 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 chapter 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 these 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 chapter. 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, 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.

It is intended that the general BAT in this chapter 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). It is foreseen that

new installations can be designed to perform at or even better than the general BAT levels presented here. It is also considered that existing installations could move towards the general BAT levels 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 limit values for any specific case will need to be determined taking into account the objectives of the IPPC Directive and the local considerations.

The foundry industry is a differentiated and diverse industry. The elements of BAT applicable to a specific foundry need to be selected according to the type of activity. A foundry basically consists of a melting shop and a casting shop, both with their supply chain. For lost mould casting this supply chain includes all activities related to moulding and core-making. In this chapter, distinction will be made on the following basis: melting of either ferrous or non-ferrous metal and casting in either lost or permanent moulds. Each foundry may be classified as a combination of a melting with a moulding class. BAT is presented for each class as well as generic BAT, common to all foundries.

5.1 Generic BAT (for the foundry industry)

Some BAT elements are generic and apply for all foundries, regardless of the processes they apply and the type of products they produce. These concern material flows, finishing of castings, noise, waste water, environmental management and decommissioning.

Material flows management

The foundry process involves the use, consumption, combination and mixing of various material types. BAT requires the minimisation of raw materials consumption and the furthering of residue recovery and recycling. Therefore, BAT is to optimise the management and control of internal flows.

BAT therefore is to:

- apply storage and handling methods for solids, liquids and gases as discussed in the Storage BREF
- apply the separate storage of various incoming materials and material grades (Section 4.1.2), preventing deterioration and hazards (Section 4.1.3)
- carry out storage in such a way that the scrap in the storage area is of an appropriate quality for feeding into the melting furnace and that soil pollution is prevented as described in Section 4.1.2. BAT is to have an impermeable surface for scrap storage with a drainage collection and treatment system. A roof can reduce or eliminate the need for such a system
- apply internal recycling of scrap metal, under the conditions discussed in Section 4.1.4, 4.1.5 and 4.1.6
- apply the separate storage of various residue and waste types to allow re-use, recycling or disposal
- use bulk or recyclable containers (Section 4.1.7)
- use simulation models, management and operational procedures to improve metal yield (Section 4.4.1) and to optimise material flows
- implement good practice measures for molten metal transfer and ladle handling (Section 4.7.4).

Finishing of castings

For abrasive cutting, shot blasting and fettling, BAT is to collect and treat the finishing off-gas using a wet or dry system. The BAT associated emission level for dust is 5 - 20 mg/Nm³. The techniques for off-gas collection and exhaust air cleaning are discussed in Section 4.5.10.1 and 4.5.10.2.

For heat treatment, BAT is all of the following, to:
- use clean fuels (i.e. natural gas or low-level sulphur content fuel) in heat treatment furnaces (Section 4.5.11.1)
- use automated furnace operation and burner/heater control (Section 4.5.11.1)
- capture and evacuate the exhaust gas from heat treatment furnaces.

Noise reduction
BAT is all of the following, to:
- develop and implement a noise reduction strategy, with general and source-specific measures
- use enclosure systems for high-noise unit operations such as shake-out (see Section 4.5.9.3)
- use additional measures as described in Section 4.10, according to local conditions.

Waste water
BAT is all of the following, to:
- keep waste water types separate according to their composition and pollutant load
- collect surface run-off water and ue oil interceptors on the collection system before discharge to surface water, as discussed in Section 4.6.4
- maximise the internal recycling of process water and the multiple use of treated waste water (Section 4.6.1)
- apply waste water treatment for scrubbing water and other waste water flows, using one or more of the techniques mentioned in Section 4.6.2 and 4.6.3.

Reduction of fugitive emissions
BAT is to minimise fugitive emissions arising from various non-contained sources in the process chain, by using a combination of the following measures. The emissions mainly involve losses from transfer and storage operations and spills, and are discussed in Section 4.5.1.1.
- avoid outdoor or uncovered stockpiles, but where outdoor stockpiles are unavoidable, to use sprays, binders, stockpile management techniques, windbreaks, etc.
- cover skip and vessels
- vacuum clean the moulding and casting shop in sand moulding foundries according to the criteria given in 4.5.1.1
- clean wheels and roads
- keep outside doors shut
- carry out regular housekeeping
- manage and control possible sources of fugitive emissions to water.

These techniques are further specified in Section 4.5.1.1. Additional storage techniques are detailed in the Storage BREF.

Additionally, fugitive emissions may arise from the incomplete evacuation of exhaust gas from contained sources, e.g. emissions from furnaces during opening or tapping. BAT is to minimise these fugitive emissions by optimising capture and cleaning, taking into account the associated emission levels as given in Sections 5.2 and 5.3. For this optimisation one or more of the following measures are used, giving preference to the collection of fume nearest to the source:
- hooding and ducting design to capture fume arising from hot metal, furnace charging, slag transfer and tapping
- applying furnace enclosures to prevent the release of fume losses into the atmosphere
- applying roofline collection, although this is very energy consuming and should only be applied as a last resort.

Environmental management
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.

BAT is to implement and adhere to an Environmental Management System (EMS) that incorporates, as appropriate to individual circumstances, the following features: (see Section 4.12)

- definition of an environmental policy for the installation by top management (commitment of the top management is regarded as a precondition for a successful application of other features of the EMS)
- planning and establishing the necessary procedures
- 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.
- checking performance and taking corrective action, paying particular attention to
  - monitoring and measurement (see also the Reference document on Monitoring of Emissions)
  - 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.
- review by top management.

Three further features, which can complement the above stepwise, are considered as supporting measures. However, their absence is generally not inconsistent with BAT. These three additional steps are:

- 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 and adherence to an internationally accepted voluntary system such as EMAS and EN ISO 14001:1996. 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 foundry sector, it is also important to consider the following potential features of the EMS:

- the environmental impact from the eventual decommissioning of the unit at the stage of designing a new plant
- the development of cleaner technologies
- 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.

Decommissioning
BAT is to apply all necessary measures to prevent pollution upon decommissioning. These are described in Section 4.11 and include:
- minimising later risks and costs by careful design at the initial design stage
- developing and implementing an improvement programme for existing installations
- developing and maintaining a site closure plan for new and existing installations.

In these measures, at least the following process parts are considered: tanks, vessels, pipework, insulation, lagoons and landfills.

5.2 Ferrous metal melting

Furnace selection
Steel is melted in both electric arc furnaces (EAF) and induction furnaces (IF). The choice between furnace types is based on technical criteria (e.g. capacity, steel grade). Due to its refining ability, the EAF allows the melting of lower grade scrap. This is an advantage in terms of the recycling of metals, but requires an appropriate flue-gas capture and cleaning system, as will be presented below.

For cast iron melting: cupola, electric arc, induction and rotary furnaces are applicable. The selection will be based on technical and economic criteria.

For the operation of any selected furnaces type, elements of BAT are given below.

Cupola furnace melting of cast iron
For the operation of cupola furnaces, BAT is all of the following, to:
- use divided blast operation (2 rows of tuyères) for cold blast cupolas (Section 4.2.1.5)
- use oxygen enrichment of the blast air, in a continuous or intermittent way, with oxygen levels between 22 and 25 % (i.e. 1 % - 4 % enrichment) (Section 4.2.1.6)
- minimise the blast-off periods for hot blast cupolas by applying continuous blowing or long campaign operation (Section 4.2.1.8). Depending on the requirements of the moulding and casting line, duplex operations must be considered
- apply good melting practice measures for the furnace operation as listed in Section 4.2.1.1
- use coke with known properties and of a controlled quality (Section 4.2.1.2)
- clean furnace off-gas by subsequent collection, cooling and dedusting using a combination of the techniques described in Section 4.5.2.1. BAT for dedusting is to use a bag filter or wet scrubber. BAT associated emission levels are given below (Table 5.1, Table 5.2)
- apply post combustion in the cupola shaft of CBC, if the off-gases can burn autothermally and then to recover the heat for internal use (Section 4.5.2.3). For HBC, use a separate combustion chamber (Section 4.5.2.2), and recover the heat for blast air preheating and other internal uses (Section 4.7.3)
- evaluate the possibility of waste heat utilisation from holding furnaces in duplex configuration and to implement heat recovery if applicable (Section 4.7.2)
- prevent and minimise dioxins and furan emissions to a level below 0.1ngTEQ/Nm³, using a combination of measures as given in Section 4.5.1.4. In some cases this may result in a preference for wet scrubbing. Industry has expressed doubts on the implementation of secondary measures that have only been proven in other sectors and in particular questions the applicability for smaller foundries
- use a wet scrubber system when melting with basic slag (basicity up to 2) (Section 4.2.1.3).

Residues produced by cupola melting include dust, slags and coke breeze.
BAT for residue management is all of the following, to:
- minimise slag forming using one or more of the in-process measures listed in Section 4.9.3
- pretreat the slags in order to allow external re-use (Section 4.9.2)
- collect and recycle coke breeze (Section 4.9.4.1).

Electric arc furnace melting of steel and cast iron

For the operation of electric arc furnaces, BAT is all of the following, to:

- apply reliable and efficient process controls to shorten the melting and treatment time (Section 4.2.2.1)
- use the foamy slag practice (Section 4.2.2.2)
- capture furnace off-gas using one of the techniques discussed in Section 4.5.3.1
- cool the furnace off-gas and dedust using a bag filter (Section 4.5.3.2).

Residues produced by EAF melting include dust and slags.

BAT for residue management is to:

- recycle filter dust into the EAF furnace (Section 4.9.5.1).

BAT associated emission levels are given below (Table 5.1, Table 5.3)

Induction furnace melting of cast iron and steel

For the operation of induction furnaces, BAT is all of the following, to:

- melt clean scrap, avoiding rusty and dirty inputs and adhering sand
- use good practice measures for the charging and operation as discussed in Section 4.2.3.1
- use medium frequency power, and when installing a new furnace, to change any mains frequency furnace to medium frequency (Section 4.2.3.2)
- evaluate the possibility of waste heat recuperation and to implement a heat recovery system if applicable (Section 4.7.2)
- use a hood, lip extraction or cover extraction on each induction furnace to capture the furnace off-gas (Section 4.5.4.1) and to maximise off-gas collection during the full working cycle
- use dry flue-gas cleaning (Section 4.5.4.2), taking into account the BAT associated emission levels as given in Table 5.1
- keep dust emissions below 0.2 kg/tonne molten iron.

Rotary furnace melting of cast iron

For the operation of rotary furnaces, BAT is all of the following, to:

- implement measures to optimise furnace yield as discussed in Section 4.2.4.1
- use an oxyburner (Section 4.2.4.2)
- collect the off-gas close to the furnace exit, apply post combustion, cool it using a heat-exchanger and then to apply dry dedusting (Section 4.5.5.1), taking into account the BAT associated emission levels as given in Table 5.1 and Table 5.4
- prevent and minimise dioxins and furan emissions to a level below 0.1ngTEQ/Nm³, using a combination of measures as given in Section 4.5.1.4. In some cases this may result in a preference for wet scrubbing. Industry has expressed doubts on the implementation of secondary measures that have only been proven in other sectors and in particular questions the applicability for smaller foundries.

Ferrous metal treatment

If an AOD converter is used for steel refining, BAT is to

- extract and collect the exhaust gas using a roof canopy.

For the production of nodular iron, nodularisation is performed. BAT for nodularisation is to:

- select a nodularisation technique with no off-gas production or to capture the produced MgO smoke, using a lid or cover equipped with extraction equipment or by using a fixed or movable hood, and to
- dedust the exhaust gas using a bag filter and to make the dust available for recycling.

BAT associated emission levels are given below (Table 5.1)

BAT associated emission levels

The following emission levels are associated to the BAT measures stated above. All associated emission levels are quoted as an average over the practicable measuring period. Whenever continuous monitoring is practicable, a daily average value is used. Emissions to air are based on standard conditions, i.e. 273 K, 101.3 kPa and dry gas.

Parameter	Emission level
Dust (1)	5 – 20 mg/Nm³
PCDD/PCDF	≤0.1 ng TEQ/Nm³
(1) The emission level of dust depends on the dust components, such as heavy metals, dioxins, and its mass flow.	

Table 5.1: Emission to air associated with the use of BAT for ferrous metal melting and treatment

Type	Parameter	Emission level (mg/Nm³)
Hot blast	Carbon monoxide	20 – 1000
	SO_2	20 – 100
	NO_x	10 – 200
Cold Blast	SO_2	100 – 400
	NO_x	20 – 70
	NM - VOC	10 – 20
Cokeless	NO_x	160 – 400

Table 5.2: Emissions to air associated with the use of BAT for the cupola melting of ferrous metals

Parameter	Emission level (mg/Nm³)
NO_x	10 – 50
CO	200

Table 5.3: Emissions to air associated with the use of BAT for the EAF melting of ferrous metals

Parameter	Emission level (mg/Nm³)
SO_2	70 – 130
NO_x	50 – 250
CO	20 – 30

Table 5.4: Emissions to air associated with the use of BAT for the rotary melting of ferrous metals

5.3 Non-ferrous metal melting

For non-ferrous metals, this document (only) considers the melting of ingots and internal scrap, since this is standard practice in non-ferrous foundries.

For aluminium melting, multiple furnace types apply. The selection of the furnace type is based on technical criteria (e.g. regime, capacity, type of casting line). These are given in Section 3.3 and Table 3.21. One foundry can use several furnace types. Operational practice and logical reasoning shows that centralised melting in higher capacity furnaces has a more favourable energy efficiency than small crucible melting for large-scale plants. No data are available however to select it as BAT.

For the melting of copper, lead and zinc and their alloys, induction or crucible furnaces are used. For copper alloys, hearth type furnaces are used as well. The selection depends on technical criteria.

For magnesium melting, only crucible furnaces are used. A cover gas is used to prevent oxidation.

Induction furnace melting of aluminium, copper, lead and zinc

For the operation of induction furnaces, BAT is all of the following, to:

- use good practice measures for the charging and operation as discussed in Section 4.2.3.1
- use medium frequency power, and when installing a new furnace, to change any mains frequency furnace to medium frequency (Section 4.2.3.2)
- evaluate the possibility of waste heat recuperation and to implement a heat recovery system if applicable (Section 4.7.2)
- minimise emissions in accordance to the associated emission levels stated below, and if needed to collect the furnace off-gas (Section 4.5.4.1) maximising off-gas collection during the full working cycle, and to apply dry dedusting.

Rotary furnace melting of aluminium

For the operation of rotary furnaces, BAT is to:

- implement measures to optimise the furnace yield as discussed in Section 4.2.4.1
- collect the off-gas close to the furnace exit and to evacuate it through a stack, taking into account the BAT associated emission levels given below.

Hearth type furnace melting of aluminium and copper

For the operation of hearth type furnaces, BAT is all of the following, to:

- collect the furnace off-gas and to evacuate it through a stack, taking into account the BAT associated emission levels given below
- capture fugitive and visible emissions according to the BAT elements for fugitive emissions as mentioned above (Section 5.1) and to apply hooding as discussed in Section 4.5.6.1.

Shaft furnace melting of aluminium

For the operation of shaft furnaces, BAT is all of the following, to:

- allow efficient exhaust collection upon tilting of the furnace, and to evacuate the exhaust gas through a stack, taking into account the BAT associated emission levels given below.

