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Integrated Pollution Prevention and Control

Draft Reference Document on Best Available Techniques in the

Cement, Lime and Magnesium Oxide Manufacturing Industries

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This document is one from the series of documents as listed below, which have to be reviewed:

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

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EXECUTIVE SUMMARY

The BAT (Best Available Techniques) Reference Document (BREF) entitled '**Cement, Lime and Magnesium Oxide Manufacturing Industries**' reflects an information exchange carried out under Article 17(2) of Council Directive 2008/1/EC (IPPC Directive). This Executive Summary describes the main findings, and provides a summary of the principal BAT conclusions and the associated consumption and emission levels. It should be read in conjunction with the Preface, which explains this document's objectives; how it is intended to be used and legal terms. This Executive Summary can be read and understood as a standalone document but, as a summary, it does not present all the complexities of the full document. It is therefore not intended as a substitute for this full document as a tool in BAT decision making.

SCOPE OF THIS DOCUMENT

This document addresses the industrial activities specified in Section 3.1 of Annex I to Directive 2008/1/EC, namely:
'3.1. Installations for the production of cement clinker in rotary kilns with a production capacity exceeding 500 tonnes per day or lime in rotary kilns with a production capacity exceeding 50 tonnes per day or in other furnaces with a production capacity exceeding 50 tonnes per day.'

Additionally to the cement and lime industry, this document covers the manufacture of magnesium oxide by using the dry process route.

This BREF document has three chapters, one for the cement industry, one for the lime industry and one for the manufacture of magnesium oxide by using the dry process route based on mined natural magnesite (magnesium carbonate $MgCO_3$). Each of these chapters has seven sections according to the general outline and guide for writing BREFs. In addition to the basic manufacturing activities of the three industrial activities mentioned above, this document covers the associated activities which could have an effect on emissions or pollution. Thus, this document includes activities from the preparation of raw materials to the dispatch of the finished products. Certain activities, e.g. quarrying/mining and shaft kilns for cement clinker production, are not covered because they are not considered to be directly associated with the primary activity.

CEMENT INDUSTRY

Key environmental issues

Cement is a basic material used for building and civil engineering construction. The production of cement in the European Union stood at 267.5 million tonnes in 2006, equivalent to about 10.5 % of world production.

In 2008 there were 268 installations producing cement clinker and finished cement in the European Union with a total of 377 kilns. In addition, there were a further 90 grinding plants (cement mills) and two clinker plants without mills. A typical kiln size has come to be around 3000 tonnes clinker/day.

The clinker burning process is the most important part of the process in terms of the key environmental issues for cement manufacture: energy use and emissions to air. Depending on the specific production processes, cement plants cause emissions to air and land (as waste). In specific rare cases, emissions to water may occur. Additionally, the environment can be affected by noise and unpleasant smells. The key polluting substances emitted to air are dust, nitrogen oxides and sulphur dioxide. Carbon oxides, polychlorinated dibenzo-p-dioxins and dibenzofurans, total organic carbon, metals, hydrogen chloride and hydrogen fluoride are emitted as well. The type and quantity of air pollution, wastes and waste water depend on different parameters, e.g. the raw materials and fuels used and the type of process applied.

To produce 1 tonne of clinker, the typical average consumption of raw materials in the EU is 1.52 tonnes. Most of the balance is lost from the process as carbon dioxide emissions to air in the calcination reaction ($CaCO_3 \rightarrow CaO + CO_2$).

Applied processes and techniques

After the mining, crushing, grinding and homogenisation of raw materials, the first step in cement manufacture is calcination of calcium carbonate followed by the reaction of the resulting calcium oxide together with silica, alumina, and ferrous oxide at high temperatures to form clinker. The clinker is then ground or milled together with gypsum and other constituents to produce cement. Naturally occurring calcareous deposits such as limestone, marl or chalk provide the source for calcium carbonate. Silica, iron oxide and alumina are found in various ores and minerals. Several types of wastes can also be used as partial replacements for the natural raw materials.