Radiant roof furnace holding of aluminium

For the operation of radiant roof furnaces, BAT is all of the following, to:

- follow the BAT elements for fugitive emissions as mentioned above (Section 5.1) and to apply hooding under the conditions discussed in Section 4.5.6.1.

Crucible melting and holding of aluminium, copper, lead and zinc

For the operation of crucible furnaces, BAT is to:

- follow the BAT elements for fugitive emissions as mentioned above (Section 5.1) and to apply hooding under the conditions discussed in Section 4.5.6.1.

Degassing and cleaning of aluminium

BAT for the degassing and cleaning of aluminium is to:

- use a mobile or fixed impeller unit with Ar/Cl_2 or N_2/Cl_2 gas (Section 4.2.8.1).

Melting of magnesium

For the melting of magnesium, BAT is to:

- use SO_2 as a cover gas or to replace SF_6 by SO_2 as a cover gas. This applies for installations with an annual output of 500 tonnes and more (Section 4.2.7.1)
- for smaller plants, use SO_2 as a cover gas or take measures to minimise SF_6 consumption and emissions, as discussed in Section 4.2.7.1. In the case where SF_6 is used, the BAT associated consumption level is <0.9 kg/tonne casting for sand casting and <1.5 kg/tonne casting for pressure die-casting.

Note: At the time of reaching this conclusion, other alternatives to SF_6 were just being brought into use (see 4.2.7.1). SO_2 can be of concern on health and safety grounds and can be corrosive to equipment.

BAT associated emission levels
The following emission levels are associated to the BAT measures stated above. All associated emission levels are quoted as an average over the practicable measuring period. Whenever continuous monitoring is practicable, a daily average value is used. Emissions to air are based on standard conditions, i.e. 273 K, 101.3 kPa and dry gas.
The BAT AEL for dust for non-ferrous metal melting and treatment is 1 – 20 mg/Nm³. Additional values for the melting of aluminium are given in Table 5.5.

The emission factor associated with BAT for dust emissions from aluminium melting is 0.1 – 1 kg/t of molten aluminium.

In order to comply with these BAT associated emission levels it may be necessary to install a flue-gas cleaning installation; in this case BAT is to use dry dedusting.

Furnace Type	Parameter	Emission level (mg/Nm³)
General	Chlorine	3
Shaft	SO_2 NO_x CO VOC	30 – 50 120 150 100 – 150
Hearth	SO_2 NO_x CO TOC	15 50 5 5

Table 5.5: Emissions to air associated with the use of BAT in the melting of aluminium

5.4 Lost mould casting

Lost mould casting involves moulding, core-making, pouring, cooling and shake-out. This includes the production of green sand or chemically-bonded sand moulds and chemically-bonded sand cores. Mould and cores are assembled and the molten metal is poured into the assembled mould. The casting is allowed to solidify and cool before shake-out. The available techniques and their environmental effects for moulding and casting are closely interlinked. BAT elements will be presented in three categories: green sand moulding, chemically-bonded sand moulding and pouring/cooling/shake-out.

Green sand moulding
Green sand preparation starts with the mixing of the sand, clay binder and necessary additives. This may be done in atmospheric- (the most common situation) or vacuum mixers (see Section 4.3.2.1). Both methods are considered to be BAT. For vacuum mixing, an additional condition is that the sand capacity needs to be higher than 60 t/h.

Furthermore, BAT for green sand preparation is to:
- enclose all the unit operations of the sand plant (vibrating screen, sand dedusting, cooling, mixing operations) and to dedust the exhaust gas (Section 4.5.8.1), taking into account the BAT associated emission levels as given in Table 5.6. If the local market allows, the captured dust is made available for external re-use (Section 4.8.13). Dust collected from shake-out, dosing and handling is recycled into the green sand circuit, at up to 50 % of the collected mass (Section 4.8.12)
- apply primary regeneration as discussed in Section 4.8.2. The new sand addition depends on the amount of cores used and their compatibility. For green sand monosystems, regeneration ratios (mass of regenerated sand/total sand mass) of 98 % is associated with the use of BAT. For systems with a high degree of incompatible cores the BAT-associated regeneration ratio is 90 – 94 %.

Chemically-bonded sand mould and core-making

Various binder types are in use, all with their own specific properties and applicability. All binders are determined as BAT if they are applied according to the discussed good practice measures, which mainly involve process control and exhaust capture measures to minimise emissions (Section 4.3.3.3, 4.3.3.4). BAT associated emission levels are given below (Table 5.6).

For chemically-bonded sand preparation, BAT is all of the following, to:

- minimise the binder and resin consumption and sand losses, using process control measures, i.e. (manual or automated) mixer control, as discussed in Section 4.3.3.1. For series production involving frequent changes of production parameters and with high production throughputs, BAT is to apply the electronic storage of production parameters (see Section 4.3.3.2)
- capture exhaust gas from the area where cores are prepared, handled and held prior to dispatching
- use water-based coatings and to replace alcohol-based coatings for the refractory coating of moulds and cores, in foundries producing medium and large series. The use of alcohol-based coatings is BAT
  - for big or complex moulds and cores
  - for water glass bonded sands
  - in magnesium casting
  - in the production of manganese steel with MgO-coating.

  Both water-based and alcohol-based coating techniques are BAT in small-scale foundries and large-scale jobbing foundries (see Section 4.3.3.5). Implementation of the water-based technique in these two foundry types is supported by the availability of microwave drying (Section 4.3.3.6) and other novel drying techniques for which no information was submitted. When alcohol-based coatings are used, BAT is to provide evacuation at the coating stand, using movable or fixed hoods, noting that in jobbing foundries that apply floor moulding this is not feasible.

Additionallly, for amine-hardened urethane-bonded (cold-box) core preparation, BAT is all of the following, to:

- treat the evacuated exhaust gas for cold-box core preparation, using one of the methods mentioned in Section 4.5.8.4. The amine emission can be maintained below 5 mg/Nm³
- recover amine from cold-box exhaust scrubbing liquor, provided the total volume allows economic operation (Section 4.6.5)
- use either aromatic-based or vegetable-based (i.e. non-aromatic) solvents. Both methods are BAT (Section 4.3.3.7).

BAT is to minimise the amount of sand going to disposal, by adopting a strategy of regeneration and/or re-use (see section 4.8.13) of chemically-bonded sand (as mixed or monosand). In the case of regeneration, the following conditions apply:

- cold setting monosands (e.g. furan sand) are regenerated using simple mechanical techniques, as presented in Section 4.8.3. This applies to all cold setting monosands, except silicate sand. A regeneration ratio of 75 – 80 % may be achieved
- uncured cold-box and cold setting core sand are hardened and broken in a specific unit, allowing a minimum internal re-circulation of 5 – 10 % of the core sand (Section 4.8.11)
- silicate monosand is regenerated using heating and pneumatic treatment. A regeneration ratio of 45 – 85 % (as yearly average) may be achieved (Section 4.8.10). The use of slow-reacting esters should be minimised
- cold-box, SO_2, hot-box and Croning monosands and mixed organic sands are regenerated using one of the following techniques: cold mechanical regeneration (e.g. grinding, impact drum, pneumatic chafing) or thermal regeneration (Sections 4.8.4, 4.8.5, 4.8.6, 4.8.7). The overall regeneration ratio depends on the amount of cores used. For core-making 40 – 100 % of regenerated sand can be used; in mould making 90 – 100 % of regenerated sand can be used
- mixed green and organic sand are regenerated using mechanical-thermal-mechanical regeneration (Section 4.8.8), grinding (Section 4.8.4) or pneumatic chafing (Section 4.8.6).

For core-making 40 – 100 % of regenerated sand can be used; in mould making 90 – 100 % of regenerated sand can be used
- the quality and composition of the regenerated sand is monitored
- regenerated sand is re-used only in compatible sand systems. Non-compatible sand types are kept apart (see Section 4.8.1).

Alternative moulding methods (Section 4.3.4) and inorganic binders (Section 6.5) are considered to have a promising potential for the minimisation of the environmental impact of moulding and casting processes.

Pouring, cooling and shake-out

Pouring, cooling and shake-out generate emissions of dust, VOCs and other organic products. BAT is to:
- enclose pouring and cooling lines and to provide exhaust extraction, for serial pouring lines (Section 4.5.9.2), and
- enclose the shake-out equipment, and to treat the exhaust gas using wet or dry dedusting as discussed in Section 4.5.9.3. The BAT associated emission level for dust is specified in Table 5.6.

BAT associated emission levels

The following emission levels are associated to the BAT measures stated above. All associated emission levels are quoted as an average over the practicable measuring period. Whenever continuous monitoring is practicable, a daily average value is used. Emissions to air are based on standard conditions, i.e. 273 K, 101.3 kPa and dry gas.

Emission Source	Parameter	Emission level (mg/Nm³)
General	Dust	5 – 20
Core shop	Amine	5
Regeneration units	SO_2 NO_x	120 150

Table 5.6: Emissions to air associated with the use of BAT for moulding and casting using lost moulds

5.5 Permanent mould casting

Permanent mould casting involves the injection of molten metal into a metal mould. The mould is opened after solidification and the casting is taken out for finishing. Chemically-bonded sand cores are used to a limited extent in gravity and low-pressure die-casting.

HPDC dies need coating and cooling in order to provide good solidification and release properties. For these purposes, a release agent and cooling water are sprayed onto the die.
BAT for permanent mould preparation is all of the following, to:
- minimise the consumption of the release agent and water for HPDC dies, using one or more of the process measures discussed in Section 4.3.5.1. This prevents the formation of a mist. If prevention measures do not allow the BAT associated emission level for organic substances as defined in Table 5.7 to be reached, use hooding and EP, as discussed in Section 4.5.8.7
- collect run-off water into a waste water circuit for further treatment
- collect water leakage liquid from hydraulic systems into a waste water circuit for further treatment, using oil interceptors (Section 4.6.4) and distillation, vacuum evaporation or biological degradation as discussed in 4.6.6.

BAT for chemically-bonded sand preparation is analogous to the elements mentioned in Section 5.4. Since lower amounts of waste sand are generated, BAT for shake-out and used sand management are different. BAT for used sand management in permanent mould foundries is to:

- enclose the de-coring unit, and to treat the exhaust gas using wet or dry dedusting as discussed in Section 4.5.9.3, taking into account the BAT associated emission level given in Table 5.7, and
- if a local market exists, make sand from de-coring available for recycling (Section 4.8.13).

BAT associated emission levels

The following emission levels are associated to the BAT measures stated above. All associated emission levels are quoted as an average over the practicable measuring period. Whenever continuous monitoring is practicable, a daily average value is used. Emissions to air are based on standard conditions**,** i.e. 273 K, 101.3 kPa and dry gas.

Parameter	**Emission level (mg/Nm^3)**
Dust	5 - 20
Oil mist, measured as total C	5 - 10

Table 5.7: Emissions to air associated with the use of BAT for permanent mould casting (incl. HPDC)

6 EMERGING TECHNIQUES FOR FOUNDRIES

6.1 Use of low cost combustible materials in cupola melting

Description
In order to reduce the consumption of (high quality) coke, techniques have been developed to allow the use of high calorific value solid waste and lower grade coke as a fuel.

A particular type of cupola, named the FAR furnace, has been developed in Brazil, that allows the melting of a conventional charge using tyres and plastic pieces (automotive shredder residue - ASR, fluff, etc.), mixed with second rate coke. The cupola structure is totally different from the conventional one. Only the metallic charge enters from the top. The solid fuel is fed in from the side, so that it reaches the hot zone very quickly. Here hydrocarbons are cracked and combusted.

Alternative injection systems allow the addition of fluff or dust directly through the tuyères or by using specific injectors.

Achieved environmental benefits
A reduction in the consumption of cokes, as they are replaced by solid waste (ASR, fluff), which is difficult to treat in conventional combustion systems.

Operational data
For the FAR furnace, the best results have been obtained using 35 % fluff and 65 % coke. This technique has been developed up to pilot scale.

Cross-media effects
The application of alternative fuels will cause a change in the flue-gas composition; leading to higher amounts of dust for disposal, possibly with a higher content of pollutants and an increased risk of dioxins, PAHs and heavy metals. The thermal efficiency will be reduced.

Applicability
The application of this specific cupola type is only possible for new installations, since it has a specific furnace layout. Injection systems for solid or fluffy fuels may be applied on existing cupola furnaces.

Economics
Since the process has only been developed up to pilot scale, there are no economic data available for industrial scale application.

Driving force for implementation
To reduce the costs for fuels and to integrate the foundry into a waste management policy.

Reference literature
[140, EU Thematic Network Foundry Wastes, 2001]

6.2 Recycling of metal-bearing filter dust (ferrous metals)

Description
Metal-bearing dust can be agglomerated either using a binder (most preferably cement) or by mixing it with chips from machining, when the foundry has a machining shop. In the latter case the agglomerates may also include metal-bearing sludge. These agglomerates will be mixed in the induction furnace charge and melted. The metal yield can be over 90 %. The rest of the dust goes into the slag. Suitable agglomeration machines exist on the market.

Achieved environmental benefits
The amount of waste to be disposed of in landfills will be reduced, as will the need to buy metallic material outside the foundry. The mineral part of the metallic dust will not melt and is taken up by the slag. Thus it is converted into a less hazardous form of waste.

Operational data
Operational data are currently not available.

Cross-media effects
It may be possible that the slag formed will increase lining wear. Also the energy used in melting may increase slightly. In steel foundries, there is a risk of carbon pick-up.

Applicability
The technique applies to new and existing iron and steel foundries using induction melting furnaces.

Economics
In its current stage of development, no ecomic data are yet available. However, in initial estimates for one iron foundry with a machining shop, the payback time was calculated to be between two and four years.

Driving force for implementation
The main driving force for implementation may be that melting dust could, at least in some cases, be classified as hazardous waste. This would incur very high disposal costs for foundries.

Example plants
No example plants are available.

Reference literature
The technique is under development in the EU in an FP5 Growth project BRICETS "Metal By-Product Recovery in Induction Furnaces - Commercial, Environmental and Technical Solutions", contract number G1RD-CT-2001-00482. The project is due to finish in spring 2004.
[140, EU Thematic Network Foundry Wastes, 2001], [202, TWG, 2002]

6.3 Amine recovery from the core-making waste gas by gas permeation

In a pilot plant, amine (DMIA) was recycled from the exhaust air of a core shop by means of gas permeation. Its composition was as follows:
- 80 – 90 % amine (DMIA)
- 10 – 20 % solvent
- 0 % water.

After several test series, the recycled amine was used to gas brake-disk cores. It was found that there was no difference between these cores and the cores which were gased with standard commercial DMIA. The test cores were poured under normal production conditions and the finished brake disks underwent the usual technical tests.

All the results turned out to be within permissible tolerance. This showed that recycled DMIA can be used under normal production conditions. Economic efficiency may be achieved after further optimisation of the plant.
[217, Paul, et al., 1994]

6.4 Separate spraying of release agent and water in aluminium die-casting

Description
In aluminium high-pressure die-casting, the permanent moulds are cooled and sprayed with release agent prior to casting to prevent the casting adhering to the mould. The conventional technique for release agent use is that a mixture of release agent and water is applied to the hot mould in one go, by means of several linearly arranged nozzles. Some of the water evaporates, cooling the mould and leaving the release agent in place, whilst another part of the mixture runs off the mould, leading to a loss of release agent and water. The evaporation may also cause the formation of a mist. (see Section 4.5.8.7)

In an alternative process, water and release agent are applied separately. For this purpose, a row of nozzles was added to the spray head for the separate application of release agent. These nozzles can be actuated individually via a computer (see Figure 6.1).

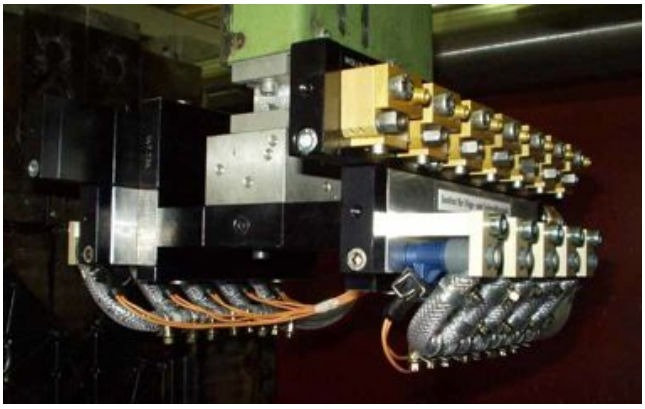


Figure 6.1: Spray head with separate nozzles for water and release agent

Water is sprayed on first, cooling the mould by approximately 20 ºC, followed by spray application of the release agent. The preliminary cooling causes less release agent to evaporate and improves its adhesion to the mould. This reduces the consumption of release agent by some 25 %. Thermographic measurements showed that the technique cools moulds more strongly and more evenly. Tests proved that it involves no leakage of release agent which otherwise would have had to be collected and disposed of.

Release agent is applied only to those parts of the mould which come into contact with the molten aluminium. This can reduce the consumption of release agent by another 30 %.

The use of computer-assisted actuation of the nozzles for the release agent has made the previously used existing array of nozzles for compressed air redundant. This function is now taken over by the nozzles for the release agent.

An advantage with small series and frequent mould changes is that the spraying programme can be saved on the computer and can thus be reproduced quickly after a mould change.

Achieved environmental benefits
The consumption of release agent can be reduced by 25 % by the separate application of water and release agent. Separate actuation of the nozzles makes it possible to achieve a further saving of up to 30 %, depending on the geometry of the casting, as the release agent is applied only to those parts of the mould which come into contact with the casting.

Water consumption can be reduced by about 15 %. There are no losses of water or release agent to be disposed of. No gaseous emissions due to evaporation of release agent are generated.

Cross-media effects
No cross-media effects apply. No increase in energy costs is expected.

Applicability
Previous tests were carried out in aluminium die-casting. The technique can also be applied in zinc die-casting and in the injection moulding of plastics. Modifications are necessary when the spray head is used at higher temperatures. These have not yet been tested.

Economics
Economic advantages result from the considerable savings in release agent and water, and from the elimination of disposal costs.

Further advantages result from the major time savings achieved in the mould change, due to the fact that spraying programmes can be saved and re-run.

The investment costs for this technique are higher than those of the conventional process. On the plus side, different moulds can be sprayed individually with the same spray head.

Driving force for implementation
Considerable saving of material and water.
The loss of release agent-water mixture, which needs to be collected, is avoided.
Short time-scales required for machine set up and adaptation.
High reproducibility of the results (consistent quality).

Example plants
The spray heads are produced and sold by a German producer from the end of 2003. Enquiries from the industry have already been received. Industrial use is expected to start by the end of 2003.

Reference literature
[234, Anders, 2003]

6.5 Inorganic binder material for core-making

Description
In order to reduce the consumption of organic binding material, which is responsible for emissions and odour in foundries (which can lead to complaints from neighbours), different compositions of inorganic binding materials have been developed for use in core-making in aluminium die-casting and have already been used in the series production of intake pipes for car engines.

The cores are produced using a binder that contains magnesium sulphate and/or polyphosphate. The inorganic binders consist essentially of salt-water mixtures, as well as small amounts of additives (e.g. ceramic) to prevent sand adhering or sticking to the casting. The proportion of binder relative to the quantity of sand by weight is 3 to 8%. About half of this amount is solvent and crystal water.

In order to achieve short drying times of 10 to 20 seconds, preheated sand (60 – 80 ºC) is blown into heated core-shooting tools (120 – 140 ºC), in which the solvent water and the crystal water evaporate and are flushed out by air. The inorganic ceramic core will then have a temperature stability of more than 1000 ºC, and will maintain high strength. When coming directly into contact with water, the core disintegrates within a few seconds. The mixing and shooting of warm sand is a patented core-shooting method.

After casting, core removal can be performed either wet or dry. In dry core removal, the lumps of sand are ground to grain size, which leaves the binder layer on the quartz sand largely intact. Therefore, once core sand is in the core sand cycle, binder must be added to it at only 5 % of the binder quantity originally used. In wet core removal, the castings are cooled rapidly by quenching. This can cause a desired improvement of the microstructure and causes the binder to dissolve completely.

The different sand flowing properties will require revision of the core models and venting upon implementation of this technique in an existing plant. In the drying step, all the moisture needs to leave the core, a requirement which may limit the core dimensions.

Achieved environmental benefits
Unlike the cold-box process, which gives rise to emissions of organic compounds such as amines, pyrolysis products and smoke, this technique involves no emissions from the binder, neither during core-shooting nor during casting. No waste is generated through the disposal of sand residues, and there is no need for costly sand regeneration. The quantity of sand to be replaced is very small.

The ceramic additives contained in the binder eliminate the need to coat the cores.

When a dry technique is used for core removal, all the binder remaining in the sand can be re-used.

Operational data
The fluidity of the binder-sand mixture is sufficient to produce complex shapes such as water jacket cores (cylinder head). The stability of test cores is 250 - 300 N/cm^3. The stability can be adapted to core requirements by adding more binder.

As no gases form during casting, no problems with gas permeability arise. The binder therefore allows the use of very fine sands, which significantly improve surface quality (e.g. depth of roughness). As the regeneration rate is high, it is economically viable to use even expensive alternative synthetic ceramic sands or e.g. zircon sand.

Cross-media effects
As there are no emissions from the binder, there is no need for waste gas collection and treatment. The heating of the binder-sand mixture and the preheating of the core-shooting tools give rise to higher energy costs compared to other core-making techniques.

Applicability
This technique is applicable for core-making in aluminium die-casting in new plants and in existing plants after adaptation of the core-shooting automates. Further developments are aimed at adapting the binder for use in iron casting and as a moulding material.

Economics
Despite the need to heat core-shooting tools, this technique leads to overall cost savings for core-making, due among other things to the lower consumption of new sand and the fact that costly thermal regeneration or the disposal of sand is no longer necessary. Costs savings can also be generated by recirculating the binder. Considerable cost reductions are achieved by the fact that there is no need for waste gas treatment systems to remove organic compounds, such as amines and pyrolysis products, which can arise during core-shooting and casting when organic binders are used.

According to rough estimates, the use of this technique reduces the costs for core-making by 30 to 50 % compared to the cold-box process.

Driving force for implementation
Considerable cost reduction.
Reduction of odour problems and organic emissions.

Example plants
Foundry of VW AG, Hanover, Germany

Reference literature
[235, Bischoff, 2003]

7 CONCLUDING REMARKS

7.1 Timing of the work

The first plenary meeting of the TWG was in April 1999. However, shortly after this, the project was put on hold from January 2000 due to a change of lead expert in the EIPPCB. The work recommenced in November 2001. A second plenary meeting of the TWG was organised in January 2002 to review the status of the work and the conclusions of the first meeting, taking into account possible new developments in the sector. The first draft of the BREF was then sent out to the TWG for consultation in November 2002. The comments were assessed and integrated into the document and a second draft, including proposals for BAT conclusions was sent out in May 2003. The final plenary meeting of the TWG was organised in October 2003. After the final meeting there was a short consultation on the concluding remarks and executive summary chapters before the final version of the document was produced.

7.2 Sources of information

Many documents were sent in by research centres, authorities and by industry as a basis of information for this document. The BAT documents from Belgium [110, Vito, 2001] and from the industry [32, CAEF, 1997] may be considered as the cornerstone documents. These were used as a starting point in the writing of the chapter on techniques to be considered in the determination of BAT (Chapter 4). These were supplemented by BAT documents and good environmental practice guides from the UK, Spain, Denmark and the Netherlands. Valuable information on specific techniques and their implementation in example plants was provided by Germany. Throughout the project there was a good and open communication with foundry experts from research centres and associations in France, Germany, Spain, UK, Finland, Belgium, Italy, Sweden and Portugal. Site visits were carried out in Germany, France, Spain, Belgium and Poland. The consultation rounds provided specific feedback from foundry operators, remarks on applicability and implementation of some techniques and additional operational data. Throughout the project, special attention was given to the involvement of the new Accession Countries that have important foundry industries. This resulted in the active participation of Poland, the Czech Republic and Hungary in particular in the information exchange.

In order to get a better view on what information was available on dioxin emission and abatement, the industry delegation organised a special workshop, in September 2003. This workshop was attended by over 30 participants, both TWG members and industry experts. It provided additional operational data and useful technical information.

The majority of the documents arising from the information exchange related to ferrous foundries. Non-ferrous foundry processes have been underrepresented throughout the exchange process. Nevertheless, there was a good communication with a few industry experts, although they did not attend the plenary meetings of the TWG. Valuable information was gathered during site visits at non-ferrous foundries in Germany, France and Belgium. The International Magnesium Association provided useful input on cover gases for magnesium melting.

The data quality of this document shows an imbalance, in that, for instance, consumption and emission levels mentioned in Chapter 3 and Chapter 4 vary from survey data for the sector in a whole country, to data covering several example plants, to specific data on single plants.

Emission data for non-ferrous metals are mainly based on single installations. For the melting of copper and zinc, only emission factors (given in kg/tonne of metal or kg/tonne of casting) were supplied. For the melting of magnesium and lead, no consumption and emission levels were provided. For the melting of aluminium, no emission data were provided for induction, rotary or

crucible furnaces. Where available, the emission factors are mentioned in Chapter 3. However, there was no clear correlation between the mentioned emission factors and applied techniques. Therefore BAT conclusions with an associated emission level were not possible for the melting of non-ferrous metals other than aluminium.

The document contains information on waste water prevention and treatment techniques. However, no data were supplied on the emission levels associated with these techniques. No operational data on waste water quality in relation to the applied treatment were provided. It was therefore not possible to determine a BAT associated emission level for waste water.

No information was provided concerning techniques for the abatement of VOC-emissions. The lack of information on abatement techniques and associated emission levels made it impossible to formulate a BAT conclusion. Techniques for the reduction of VOC-emissions related to coating processes (as applied to cores and moulds) may be found in the BREF on Surface Treatment Using Solvents.

In the discussion on the re-use of dust and residues, no information was provided on treatment or re-use techniques for dust from induction furnace melting, for dross from aluminium melting, fettling dusts, abrasives or for blasting grit, although a re-use of most of these materials into secondary metal production is possible.

Legislation surveys were sent in by two member states, but these are not necessarily representative for the whole of the European Union. Information on the applicable legislation in these two member states can be found at the following internet addresses:
- Austria: http://www.ris.bka.gv.at/
- Germany: http://www.bmu.de/de/txt/download/b_taluft/

7.3 Degree of consensus reached

The conclusions of the work were agreed at the final plenary meeting in October 2003 and a high level of consensus was reached. The industry expressed one concern on the dioxin issue, as expressed in detail in Section 5.2. Besides this concern, there was full agreement on all the BAT conclusions as presented in this document.

The main issues of discussion at the final meeting concerned the techniques for the collection and treatment of off-gas, the minimisation of fugitive emissions, noise reduction, the role of environmental considerations in technical choices and the BAT associated emission levels. For some processes, mainly in the field of non-ferrous metal melting, the information was incomplete and therefore no BAT AEL could be agreed. During the meeting, there was little discussion on the techniques that are specific for non-ferrous foundries, partially due to the absence of industry experts in this field.

The issue about whether environmental considerations play a detrmining role in the basic choice of melting furnaces and moulding methods, as formulated in Chapter 4 of the document, was carefully considered. There was a general agreement that these choices are complex and should be based on technical reasons and market considerations, on a case-by-case basis. Therefore the issue was not selected as BAT.

The discussions on the treatment of off-gases concluded with an agreement that for most operations in ferrous foundries both dry systems and well-performing wet systems are BAT. The associated emission levels were based on the information available in the document.

Concerning the reduction of fugitive emissions and noise, there was some discussion on the presentation of the topics and the level of detail to be given in Chapter 4 and Chapter 5. There was a general agreement not to conclude on a specific level of noise which could be associated with BAT.

7.4 Recommendations for future work

The information exchange and the result of this exchange, i.e. this document, present an important step forward in achieving the integrated prevention and control of pollution from the foundry industry. On a few topics, however, the information is incomplete and did not allow BAT conclusions to be reached. The main issues have been presented in Section 7.2. Future work could usefully focus on collecting the following information:

- *Techniques for VOC-abatement*: VOC-emissions are generated by the thermal decomposition of the binders upon pouring, in coating the cores and moulds and in the melting of dirty scrap, and are one of the key environmental issues for the sector. VOC-emissions in foundries typically involve large-volume, low-level flows, which represent a significant load to the environment and may result in an odour emission. Information is needed on techniques for the efficient capture and treatment of these flows, together with associated emission and economic data. The prevention of VOC emissions through the use of alternative binder and coating materials, also deserves further study. Data should be gathered and reported from the implementation of these techniques in operational practice
- *Waste water treatment*: Waste water treatment is presented in a general descriptive way in this document, and indeed operational data are given for only one example plant. The basis for discussion should be broadened, through an exchange of information on the performance of a broader range of treatment plants and providing further operational data. In view of the selection of wet scrubbing as part of BAT, information should be gained on the associated treatments of waste water and on emission levels to surface and sewage water flows
- *Melting of non-ferrous metals*: The discussion on non-ferrous metal melting is based on the melting of clean ingots and clean internal return material. On this basis, low emission levels are presumed. There is a need for more complete information on both guided and fugitive emissions (e.g. of metals, organics) from non-ferrous metal melting in foundries, based on operational practice and expressed both as an emission level (mass/exhaust volume) and as a mass flow (mass/output of metal or castings)
- *Economic data*: There is a lack of economic information for many of the techniques presented in Chapter 4. This information needs to be collected by industry and Member States from ongoing projects dealing with the implementation of the presented techniques
- *Energy Efficiency:* Examples of techniques for heat recovery for induction and cupola furnaces are given in this document. There is a need for additional examples of heat recovery systems, with performance data. Information should be gathered concerning enrgy consumption and energy losses for all types of furnaces, related to specific techniques to increase the energy efficiency. This may then allow the determination of BAT-associated energy consumption levels for metal melting.

7.5 Suggested topics for future R&D projects

The information exchange has also exposed some areas where additional useful knowledge could be gained from research and development projects. These relate to the following subjects:

- *Dioxin monitoring and abatement:* In order to allow the full implementation of primary measures for dioxin prevention, there is a need for a better understanding of the contribution of the process parameters to the formation of dioxins. This requires the monitoring of dioxin emissions for various installations and under varying conditions. Additionally, there is a need for research on the use and effectiveness of secondary measures in the foundry industry. Secondary measures (e.g. additive injection, catalytic filter bags) have been implemented in other sectors (e.g. steel, waste incineration, non-ferrous metals production), but there is very little experience of their performance and of possible operational problems which may occur in applying then in foundries

- *Mercury emissions:* Stack emissions of metals are largely related to dust. The minimisation of dust emissions, as presented in the BREF will therefore also minimise possible metal emissions. This holds true for all metals of concern for the sector, besides mercury. Uniquely for metals the high volatility of mercury may cause gaseous emissions which are not related to dust. In view of the implementation of a European policy on mercury emissions, there is a need for research on the emissions of mercury from melting processes in general and more specifically from (non-ferrous) foundries in particular
- *Oxygas burners and their use in cupola furnaces*: The application of oxygas burners in the cupola furnace is described in Section 4.2.1.10. The technique shows some environmental benefits. The difficulties encountered in the implementation of this technique, however limit its widespread take-up. The TWG reported that new applications have been set up as a result of ongoing research. There is a scope for further research and development here, to bring this technique up to a development level that allows its further implementation.
- *Alternative replacement gases for SF_6 in magnesium melting:* Alternative covers gases to replace SF_6 such as HFC-134a and Novec 612 have been developed and successfully tested with some recent industrial implementation. These gases present an alternative for the substitution by SO_2. Further research and demonstration projects would provide more detailed knowledge on the protective properties decomposition behaviour and emission pattern of these compounds. This should allow a clearer indication of the applicability and may support industrial implementation.

8 REFERENCES

2 Hoffmeister, J.; Reichardt, N. and Alwast, H. (1997). "NE-Metallindustrie - Betreiberleitfaden für Anlagen zum Gießen in verlorenen Formen - Sandgußverfahren", Ministerium Umwelt, Raumordnung u. Landwirtschaft NRW.

9 Schneider, B. (1993). "Verwertung von Gießereialtsanden durch thermisch-mechanische Aufbereitung in einer zentralen Anlage", Umweltbundesamt, 30 441-5/9.

11 Schachtner, J. and Müller-Späth, G. (1993). "Demonstrationsanlage zur thermischen Altsandregenerierung mit Komponententrennung für Quarz- und Chromerzsand (Demonstration Plant for Thermical Regeneration of Used Sand with Components Separation of Silica and Chromite Sand - Final Report 9010)", Umweltbundesamt, UBA3 0 441-2/4.

15 Gwiasda, F. (1984). "Erfassung und Reinigung von Abgasen bei der Kernfertigung einer Gießerei", Umweltbundesamt.

16 Gerber, E. and Gwiasda, F. (1981). "Erfassung und Reinigung von Abgasen an Ausschlagrosten einer Gießerei", Umweltbundesamt.

17 Strauß, D. (1983). "Emissionsminderung druch Umbau einer Kupolofenanlage (Reduction of Emissions by Reconstruction of Cupola Furnace Melting Plant - Final Report 1018)", Umweltbundesamt.

18 Rademacher, H. (1993). "Errichtung und Betrieb einer Absaugung der Induktionsofen-Schmelzerei und Nebenbetriebe (Establishment and Operation of Exhausting the Induction Furnaces Melting Equipment and its Sub-Plants - Final Report 1107", Umweltbundesamt, 50 441-5/168.

20 Gapp, H. (1998). "Reduzierung des Gehaltes an Benzol in den Abgasen von Gieß- und Kühlstrecken durch den Einsatz eines Bio Filters (Reduction of the Benzene Content in the Exhaust Gas from Casting and Cooling Lines by Using of a Biological Filter - Final Report 2041)", Umweltbundesamt, 50 441 - 7/10.

21 Strauß, D. (1994). "Emissionsminderung durch Anwendung moderner Prozesstechniken in einer Gießerei (Reduction of Dust and Gaseous Emissions in a Foundry by Applying Modern Process Techniques - Final Report 1095)", Umweltbundesamt, 0 441-5/145.

23 Brettschneider, D. and Vennebusch, B. (1992). "Luftreinhaltung - Verbesserung der Emissionssituation eines Gießereischmelzbetriebes mit zwei Drehtrommelöfen (Improvement of Conditions for Emissions of a Melting Range with Two Rotary Furnaces) - Final Report 1119", Umweltbundesamt, 50 441 - 1/56.

27 Kran, H.-P.; Rudolph, A. and Reinhold, M. (1995). "Reduction of Emissions of a Hot Blast Copula Furnace by Application of a Fabric Filter and by Using of Waste Heat and Residue - Final Report", Umweltbundesamt, UBA 0 441-/ZII 1.1-50 441-5/178.

29 Batz, R. (1986). "Stand der Technik bei der Emissionsminderung in Eisen-, Stahl- und Tempergießereien", Umweltbundesamt.

32 CAEF (1997). "BAT for the Abatement of Atmospheric Pollution in the Ferrous Foundry Industry", European Commission - DG XI.E.1.

34 Binninger, W. (1994). "Vermeidung von Abfällen durch abfallarme Produktionsverfahren - Reststoffe aus Schelzanlagen für Nichteisenmetalle (NE-Schwermetallguß)", Abfallberatungsagentur (ABAG).

36 Winterhalter, J.; Mauersberger, G.; Bars, P. and Toussaint, D. (1992). "Vermeidung von Abfällen durch abfallarme Produktionsverfahren - Gießereialtsande aus Nichteisenmetallgießereien", Abfallberatungsagentur (ABAG).

37 Winterhalter, J.; Mauersberger, G.; Bars, P. and Toussaint, D. (1992). "Vermeidung von Abfällen durch abfallarme Produktionsverfahren - Gießereialtsande aus Eisen-, Stahl- und Tempergießereien", Abfallberatungsagentur (ABAG).

42 US EPA (1998). "EPA Office of Compliance Sector Notebook Project: Profile of the Metal Casting Industry", U.S. EPA, EPA/310-R-97-004.

43 Batz, R. (1996). "Dioxin- und Furanemissionen aus Schmelzanlagen in Eisen-, Temper- und Stahlgießereien", Umweltbundesamt, 0722 186X.

44 ETSU (1993). "Cupola Melting of Cast Iron in Iron Foundries (Good Practice - Guide 58)", Energy Efficiency Office - Department of the Environment.

45 ETSU (1990). "Achieving High Yields in Iron Foundries (Good Practice - Guide 17)", Energy Efficiency Office - Department of the Environment.

46 ETSU (1995). "Energy Saving in Foundry Services (Good Practice - Guide 166)", Energy Efficiency Office - Department of the Environment.

47 ETSU (1992). "Guidance Notes for the Efficient Operation of Coreless Induction Furnaces (Good Practice - Guide 50)", Energy Efficiency Office - Department of the Environment.

48 ETSU (1994). "Improving Metal Utilisation in Aluminium Foundries (Good Practice - Guide 142)", Energy Efficiency Office - Department of the Environment.

55 ETSU (1993). "Electric Holding of Hot Metal in Iron Foundries", Energy Efficiency Office - Department of the Environment.

64 ETSU (1997). "Non-Ferrous Foundries (second edition)", Energy Efficiency Office - Department of the Environment.

70 ETSU (1998). "Optimising Sand Use in Foundries", Energy Efficiency Office - Department of the Environment.

71 ETSU (1998). "Cost-Effective Management of Chemical Binders in Foundries (GG104)", Energy Efficiency Office - Department of the Environment.

72 ETSU (1995). "Chemically Bonded Sand: Use and Reclamation (EG4)", Energy Efficiency Office - Department of the Environment.

73 ETSU (1995). "Foundry Greensand: Use and Reclamation (EG 5 Guide)", Energy Efficiency Office - Department of the Environment.

75 ETSU (1996). "Improved Process Control Reduces Mould Losses", Energy Efficiency Office - Department of the Environment.

78 ETSU (1996). "Environmental Management Systems in Foundries (GG 43 Guide)", Energy Efficiency Office - Department of the Environment.

80 ERM Lahmeyer International GmbH (1999). "Aufkommen und Entsorgung von Gießereialtsanden (Amount of Waste Foundry Sand and Disposal)", Umweltbundesamt.

82 IfG - Institut für Gießereitechnik (1996). "Untersuchung von Eisen- und NE-Metallgießereien - Branchengutachten", Ministerium Baden-Württemberg, 0941-780 X.

96 Spillner, A. (1997). "Vermeidung von Kernsanden und Aminabfällen durch den Einsatz des Lost-foam-Verfahrens im Leichtmetall-Serienguß", Abfallberatungsagentur (ABAG).

103 Vereniging van Nederlandse Gemeenten (1998). "Werkboek milieumaatregelen Metaal - en Elektrotechnische Industre", VNG Uitgeverij.

108 FEAF (1999). "Fundición de Metales Ferrosos", Fundación Entorno Empresa y Medio Ambiente.

110 Vito (2001). "Beste Beschikbare Technieken voor de Gieterijen", Vito, ISBN 90 382 0312 8.

112 Salminen, S. and Salmi, J. (1999). "The Biological Air Purification System in Purifying Odours Produced in a Foundry Process", Vapo Oy Biotech.

122 Kirst, J. (1999). "Regenerierung von Kernformstoffen und Formstoffen", Umweltbundesamt, UBA III 2.2-50441-14/7.

126 Teknologisk (2000). "A Survey of the Pollution and Environmental Conditions in the Foundry Industry", Danish Technological Institute.

128 IHOBE (1998). "Arenas de Moldeo en Fundiciones Ferreas", Gobierno Vasco.

129 infoMil (1999). "Reductie van de uitstoot van isopropylalcohol door ijzergieterijen", infoMil.

130 de Wilde, J. M. and ten Houten, M. R. (1999). "LCA van drie gietsystemen voor gietijzer op basis van de LCA van een compressor casing ten behoeve van een rotorhuis Z3", TNO Industrie.

133 De Globe B.V. (1999). "Aanvraag revisievergunning Wet milieubeheer", Provincie Limburg.

138 Metaalgieterij Giesen B.V. (1996). "Emissiemeetprogramma Thermische Zandregeneratie", Provincie Limburg.

140 EU Thematic Network Foundry Wastes (2001). "Foundry Waste Possibilities in the Future", Inasmet.

141 CERP (1999). "Foundry Process Emission Factors: Baseline Emissions from Automotive Foundries in Mexico", Casting Emission Reduction Program.

143 Inasmet and CTIF (2002). "Eurofond 2002: Sand Moulding: Key to Competitiveness" Eurofond 2002, *San Sebastian (E)*.

144 US Dept. of Energy (1998). "Advanced Lost Foam Casting", Office of Industrial Technologies, http://www.oit.doe.gov/factsheets/metalcast/pdfs/lostfoam.pdf.

145 Inductotherm (2002). "Inductotherm Safety Manual On-line", Inductotherm, http://www.inductotherm.com/safety/safety.htm.

148 Eurofine (2002). "European Foundry Internet Network", http://eurofine.reflexe.fr/BDdebut_an.html.

149 Beauvais, P. and Choplin, L. (2001). “New technologies for the application of water-based coatings", Fonderie Fondeur Aujourd'hui, 201, pp. 9-29.

150 ETSU (1998). "Long campaign hot-blast cupolas in iron foundries", GPCS366.

151 Gemco (1999). "Sand Cleaner", Gemco Engineers Foundy Projects.

152 Notzon, I. and Heil, D. (1998). "Verminderung von Kernsanden aus dem CO2-Wasserglas-Verfahren durch mechanische Regenerierung", Abfallberatungsagentur (ABAG).

153 Umweltbundesamt (2002). "Techniken zur Regenerierung von Mono- und Mischsanden aus Giessereien", Umweltbundesamt, personal communication.

154 Baum (2002). "personal communication", firma Bröer, personal communication.

155 European IPPC Bureau (2001). "Reference Document on Best Available Techniques in the Non-Ferous Metal Industries", European Commission.

156 Godinot, P. (2001). “Evolution of the Cupola in Europe", Fonderie Fondeurs Aujourd'hui, 205, pp. 28-40.

157 Godinot, P.; Charbonnier, M.; Dervin, B. and Morin, A. (1999). “Le traitement des fumées de cubilot", Fonderie Fondeurs d'Aujourd'hui, 188, pp. 37-43.

158 Charbonnier, M.; Godinot, P. and Stephan, J. (1998). “Devenir des poussières de cubilots dépoussierés à sec", Fonderie Fondeur Aujourd'hui, 174, pp. 44-52.

160 UK Environment Agency (2002). "Interim Guidance for the A2 Ferrous Foundries Sector - External Consultation Draft", IPPC S(A2)2.01 (2002).

161 UK Environment Agency (2002). "Process Guidance Note Draft Electrical, Crucible and Reverberatory Furnaces", UK Environment Agency, PG 2/3 (2002).

163 UK Environment Agency (2002). "DRAFT Process Guidance Note: Hot and cold blast cupolas and rotary furnaces", UK Environment Agency, 163.

164 UK Environment Agency (2002). "Draft Process Guidance Note Processes for melting and producing aluminium and its alloys", UK Environment Agency, PG 2/6a(2002).

165 UK Environment Agency (2002). "Draft Process Guidance Note Processes for melting and producing magnesium and its alloys", UK Environment Agency, PG 2/6b(2002).

168 CAEF (2002). "Data relating to the European Foundry Industry", Committee of European Foundry Associations, http://www.caef-eurofoundry.org/industry.htm.

169 Orkas, J. (2001). "Technical and environmental requirements for surplus foundry sand utilisation", Helsinki University of Technology.

170 Godinot, P. and Carlier, P. (1999). “Le Cubilot sans Coke", Fonderie - Fondeurs d'Aujourd'hui, 185, pp. 32-38.

171 The Castings Development Centre (1999). "Beneficial Re-use for Managers", The Castings Development Center.

172 Neumann, F. (1994). "Gusseisen", expert verlag.

173 Huelsen, W. B. (1985). “Arc furnace emission control", The British Foundryman, july 1985, pp. 302-309.

174 Brown, J. R. (2000). "Foseco Ferrous Foundryman's Handbook", Butterworth-Heinemann, ISBN0 7506 4284 X.

175 Brown, J. R. (1999). "Foseco Non-ferrous Foundryman's Handbook 11th Ed.", Butterworth Heineman, ISBN 0 7506 4286 6.

176 ETSU (1998). "Induction Melting of Aluminium", Good practice guide 229.

177 Silva Ribeiro, C. A. (2002). "Mass balance data for non-ferrous foundries", Associação Portuguesa de Fundição.

178 Wenk, L. (1995). "Use of hexachloroethane for refinement of aluminium alloys and grain refinement of aluminium containing magnesium alloys", Verein Deutscher Giessereifachleute (VDG), personal communication.

179 Hoppenstedt (2002). "Guss Produkte Jahreshandbuch", Giessereien - Zulieferer - Ausstatter.

180 Assofond (2002). "Italian Foundry dust emission data", Assofond.

181 Ruffin, A. and Godinot, P. (1998). “Recyclage des poussières du cubilot", Fonderie Fondeurs Aujourd'hui, 175, pp. 18-41.

182 Closset, B. (2002). "SF6 replacement", International Magnesium Association, personal communication.

183 Goovaerts, L. (2002). "Emission data from site visits", Vito, personal communication.

184 Godinot, P. and Ressent, S. (2002). “Bibliographical study and survey on the coke-gas cupola", Fonderie fondeur d'aujourd'hui, 216, pp. 32-41.

185 Spitz, G. (2002). "Operational data PSA foundry", PSA Sept-Fons, personal communication.

186 Stephan, J. (1996). “Régénération thermique des sables de fonderie - caractérisation d'une installation Regetherm 500", Fonderie Fondeurs d'Aujourd'hui, 158, pp. 37-47.

187 Stephan, J. (1997). “Régénération thermique des sables de fonderie - caractérisation d'une installation Richards PX800", Fonderie Fondeurs d'Aujourd'hui, 170, pp. 21-53.

188 Stephan, J. (2000). “Régénération thermique des sables de fonderie - caractérisation d'une installation Fataluminium Eco-Rec", Fonderie Fondeurs d'Aujourd'hui, 198, pp. 54-69.

189 Hüttenes-Albertus (2002). "Die neue Cold-box Generation".

190 Schubert, W. and Gjestland, H. “Use of SO2 as protection gas in magnesium die casting".

191 IMA; Erickson, S. E.; King, J. F. and Mellerud, T. "Recommended practices for the conservation of sulphur hexafluoride in magnesium melting operations", International Magnesium Association, technical committee report.

192 Gjestland, H. and Westengen, H. (1996). "Use of SF6 in the megnesium industry, an environmental challenge" 3rd International Magnesium Conference, *Manchester*.

194 UNEP IPCC (2002). "Climate change 2001: the Scientific basis", Intergovernmental Panel on Climate Change, http://www.grida.no/climate/ipcc_tar/wg1/001.htm.

195 UBA (2003). "Waste Water from Iron, Steel and Malleable Iron Foundry", Umweltbundesamt.

196 Unido (2002). "Cleaner Production in Metalworking (foundry)", Unido Information Sources on Cleaner Production, http://www.unido.org/ssites/env/sectors/sectors303.html#1.

197 Nalonchem (2002). "Foundry coke", http://www.nalonchem.com/productos.htm.

198 Georg Fischer "Einsaugsystem für Kupolöfen", GF.

199 Metalodlew s.a. (2002). "De-dusting system for Electric Arc Furnaces in the cast steel foundry Metalodlew s.a.", Metalodlew s.a.,.

200 Metalodlew s.a. (2002). "A site for regenerating of self-hardening moulding core sands in the cast steel foundry Metalodlew s.a.", Metalodlew.

201 CEN (2000). "Definition and classification of grades of steel (EN10020)", European Committee for Standardisation, EN10020.

202 TWG (2002). "Comments to first draft".

203 Linxe, D. (2002). "Le prototypage rapide et ses applications en fonderie", CTIF.

204 Carnicer Alfonso, P. L. (2001). "Emisiones de un Horno Rotativo de Oxigas para la fabricación de fundición férrea. Diagnóstico y medidas correctoras.", Universidad del Pais Vasco.

205 European IPPC Bureau (2003). "Reference Document on Best Available Techniques on Emissions from Storage", European Commission.

206 Ditze, A. and Scharf, C. (2000). "Remelting of Magnesium type 1 scrap with or without flux?", Magnesium Industry Website, http://www.magnesium-industry.com/Library/Highlights/Paper%20of%20the%20Month/papers/Remelting%20of%20Magnesium%20Type%201%20Scrap%20with%20or%20without%20Flux.pdf.

207 Drews, B. (1996). “Simultaneous mixing and cooling of moulding sand under vacuum", Casting Plant+Technology International, 2, pp. 4-10.

208 Devinny, J. S. (1998). “Cleaning the Air, Biologically", Civil Engineering, september, pp. 46-49.

209 Metalodlew s.a. (2003). "Environment-frienly conditions and improvement of work conditions", Metalodlew, http://metalodlew.nss.pl/eng/produkcja/srodowisko/index.php.

210 Martínez de Morentin Ronda, J. (2002). "Operational data Lur-Sue Foundry", Lur-Sue, personal communication.

211 European IPPC Bureau (2000). "Best Available Techniques Reference Document on the production of iron and steel", European Commission.

212 Zalensas, D. L. (1993). "Aluminium Castings Technology, 2nd ed.", American Foundrymen Society.

213 CTIF and CQRDA (2002). "Cast Aluminium Alloys - The reference guide", Artecomm document engineering.

214 Gerl, S. (2003). "Aufbereitung von Feststoffmischungen mit Evactherm-Vakuummischern", Giesserei-Praxis, 1-2003, pp. 17-22.

215 Müller, G. (1996). "Direkterfassung von Emissionen aus Formkästen im Groß- und Einzelguß (Hohl- und Vollform)", BIA, ISBN 3-88383-425-4.

216 Hobelsberger, H.; Kröger, H. and Nisi, D. (1997). "Erste Erfahrungen met einem weiterentwickelten umweltverträglichen Cold-Box-System bei Daimler-Benz", Giesserei, 84/21, pp. 48-49.

217 Paul, H.; Nisi, D. and Timm, J. (1994). "Solvent (amine) recycling from the exhaust air of a core shop by means of gas permeation" GIFA-Kongress Giessereitechnik '94, *Düsseldorf (D)*.

218 Harnisch, J. and Schwarz, W. (2003). "Cost and impact on emissions of potential regulatory framework for reducing emissions of hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride", Ecofys GmbH, Öko-Recherche, B4-3040/2002/336380/MAR/E1.

219 Castings Technology International (2003). "Replicast (R)", CTI, http://www.castingsdev.com/tech_services/replicast/replicast.htm.

223 Rauch, E.; Sigmund, A. and Galovsky, U. (2003). "Technische und betriebswitrschaftliche Aspekte des Inhouse-Recycling von Mg-Legierungen", http://www.lkr.at/german/news/news1/pdf/technische_betriebswirtschaftliche.pdf.

224 Helber, J.; Bautz, H. and Wolf, G. (2000). "PCDD-/PCDF-Emissionnen bei Kupolöfen" Conference Internationale sur le Cubilot, *Strasbourg*.

225 TWG (2003). "Comments to the Second draft".

226 CTIF (1997). "Evolution des moyens d'élaboration de la fonte liquide", Ademe, 4.02.0025.

227 Godinot, P. (2004). "The economical future of cupola" International cupola conference, *Trier*.

228 Galante, G.; Michilli, O. and Maspeto, R. (1997). "No-bake as we see it", Impianti Machine Fonderia.

229 Lilja, B. G.; Westberg, H. and Nayström, P. (2000). "Survey of isocyanates in foundries, parts 1-5", Swedish Foundry Association - Svenska Gjuteriföreningen, 000317.

230 CAEF (2003). "Presentations of the Dioxin Workshop" Dioxin Workshop 24/09/2003, *Brussels*.

231 UNEP (2003). "Formation of PCDD and PCDF - an overview" Stockholm convention on persistent organic pollutants, expert group on BAT and BEP, *Research Triangle Park (USA)*.

232 Novem (2000). “Vervangen cokes-gestookte kroesoven door aardgas/zuurstof-gestookte trommeloven", Tenders Industriële Energiebesparing, 39520/0047.

233 IARC (1997). "Silica, some silicates, coal dust and para-aramid fibrils", International Agency for Research on Cancer.

234 Anders, U. (2003). “Ökologisch und ökonomisch optimierter Trennstoffeinsatz beim Aluminium-Druckguss", Integrierter Umweltschutz in Gießereien, Verein Deutscher Gießereifachleute.

235 Bischoff, U. (2003). "Untersuchungen zum Einsatz eines wasserlosen, anorganischen Kernbinders auf Basis von Magnesiumsulfat in einer Aluminiumleichtmetallgießerei", Universität Bergakademie.

236 UK Environment Agency (2001). "Guidance for the recovery and Disposal of hazardous and non-hazardous waste (other than by incineration and landfill)", SEPA, IPPC S5.06.

237 HUT (2003). "Foundry pictures database", Helsinki University of Technology.

Note: The numbers do not follow sequentially. They refer to the document numbers in the EIPPCB database (Technical material on Smitheries and Foundries). Only the references utilised in this document are quoted here.

9 GLOSSARY

9.1 Abbreviations

AEL	associated emission level
ADI	austempered ductile iron
AFS	American Foundrymen Society
AFS-number	measure of particle size distribution of foundry sand
AOD converter	argon oxygen decarburisation converter
AOX	absorbable organic halides
BAT	best available techniques
BREF	BAT reference document
BTEX	benzene, toluene, ethylbenzene,xylene
BTX	benzene, toluene,xylene
CAD	(before number): Canadian Dollar - ISO currency unit
CAD	(general): Computer aided design
CAEF	Committee of Associations of European Foundries
CAM	computer-aided manufacturing
CBC	cold blast cupola
CNC	computer numerical controlled
DEM	Deutsche Mark (German Mark - ISO currency unit)
DMEA	dimethyl ethyl amine
DMIA	dimethyl isopropyl amine
DMPA	dimethylpropylamine
DS	dry solid
EAF	electric arc furnace
EEA	European Environment Agency
EFR	Emission Factor Rating
EIPPCB	European IPPC Bureau
EMS	environmental management system
EP	electrostatic precipitator
EPER	European Pollutant Emission Register
EPS	expanded polystyrene
EUR	euro
FA	furfuryl alcohol
GWP	global warming potential
GBP	Great Britain Pound – ISO currency unit
HBC	hot blast cupola
HCE	hexachloroethane
HFC	hydrofluoro carbon
HIP	hot isostatic pressing
HP	high purity (for Magnesium alloys)
HPDC	high pressure die-casting
ID-fan	induced draught fan
IEF	Information Exchange Forum (informal consultation body in the framework of the IPPC Directive)
IF	induction furnace
IMA	International Magnesium Association
IPA	isopropyl alcohol
IPPC	integrated pollution prevention and control
IPTS	Institute for Prospective Technological Studies
JRC	Joint Research Centre
l.	left
LCA	life cycle assessment
LOI	loss on ignition

m.	middle
MDI	methyl di-isocyanate
n.a	not applicable
n.d	no data
NM-VOC	non-methane volatile organic carbons
OU	odour units
PAH	polycyclic aromatic hydrocarbon
PCDD/F	polychlorinated dibenzodioxins and -furans
PCB	polychlorinated biphenyl
PE	polyethylene
PEVA	polyethylene vinyl acetate
PF	phenol - formaldehyde
PFC	perfluorinated carbon
PM	particulate matter
PMMA	polymethylmethacrylate
ppm	parts per million
r.	right
RF	rotary furnace
RP	rapid prototyping
RPM	respirable particulate matter
SG	spheroidal graphite
SME	small and medium enterprise(s)
TEA	triethyl amine
TEQ	toxicity equivalent factor
TWA	time-weighted average
TWG	technical working group
VOC	volatile organic compound
VODC	vacuum oxygen decarburisation converter
UF	urea-formaldehyde
USD	United States Dollar – ISO currency unit

9.2 Terms

Annealing	a heat treating process that softens the alloy by slow cooling the metal through its critical temperature range
Austenitising	a heat treating process that holds the alloy above the critical temperature for a sufficient period of time to ensure that the matrix is fully transformed to austenite
Air factor	λ, the ratio of the air added to a combustion process over the stoechiometric quantitiy of air needed for complete oxidation
Cast iron	a ferrous alloy which solidifies with an eutectic solidification reaction, whatever the chemical composition, but normally with a carbon content above 2 %
Casting *(noun)*	general term used for products at or near their finished shape, formed by solidification of a metal or alloy in a mould (ISO 3134-4: 1985)
Diffuse emission	emissions arising from direct contact of volatile or light dusty substances with the environment (atmosphere, under normal operating circumstances). These can result from: - inherent design of the equipment (e.g. filters, dryers…) - operating conditions (e.g. during transfer of material between containers) - type of operation (e.g. maintenance activities) - or from a gradual release to other media (e.g. to cooling water or waste water). Fugitive emissions are a subset of diffuse emissions
Emission	the direct or indirect release of substances, vibrations, heat or noise from individual or diffuse sources in the installation into the air, water or land
“End-of-pipe” technique	a technique that reduces final emissions or consumptions by some additional process but does not change the fundamental operation of the core process. Synonyms: "secondary technique", "abatement technique". Antonyms: "process-integrated technique", "primary technique" (a technique that in some way changes the way in which the core process operates thereby reducing raw emissions or consumptions)
Existing installation	an installation in operation or, in accordance with legislation existing before the date on which this Directive is brought into effect, an installation authorised or in the view of the competent authority the subject of a full request for authorisation, provided that that installation is put into operation no later than one year after the date on which this Directive is brought into effect
Ferrous materials	those materials of which iron is the major constituent, i.e. the content of Fe (%w/w) is higher than that of any other element (following EN10020:2000; §2.1)
Full mould process	moulding technique using a foam model in chemically bonded sand, in which the model is lost upon pouring, generally used only for large castings
Grain refinement	a liquid metal treatment made late in the melting operation to produce a finer and equiaxed grain during solidification.
Green sand	mix of sand, clay and additives as used for mould making
Grey iron	cast iron with grey-coloured fracture; may be found with lamellar, nodular and compact graphite but the term is most often used for lamellar iron
Hearth type furnace	static furnace with direct heating, also called reverberatory furnace and bale-out furnace

Inclusion	(specific term for this sector) impurity in the metal structure, producing structural defects; mostly used for non-ferrous metals (e.g. oxides in magnesium, hydrogen in aluminium)
Jungbüth or net diagram	diagram representing the influence of the blast rate and the coke charge on the tapping temperature of the metal and the melting rate; used for cupola furnaces
Lamellar iron	cast iron with carbon in the form of flakes
Lost Foam process	moulding technique using foam models in unbonded sand, in which the model is lost upon pouring of the metal, used for series production
Lost mould	or single use moulds, a mould that is specially made for each casting and is destroyed after pouring. The moulds are generally made of sand, chemically-bonded or clay-bonded, or even unbonded. Investment casting can also be included in this family
Lost mould casting	all processes of the moulding and casting shop in a foundry using lost moulds, such as sand preparation, moulding, core-making, pouring, cooling and shake-out
Malleable iron	iron that is capable of extension or of being shaped under the hammer; produced by decarburising (whiteheart malleable iron) or not decarburising (blackheart malleable iron) heat treatment of graphite-free iron with white fracture surface (white cast iron)
Melting capacity	the aggregate 'plated' capacity of the furnaces at an installation; where the hourly rate multiplied by 24 should be used if appropriate
Modulus	silica-to-soda ratio SiO_2/Na_2O, used to characterise (sodium) silicates
Nodular iron	cast iron with carbon in nodular/spheroidal shape, commonly refered to as ductile iron
Nodularisation	magnesium treatment of cast iron to change the carbon particles into nodular/spheroidal shape
Non-ferrous materials	all materials that are not ferrous
Normalising	a heat treating process that cools the alloy in air from a temperature above its critical range
Off-site sand re-use	utilisation of sands in various ways
Permanent mould	or multi use a mould, mould that is used for gravity and low-pressure casting, pressure die-casting, or centrifugal casting; typically the moulds are metallic
Permanent mould casting	all processes of the coreshop and casting shop in a foundry using permanent moulds, such as sand preparation, core-making, die-casting, take-out and decoring
Pollutant	individual substance or group of substances which can harm or affect the environment
Post combustion	ignition and burning of exhaust gas through the injection of air or the use of a burner; used in order to reduce the amount of CO and (volatile) organic compounds
Primary regeneration	the processing of used green sand for internal re-use in the sand circuit, using screening, sieving, cooling and mixing with new sand, fresh bentonite and other additives
Production capacity	production of 'good castings' and capacity based on the theoretical capacity of the foundry if it was operated for 24 hours, provided that it is technically able to operate that way
Regeneration ratio	the ratio between the mass of regenerated sand and the total mass of sand used in mould and core-making, expressed as a percentage

Sand circuit	the various parts of the installation for storage, transport, preparation and treatment of sand
Sand recycling	on-site used-sand preparation, for external re-use
Secondary (sand) regeneration	measures (mechanical, pneumatic, thermal and wet) aimed at removing spent binder layers from the sand corn (= reclamation); returning the sand to a quality similar to, or better than, new sand
Steel	a ferrous alloy which solidifies according a preritetic reaction. The (mass) content of iron is bigger than that of any other element, and the carbon content is generally lower than 2%; the alloy also usually contains other elements
Tempering	a heat treatment that after the hardening of the alloy consists of heating to a temperature below Ac_1 and cooling in air; after austenitising and liquid quenching, this provides to the alloy the highest possible hardness and strength

9.3 Lexicon

English	Deutsch	Français	Nederlands	Español	Italiano	Magyar
bentonite	Bentonit	bentonite	bentoniet	bentonita	bentonite	bentonit
bridging	Brückenbildung	accrochage	brugvorming	colgadura	formazione di corona	adagfennakadás
burr	Grat	barbe	braam	rebarba	bava	fánc
cast iron	Gusseisen	fonte	gietijzer	hierro	ghisa	öntöttvas
cast steel	Stahlguss	acier moulé	gietstaal	acero moldeado	getti d'acciaio	öntött acél
casting	Giessen	couler	het gieten	fundición	colata	öntés
chamfer	Abschrägung	chanfrein	gietsysteem	chaflán	cianfrinatura	formázási ferdeség
channel induction furnace	Rinnenofen	four à induction à canal	kanaal inductieoven	horno de inducción de canal	forno a canale	csatornás indukciós kemence
coating	Schlichte	enduit, poteyage	coating/deklaag	pintura	vernice, verniciatura	formabevonó anyag
cold-box	kalter Kernkaste, Cold-box	boîte froide	cold-box	caja fria	cassa fredda	cold-box
core	Kern	noyau	kern	macho	anima	mag
corebox	Kernkasten	boîte à noyaux	kerndoos	caja de macho	cassa d'anima	magszekrény
core-making	Kernfertigung	noyautage	kernmakerij	macheria	formatura di anime	magkészítés
crucible furnace	Tiegelofen	four à creuset	kroesoven	horno de crisol	forno a crogiolo	tégelykemence
decoring	Entkernen	debourrage	ontkernen	extracción de macho	sterratura delle anime	kimagozás
die	Druckgiessform	moule	vorm	mole metálico	stampo	kokilla, nyomásos öntőforma
die lubricant	Druckgiessschlichte	poteyage	koelsmeermiddel	lubricante	distaccante	kokilla-, nyomásos öntőforma kenőanyag
drying oven	Backofen	étuve	droogstoof	estufa	essiccatore	szárító kemence
fettling	putzen	ébarbage	ontbramen	desmazarotado	sbavatura	tisztítás
grinding	schleifen	meulage	slijpen	esmerilada	molatura	csiszolás, köszörülés
induction furnace	Induktionsofen	four à induction	inductieoven	horno de inducción	forno ad induzione	indukciós kemence
lamellar iron *or* grey cast iron	Grauguss, GGL	fonte lamellaire, fonte grise	lamellair gietijzer	hierro gris	ghisa a grafite lamellare, ghisa grigia	lemezgrafitos *vagy* szürke öntöttvas
lustrous carbon	Glanzkohlenstoff	carbone brillant	glanskoolvormer	carbono brillante	carbonio brillante	fényes karbon
malleable iron	temperguss (GT)	fonte malléable	smeedbaar gietijzer	fundición maleable	ghisa malleabile	tempervas
mixer	Menger	malaxeur	menger	mezclador	mescolatore	keverő
mould	Form	mote	vorm	molde	forme	forma
nodular iron, ductile iron, SG iron	GGG, Gusseisen mit Kugelgraphit	fonte à graphite sphéroidal, fonte ductile	nodulair gietijzer	hierro nodular	ghisa sferoidale	gömbgrafitos öntöttvas
pouring	Giessen	couler	gieten	colada	colata	öntés
sand	Sand	sable	zand	arena	sabbia	homok

English	Deutsch	Français	Nederlands	Español	Italiano	Magyar
shaft furnace	Schachtofen	four à cuve	schachtoven	horno de cuba	forno a tino	aknás kemence
shake-out	Ausleeren	décochage	uitschudden	desmoldeo	distaffatura	ürítés, kirázás
shot blasting	Schleuderstrahlen	grenaillage	gritstralen	granallado	granigliatura	szemcseszórás
sprue	Einguss	canal de coulée	voedingskanaal	canal de colada	canale di colata	álló beömlő
turnings	Späne	copeaux	spanen	viruta	trucioli	forgács
veins	rissen	gerces	vinnen	venas	crestine	repedések

10 ANNEXES

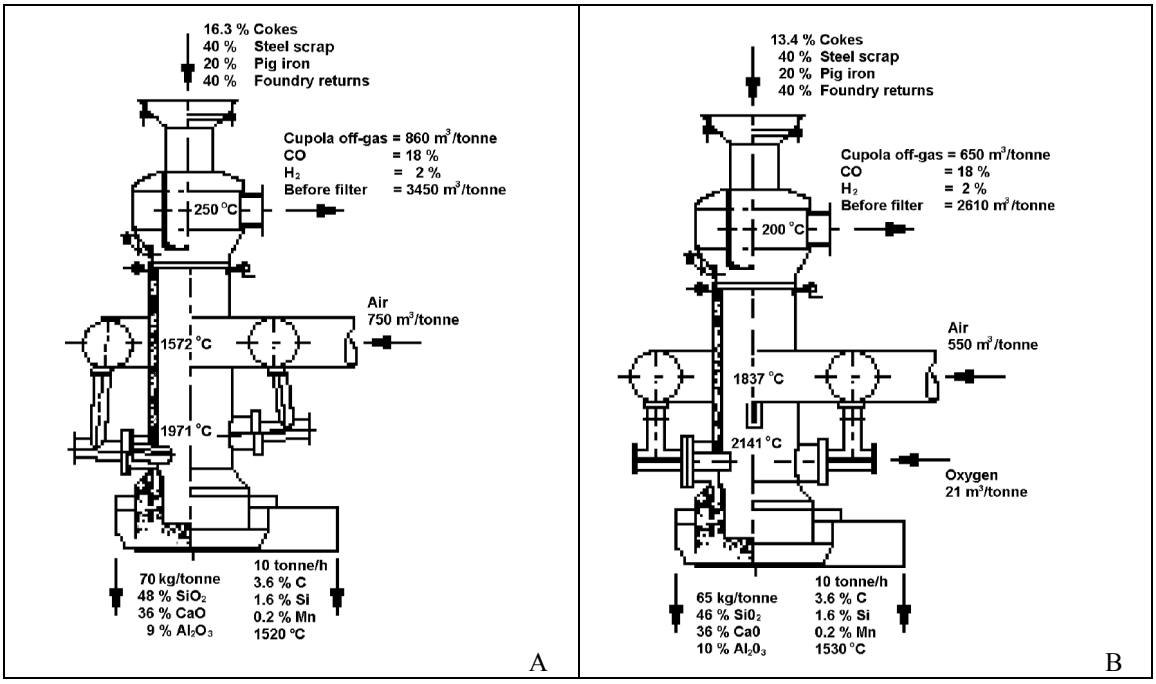
10.1 Annex 1 Overview of data for cast iron melting in various cupola types and in the induction furnace

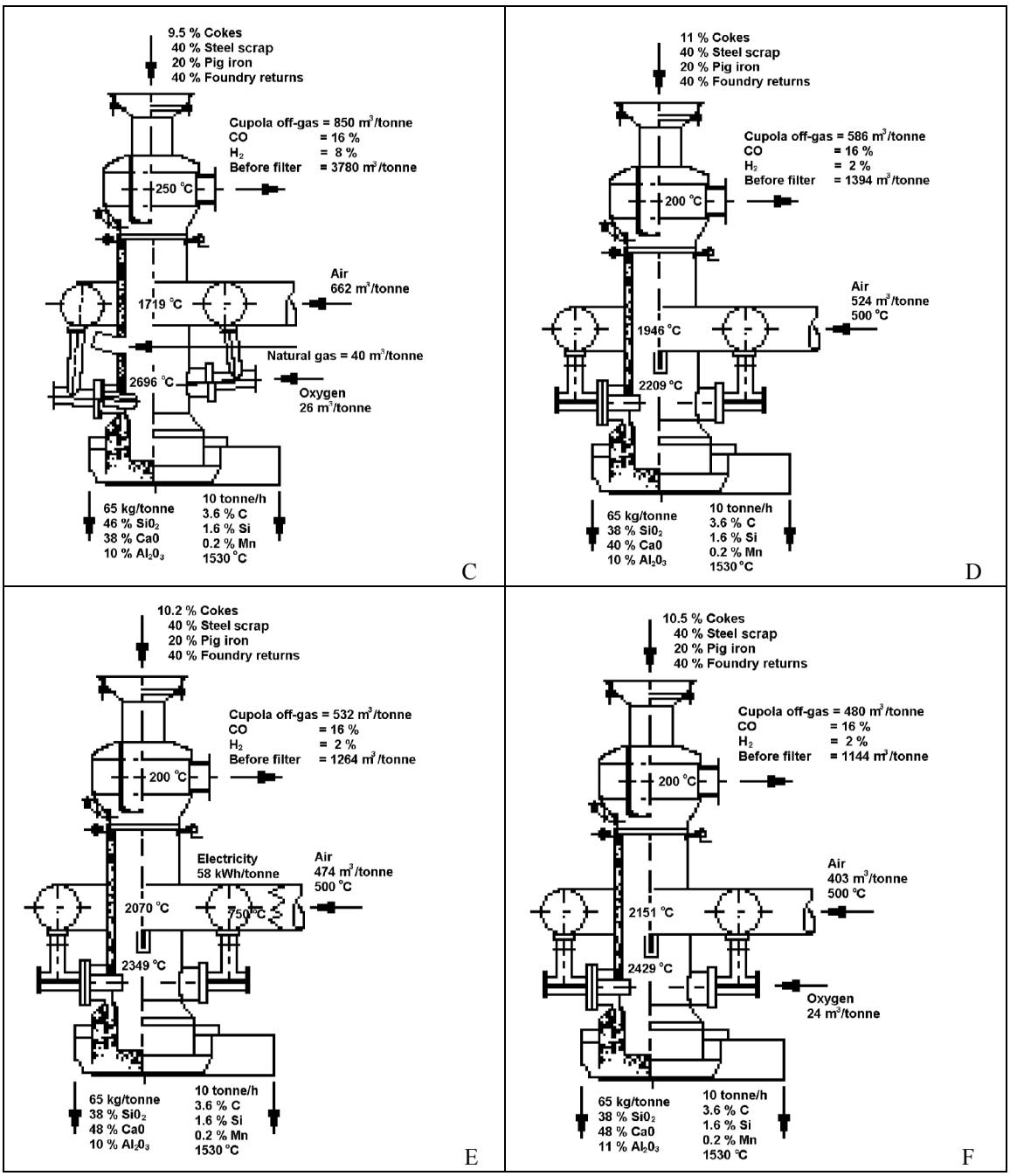
A survey of the consumption and emission levels of the various technical modifications of cupola melting was set up by Neumann in 1994, as given below. All data refer to a system for the production of 10 tonne/h nodular iron with 3.6 % C and 1.6 % Si and at a pouring temperature of 1530 ºC. The balances in Figure 10.1 show inputs, outputs and process temperatures. The latter will be higher compared to operational practice. Comparison of the various balances allows an assessment of the effect of all the modifications.

Additional operational data for cold and hot blast cupolas, with various flue-gas cleaning equipment types, are given and discussed in Section 4.5.2. Those data are taken from operating plants.

The pictures show the following techniques:

(A): cold blast, secondary row of tuyères
(B): cold blast, oxygen injection
(C): cold blast with gas burner, oxygen injection
(D): hot blast (500 ºC), long campaign
(E): hot blast with electrical support heating (750 ºC)
(F): hot blast, oxygen injection (6 %)
(G): hot blast, with plasma support heating (1450 ºC)
(H): cokeless cupola in duplex operation (electrical superheating).




9.5 % Cokes
40 % Steel scrap
20 % Pig iron
40 % Foundry returns
Cupola off-gas = 850 m³/tonne
CO = 16 %
H₂ = 8 %
Before filter = 3780 m³/tonne
250 °C
Air
662 m³/tonne
1719 °C
Natural gas = 40 m³/tonne
2696 °C
Oxygen
26 m³/tonne
65 kg/tonne
46 % SiO₂
38 % CaO
10 % Al₂O₃
10 tonne/h
3.6 % C
1.6 % Si
0.2 % Mn
1530 °C
C
11 % Cokes
40 % Steel scrap
20 % Pig iron
40 % Foundry returns
Cupola off-gas = 586 m³/tonne
CO = 16 %
H₂ = 2 %
Before filter = 1394 m³/tonne
200 °C
Air
524 m³/tonne
500 °C
1946 °C
2209 °C
65 kg/tonne
38 % SiO₂
40 % CaO
10 % Al₂O₃
10 tonne/h
3.6 % C
1.6 % Si
0.2 % Mn
1530 °C
D
10.2 % Cokes
40 % Steel scrap
20 % Pig iron
40 % Foundry returns
Cupola off-gas = 532 m³/tonne
CO = 16 %
H₂ = 2 %
Before filter = 1264 m³/tonne
200 °C
Electricity
58 kWh/tonne
Air
474 m³/tonne
500 °C
2070 °C
750 °C
2349 °C
65 kg/tonne
38 % SiO₂
48 % CaO
10 % Al₂O₃
10 tonne/h
3.6 % C
1.6 % Si
0.2 % Mn
1530 °C
E
10.5 % Cokes
40 % Steel scrap
20 % Pig iron
40 % Foundry returns
Cupola off-gas = 480 m³/tonne
CO = 16 %
H₂ = 2 %
Before filter = 1144 m³/tonne
200 °C
Air
403 m³/tonne
500 °C
2151 °C
2429 °C
Oxygen
24 m³/tonne
65 kg/tonne
38 % SiO₂
48 % CaO
11 % Al₂O₃
10 tonne/h
3.6 % C
1.6 % Si
0.2 % Mn
1530 °C
F

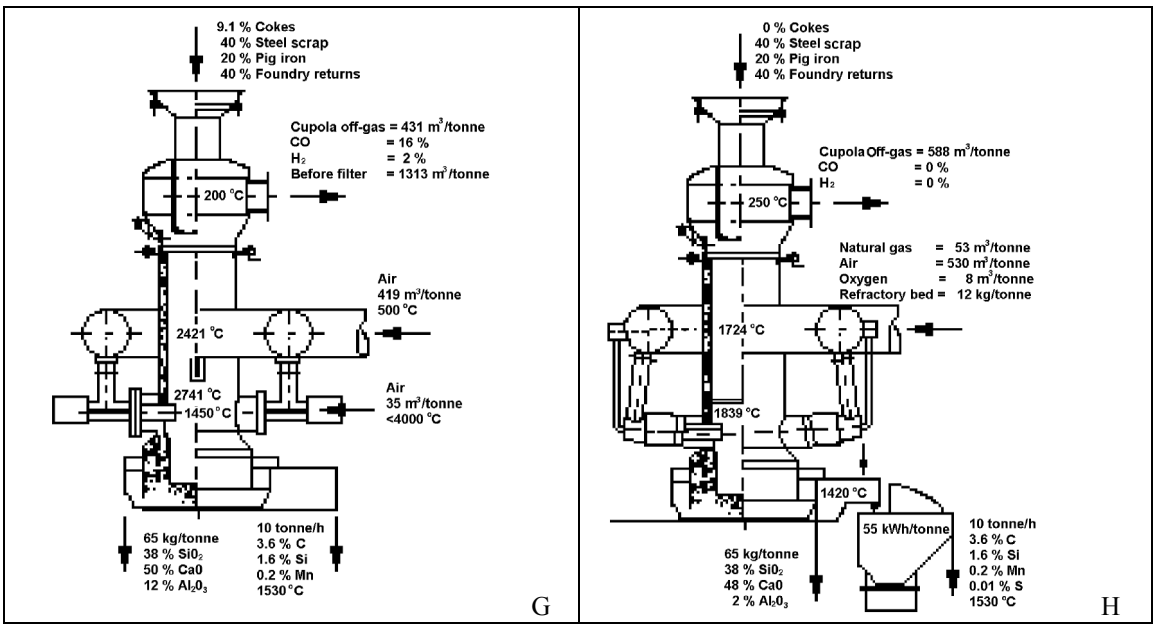


Figure 10.1: Input-output balance for various technical modifications of cupola melting [172, Neumann, 1994]

Operational data are given in Table 10.1, Table 10.2 and Table 10.3. These include economic data based on the stated unit costs. Operational data are based on the production of a cast iron with 3.3 % C and 2 % Si. In the cold blast operation 35 % steel scrap is used, while the hot blast operation allows 60 %. This is taken into account when considering the necessary carburisation. For this, C is also supplied through the addition of the SiC briquettes.

Calculation of the heat balance results in the stated heat transfer efficiencies. The cold blast cupola shows an efficiency of <30 %. The application of oxygen or secondary air increases the efficiency to 37 – 40 %. The hot blast cupola shows a further increased efficiency, providing the furnace wall is refractory lined. In liningless operation, the efficiency drops below 40 %, which may be somewhat compensated for by adding oxygen. The cokeless cupola with inductive superheating results in a very high efficiency, close to 60 %.

The calculated operational costs include depreciation of the investment cost, but exclude personnel costs. The cost difference between the various techniques is rather small. The calculation takes account of higher cokes consumption and more expensive scrap/raw material costs for the cold blast cupola. In the case of air preheating using a plasma torch, the increased electricity use leads to increased costs. In practice, this increase may be balanced by an increased usage of swarf as raw material. The cokeless cupola shows the lowest cost. In this evaluation, however, local cost effects and uncertainties, such as the effect of hourly rate, have not been taken into account, but need to be considered. The quoted data are all for installations with a significant hourly rate. This disfavours the performance of cold blast cupolas.

	Units or Cost per unit	Normal	O_2	Second-ary row	Second-ary + O_2
Specific quantity					
Melting cokes	kg/tonne	150	125	120	105
Cokes for carburisation	kg/tonne	10	10	10	10
Natural gas	m^3/tonne				
Electricity	kWh/tonne	20	20	20	20
Oxygen	%	-	3	-	2
Blast air	m^3/tonne	711	562	604	517
Cupola off-gas	m^3/tonne	902	724	731	628
Filtered off-gas	m^3/tonne	3022	2150	1765	1646
Slags	kg/tonne	36	35	46	45
Refractory	kg/tonne	5.2	5.2	4.8	4.8
SiC- briquettes(45 % SiC)	kg/tonne	28.5	28.5	31.3	30.3
Total heat input	MJ/tonne	5003	3643	3588	3416
Heat transfer to iron	%	26.9	37.2	37.8	39.8
Costs					
Investment	EUR million	2.81	2.91	3.06	3.16
Alloy	EUR 332/tonne	9.44	9.44	10.36	10.36
Additives	EUR 10/tonne	0.20	0.20	0.20	0.20
Cokes	EUR 204/tonne	32.65	27.55	26.53	23.47
Steel scrap	EUR 128/tonne	44.64	44.64	44.64	44.64
Scrap iron	EUR 128/tonne	12.76	12.76	12.76	12.76
Pig iron	EUR 194/tonne	38.78	38.78	38.78	38.78
Natural gas	EUR 153/1000 m^3	0.31	0.31	0.31	0.31
Electricity	EUR 89/MWh	1.79	1.79	1.79	1.79
Oxygen	EUR 179/1000 m^3	-	3.01	-	1.84
Graphite	EUR 561/tonne	-	-	-	-
Refractory	EUR 765/tonne	3.98	3.98	3.67	3.67
Capital	10 years/8 %	11.22	11.63	12.24	12.65
Total melting cost	**EUR/tonne**	**155.77**	**154.08**	**151.28**	**150.46**
Iron composition: 3.3 % C; 2.0 % Si; 0.3 % Mn; 0.1 S; 1500 ºC Load composition: 35 % steel scrap; 35 % returns; 20 % pig iron; 10 % scrap iron					

Table 10.1: Operational data of a cold blast cupola (10 tonne/h) [172, Neumann, 1994]

	Units or Cost per unit	Type A*	Type B	Type C	Type D	Type E
Characteristics						
Daily furnace change		Yes	No	No	No	No
Oxygen enrichment		No	No	Yes	No	Yes
Lining		Yes	Yes	Yes	No	No
Specific quantity						
Melting cokes	kg/tonne	95	100	85	115	100
Cokes for carburisation	kg/tonne	8	7	7	8	8
Oxygen	%	-	-	3	-	3
Air	m^3/tonne	571	566	425	626	473
Cupola off-gas	m^3/tonne	680	667	519	746	586
Filtered gas	m^3/tonne	1798	1471	1134	1819	1473
Slag	kg/tonne	60	60	60	60	60
Refractory	kg/tonne	15	6	6	1.5	1.5
SiC- briquettes(45 % SiC)	kg/tonne	50	53	53	50	50
Total heat input	MJ/tonne	3756	3630	3076	4098	3534
Heat transfer to iron	%	39.8	40.2	44.9	36.5	38.7
Costs						
Investment	EUR million	3.42	3.57	3.65	3.49	3.55
Alloy	EUR 332/tonne	16.58	17.60	17.60	16.58	16.58
Additives	EUR 10/tonne	0.20	0.20	0.20	0.20	0.20
Cokes	EUR 204/tonne	21.02	21.84	18.78	25.10	22.04
Scrap steel	EUR 128/tonne	76.53	76.53	76.53	76.53	76.53
Scrap iron	EUR 128/tonne	12.76	12.76	12.76	12.76	12.76
Oxygen	EUR 179/1000 m^3	-	-	3.06	-	3.42
Refractory	EUR 765/tonne	11.48	4.59	4.59	1.12	1.12
Capital	10 years/8 %	13.67	14.29	14.59	13.98	14.18
Total melting cost	**EUR/tonne**	**152.24**	**147.81**	**148.11**	**146.28**	**146.84**

* Is no longer built as new plant
Iron Composition: 3.3 % C; 2.0 % Si; 0.3 % Mn; 0.1 S; 1530 ºC
Load composition: 60 % steel scrap; 30 % returns; 10 % scrap iron

Table 10.2: Operational data of a hot blast long campaign cupola (10 tonne/h) [172, Neumann, 1994]

	Units or Cost per unit	Cokeless Cupola with O_2 + induct. superh.	Hot blast cupola	
			air preh. using plasma	air preh. using electric resistance
Specific quantity				
Melting coke	kg/tonne	-	81	90
Coke for carburisation	kg/tonne	-	10	12
Natural gas	m^3/tonne	55	2	2
Electricity	kWh/t	80	175	82
Oxygen	%	1.5	-	-
Air	m^3/tonne	5.30	419	474
Cupola off-gas	m^3/tonne	692	451	531
Cleaned off-gas	m^3/tonne	815	1313	1264
Slags	kg/tonne	58	59	60
Refractory	kg/tonne	16	9.3	4.3
SiC- briquettes (45 % SiC)	kg/tonne	-	13.7	15.4
FeSi- briquettes (1 kg Si per briquette)	kg/tonne	8	-	-
Total heat input	MJ/tonne	2562	3952	3320
Heat transfer to iron	%	58.4	41.4	41.5
Cost				
Investment	EUR million	2.81	5.10	3.83
Alloy	EUR 332/tonne		4.54	5.10
Fe-Si-briquettes	EUR 454/tonne Si	3.62		
Additives	EUR 10/tonne	0.56	0.56	0.56
Cokes	EUR 204/tonne		18.57	23.06
Electricity	EUR 89/MWh	7.14	15.61	7.30
Gas	EUR 128/1000 m^3	6.99	0.31	0.31
Scrap steel	EUR 128/tonne	44.64	44.64	44.64
Scrap iron	EUR 128/tonne	44.64	44.64	44.64
Graphite	EUR 561/tonne	6.73		
Oxygen	EUR 179/1000 m^3	1.43		
Refractory	EUR 102/tonne	0.61	0.31	0.20
Refractory	EUR 765/tonne	7.65	4.80	1.79
Capital	10 years/8 %	11.22	20.41	15.31
Total melting cost	**EUR/tonne**	**135.26**	**154.39**	**142.91**
Iron composition: 3.3 % C; 2.0 % Si; 0.3 % Mn; 0.1 S; 1530 ºC Load composition: 35 % steel scrap; 30 % returns; 35 % scrap iron				

Table 10.3: Operational data of a cokeless cupola and hot blast cupola with air preheating [172, Neumann, 1994]

CTIF also calculated the costs of liquid cast iron in a comparative study about the different melting ways [226, CTIF, 1997]. This study, made in 1997, was updated in 2003 [227, Godinot, 2004].

Units	GRADE	Lamellar cost iron (ENGJL 250)				Nodular cost iron (ENGJS 400 – 15)		
	Melting device	Cold blast cupola	Hot blast cupola	Cokeless cupola	Induction furnace	Hot blast cupola	Cokeless cupola	Induction furnace
EUR/t	Metallic charge	95.80	59.52	96.68	72.97	49.75	73.52	59.80
	Ferro alloys + additives	7.62	13.09	27.22	25.72	5.27	24.17	24.85
	Energy and fluids	33.14	35.26	20.29	27.28	40.12	21.07	27.28
	Linings	3.73	4.29	8.79	1.47	4.55	8.79	1.47
	Personnel costs	10.05	10	11	9.10	10.42	11	9.10
	Maintenance	1.55	3.15	0.16	0.93	3.15	0.16	0.93
	Environment	4.50	4.30	3.15	0.55	4.30	3.15	0.55
	Desulphurisation					10.33		
	Depreciation of investment	5.92	14.81	8.89	8.89	14.81	8.89	8.89
	Total per tonne charged	162.31	144.42	176.78	146.91	142.70	150.75	132.97
%	Fire loss	5	5	5	3	5	5	3
EUR/t	Total per tonne liquid	170.85	152.02	185.45	151.45	150.21	158.68	136.98
%	Returns percentage	35	40	35	40	50	50	50
EUR/t	Total per tonne of casting	262.85	253.36	285.31	252.42	300.42	317.37	273.96

Table 10.4: Comparison of liquid cast iron costs -June 2003. Mass production – 10 t/h

		Cold blast cupola			Induction			Coreless furnace			Hot blast cupola			Cokeless cupola		
Characteristic	**Unit**	Price EUR/unit	Ratio	Price EUR/t	Price EUR/unit	Ratio	Price EUR/t	Price EUR/unit	Ratio	Price EUR/t	Price EUR/unit	Ratio	Price EUR/t	Price EUR/unit	Ratio	Price EUR/t
Coke	tonne	210	0.145	30.45							210	0.125	26.25			
Electricity	kWh	0.0513	20	1.027	0.0448	609	27.28	0.0448	609	27.28	0.0513	128	6.57	0.0513	165	8.46
Oxygen	Nm^3	0.535	2	1.07							0.535	2	1.07	0.23	11	2.53
Gas	kWh (NCV)	0.0296	20	0.59							0.228	60	1.37	0.0186	500	9.30
Sub total				33.14			27.28			27.28			35.26			20.29
Returns	tonne	0	0.35	0	0	0.40	0	0	0.50	0	0	0.40	0	0	0.35	0
Pig iron	tonne	185	0.20	37	185	0.15	27.75	200	0.10	20				185	0.25	46.25
Scrap iron	tonne	167	0.20	33.4										167	0.15	25.05
Scrap steel (E3)	tonne	101.5	0.25	25.4	101.5	0.225	22.83				101.5	0.30	30.45	101.5	0.25	25.38
Scrap steel (E8)	tonne				99.5	0.225	22.39	99.5	0.40	39.80						
Scrap steel (E1 C)											96.9	0.30	29.07			
Sub total				95.8			72.97			59.80			59.52			96,68
Graphite	kg				0.70	16.7	11.69	0.80	17.92	14.34				0.7	8.12	5.68
FeSi	kg Si	0.68	8	5.44	1.13	10.6	11.98	1.13	9.39	10.61	0.68	15.8	10.74	0.68	11. 71	7.96
FeMn	kg Mn	0.595	2.7	1.60	0.79	2.6	2.05				0.59	3.2	1.89	0.595	1.45	0.86
$CaCO_3$ + div	tonne	12.2	0.048	0.58							12.2	0.0375	0.46			12.72
Balls	tonne															
Sub total				7.62			25.72			24.95			13.09			27.22

Table 10.5: Price of lamellar cast iron: Metallic charge + energy

	Units	Hot blast cupola			Cokeless cupola		
		Price EUR/unit	Ratio	Price EUR/t	Price EUR/unit	Ratio	Price EUR/t
Coke	tonne	210	0.14	29.40			
Electricity	kWh	0.0513	140.5	7.21	0.0513	180	9.23
Oxygen	Nm^3	0.535	4	2.14	0.23	11	2.53
Gas	kWh (NCV)	0.0228	60	1.37	0.0186	500	9.30
Sub total				40.12			21.07
Returns	tonne	0	0.40	0	0	0.40	0
Pig iron	tonne				199	0.20	39.8
Scrap iron	tonne				167	0.05	8.35
Scrap steel (E8)	tonne	99.55	0.50	49.75			
Scrap steel (E3)	tonne				101.5	0.25	25.38
Sub total				49.75			73.52
Graphite	kg				0.7	12.37	8.66
FeSi	kg Si	0.68	7	4.76	0.68	4.11	2.79
FeMn	kg Mn						
$CaCO_3$ + div	tonne	12.2	0.042	0.51			12.72
Balls	tonne						
Sub total				5.27			24.17

Table 10.6: Price of nodular cast iron: Metallic charge + energy

Table 10.4 summarises the costs of cast iron calculated for the 3 main cupola types compared with coreless induction furnace. Some items greatly depend on the melting device and the grade: energies and fluids, metallic charge and ferro alloys. They are detailed in Table 10.5 and Table 10.6.

The compared melting devices melt at 10 - 12 t/h, in 2 shifts for a mass production typically, e.g. the automotive industry. The investments are paid in 10 years and correspond to the industrial practice in each case, i.e.:

Cold blast cupola
- 2 daily drop cupolas (one per day)
- treatment of fumes: combustion, cooling, dry filtration.

Hot blast cupola
- long campaign cupola
- treatment of fumes: combustion, blast heating, cooling, dry filtration
- holding in a channel induction furnace.

Cokeless cupola
- long campaign cupola
- treatment of fumes: cooling, dry filtration
- heating and recarburisation in a superheater
- holding in a channel induction furnace.

Introduction furnace
- 2 furnaces 12 tonne
- 1 power supply 10MW – 250 Hz.

The cost of cast iron must take into account its downstream recarburisation (cokeless cupola), its holding and also the importance of the fume treatment system.

The price of cast iron was compared for 2 different alloys in the case of mass automotive industry:

- lamellar cast iron (ENGJL 250)
- nodular graphite base cast iron (base for ENGJS 400-15).

The cold blast cupola is increasingly less used for nodular cast iron and was not considered in this case.

Comparing the calculations of CTIF and Neumann:

The position of the melting devices, from the least to the most expensive, is not the same depending on the type of alloy and the authors:

- Lamellar graphite cast iron (LG cast iron)
  CTIF: induction furnace, hot blast, cold blast, cokeless cupola
  Neumann: cokeless, hot blast, cold blast cupola
- Nodular base cast iron
  CTIF: induction furnace, hot blast, cokeless (little different).

The comparison of the different items for Neumann and Godinot leads to the following conclusions:

1. Energies and fluids
- the cokeless cupola is the least expensive in all cases
- it is noticeable that the energy costs strongly depend on the country, particularly with regard to the price and availability of electricity and gas. In the CTIF study, energy costs correspond to the French case (prices published in the review "Energy Plus").

2. Metallic charges and ferro alloys
The classification technique applied of disadvantages the cokeless cupola for CTIF and not for Neumann. The principal differences are the following ones:

- Neumann indicates 0 % pig iron for cokeless cupola, when Godinot indicates a minimum of 25 % according to the industrial practice. Pig iron is the most expensive metallic charge.
- Neumann gives the same cost for steel scrap and cast iron scrap. In the French case, the ratio between these 2 costs has been between 2 and 1.3 for 10 years. This ratio was 1.6 in June 2003, the date considered for the calculation, as indicated in the attached Figure 10.2.

It is noticeable that the cost of raw materials, including scrap, are fixed today at an international level.

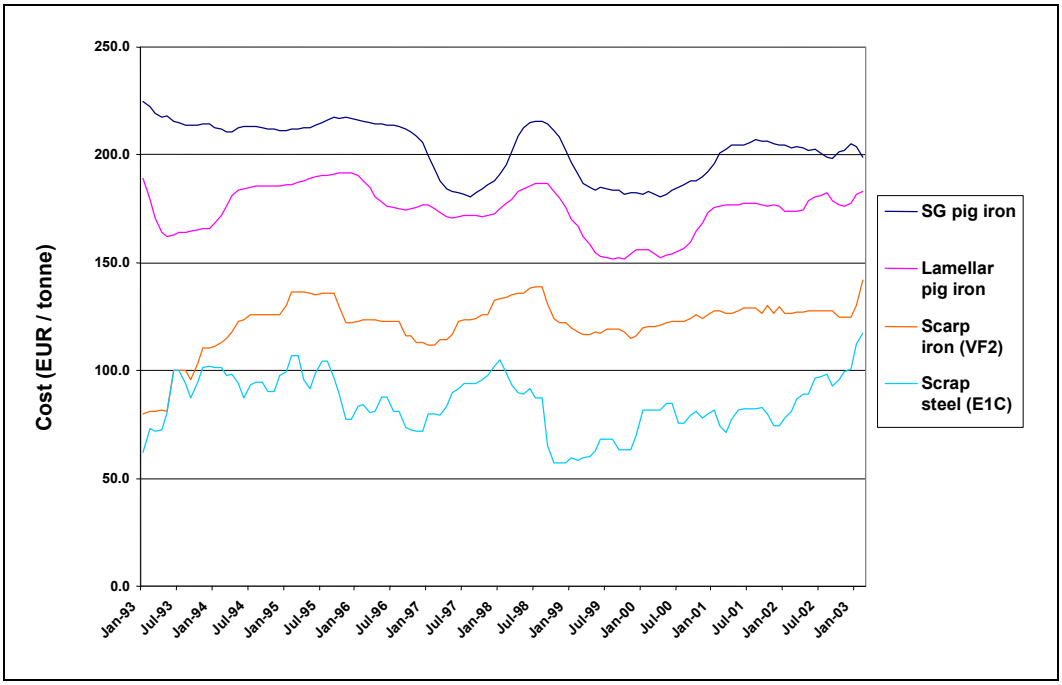


Figure 10.2: Cost of raw materials (France: 1993 to 2003)

3. Other items

The investment is less important than for cold blast, cokeless cupola and coreless induction furnace.

- in the case of the cold blast cupola liquid, cast iron is produced at a good temperature and analysis is possible at the spout of the cupola; moreover the metallurgical results depend little on the hourly production. It is not necessary to hold the cast iron in a channel induction furnace
- in the case of the hot blast cupola, or of the cokeless cupola, it is difficult to modify the hourly production. A reservoir of liquid metal is necessary between the cupola and the moulding shop, i.e. generally a channel induction furnace
- in the case of the cokeless cupola, the specific volume of fumes to be treated is low and it is not necessary to burn CO
- finally, in the case of the coke cupola (hot or cold blast), a desulphurisation is generally practised before holding the base nodular liquid cast iron. The cost of this operation is high, which is favours the cokeless cupola, whose cast iron does not contain any sulphur.

4. Conclusion

Taking industrial practice into account, according to Godinot, the cokeless cupola has the advantage of a low energy consumption but it incurs extra cost for the raw charging materials.

In the case of base nodular cast iron, the cokeless cupola produces a metal without sulphur and with a cost level similar to the hot blast. In the case of lamellar cast iron, in France, this melting device produces a more expensive metal than coke cupolas.

Today, for this type of production in France the limit between cupola and induction is 10 t/h (lamellar cast iron) and probably more in the case of nodular cast iron (the cupola is less expensive for 20 t/h).

These calculations have been made for an automotive type mass production. For other applications, they need to be slightly modified. At least it is possible to say the relative order depends on the local conditions, especially energy costs which depend strongly on the country of application.

10.2 Annex 2 Dust control equipment at a large-scale automotive foundry

Dust emission monitoring data were provided by a Swedish large-scale automotive foundry. The foundry uses a continuous particulate emission monitoring system on 17 bag filter exhausts. Data were plotted on a graph for various time ranges and for 4 measurement points as shown in Figure 10.3, Figure 10.4 and Figure 10.5. The figures show a continuous dust level well below 1 mg/Nm³ for sand preparation and shot blasting. A 24h-average of 1.3 – 1.6 mg/Nm³ was obtained for the sand transport.

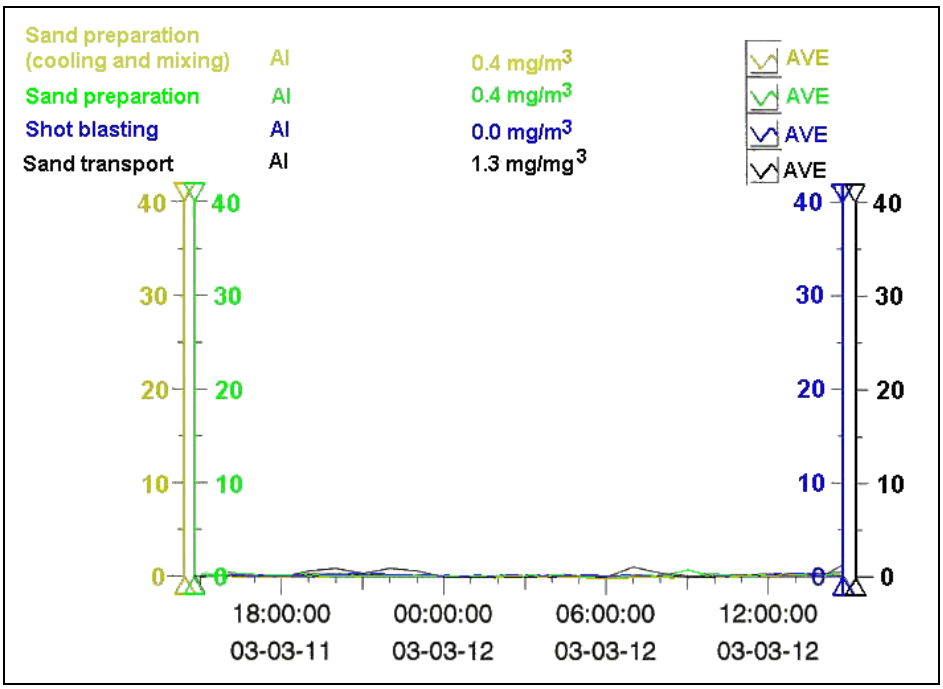


Figure 10.3: Monitoring data for dust emissions from 4 locations in the sand plant (24 hours continuous monitoring)

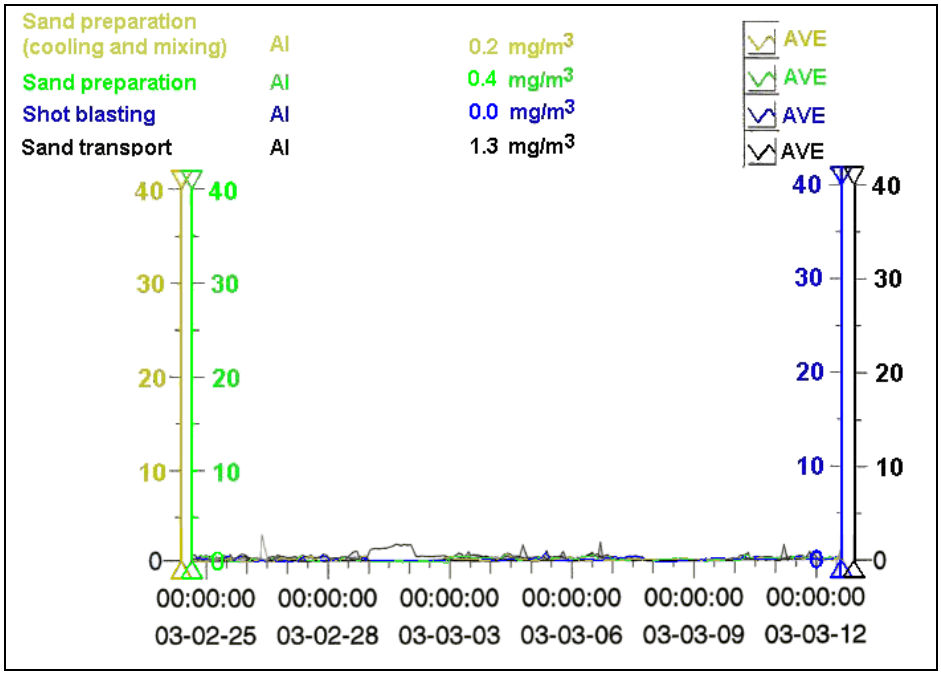


Figure 10.4: Monitoring data for dust emissions from 4 locations in the sand plant (2 weeks continuous monitoring)

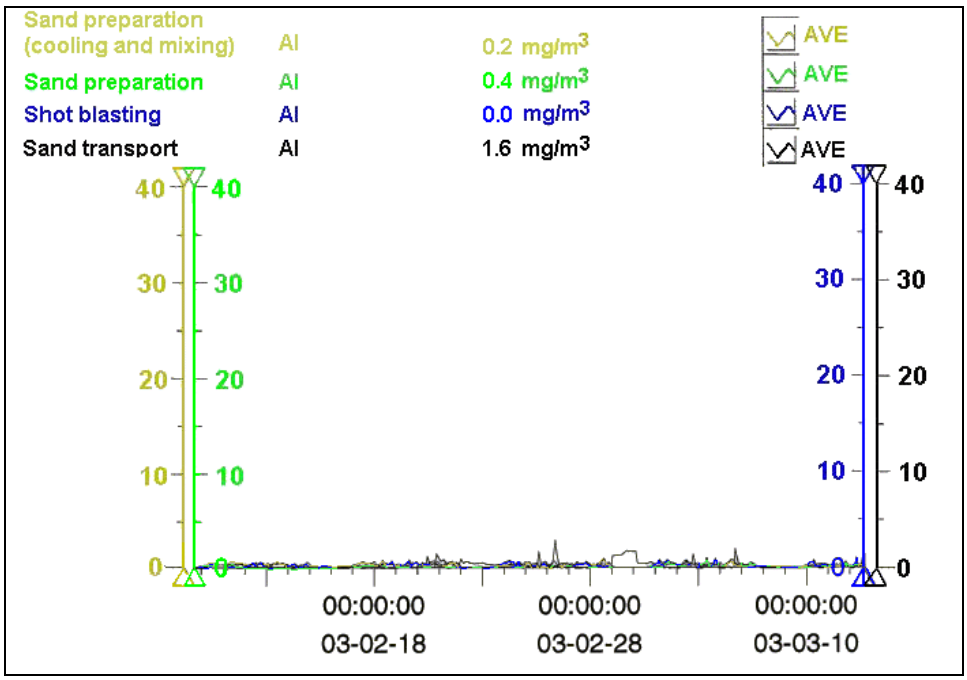


Figure 10.5: Monitoring data for dust emissions from 4 locations in the sand plant (30 days continuous monitoring)

This example plant has a permitted emission limit value for dust of 10 mg/Nm³. The monitoring system has an alarm limit of 5 mg/Nm³. If this limit is passed, the filter is checked and tested with fluorescence material. If the measured value passes 10 mg/Nm³, the production and filter are stopped. Calibration of the monitoring equipment is performed twice a year by an external contractor.

The service and maintenance instructions are as follows:

- daily
  - pressure drop check
  - visual check
  - magnetic valve check
  - condensation water drain
- monthly
  - check tightness
- quarterly (every 3 months)
  - control with fluorescence material.