The cement industry is an energy intensive industry with energy typically accounting for about 40 % of production costs (i.e. excluding capital costs but including electricity costs). Various conventional fossil and waste fuels can be used to provide the thermal energy demand required for the process. In 2006, the most commonly used fuels were petcoke, coal and different types of waste, followed by lignite and other solid fuels, fuel oil, and natural gas.

Basically, characteristics of the clinker burning process itself allow the use of wastes as raw materials and/or as fuels. Clinker burning takes place in a rotary kiln which can be part of a wet or dry long kiln system, a semi-wet or semi-dry grate preheater (Lepol) kiln system, a dry suspension preheater kiln system or a preheater/precalciner kiln system. In 2008, about 90 % of Europe's cement production was from dry process kilns, a further 7.5 % of production was accounted for by semi-dry and semi-wet process kilns, with the remainder of European production, about 2.5 %, coming from wet process kilns. The wet process kilns operating in Europe are generally expected to be converted to dry process kiln systems when renewed, as are semi-dry and semi-wet process kiln systems.

LIME INDUSTRY

Key environmental issues

Lime is used in a wide range of products, for example as a fluxing agent in steel refining, as a binder in building and construction, and in water treatment to precipitate impurities. Lime is also used extensively for the neutralisation of acidic components of industrial effluent and flue-gases. In 2004, the European production market represented almost 25 million tonnes of lime for a total European production of 28 million tonnes including commercial and captive lime production, which accounted for 20 % of the world's total lime production.

In 2003, there were approximately 211 installations producing lime in the EU-27 (excluding captive lime production) and in 2006, there were a total of 597 kilns producing commercial lime, of which 551 (or about 90 %) were shaft kilns. Typical kiln size lies between 50 and 500 tonnes per day for shaft kiln types. Lime production generally uses between 1.4 and 2.2 tonnes of limestone per tonne of saleable quicklime. Consumption depends on the type of product, the purity of the limestone, the degree of calcination and the quantity of waste products. Most of the balance is lost from the process as carbon dioxide emissions to air.

The lime industry is a highly energy intensive industry with energy accounting for up to 60 % of total production costs. Kilns are fired with gaseous fuels (e.g. natural gas, coke oven gas), solid fuels (e.g. coal, coke/anthracite) and liquid fuels (e.g. heavy/light fuel oil). Furthermore, different types of wastes are used as fuels, e.g. oil, plastics, paper, animal meal, sawdust.

The key environmental issues associated with lime production are air pollution and the use of energy. The lime burning process is the main source of emissions and is also the principal user of energy. The secondary processes of lime slaking and grinding can also be of significance. Depending on the specific production processes, lime plants cause emissions to air, water and land (as waste). Additionally, the environment can be affected by noise and unpleasant smells. The key polluting substances emitted to air are dust, nitrogen oxides, sulphur dioxide and carbon monoxide. Polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans, total organic carbon, metals, hydrogen chloride and hydrogen fluoride can be relevant depending on the raw materials and fuels used.

Applied processes and techniques

The term ‘lime’ includes quicklime and slaked lime and is synonymous with the term ‘lime products’. Quicklime, or burned lime, is calcium oxide (CaO). Slaked lime consists mainly of calcium hydroxide ($Ca(OH)_2$) and includes hydrated lime (dry calcium hydroxide powder), milk of lime and lime putty (dispersions of calcium hydroxide particles in water).

The lime making process consists of the burning of calcium and/or magnesium carbonates to liberate carbon dioxide and to obtain the derived oxide ($CaCO_3 \rightarrow CaO + CO_2$). The calcium oxide product from the kiln is generally crushed, milled and/or screened before being conveyed to silo storage. From the silo, the burned lime is either delivered to the end user for use in the form of quicklime, or transferred to a hydrating plant where it is reacted with water to produce slaked lime.

MANUFACTURE OF MAGNESIUM OXIDE (DRY PROCESS ROUTE)

Key environmental issues

Magnesium oxide (MgO/magnesia) is the most important industrial magnesium compound and is mainly used in the steel and refractory industry, but also in many other industrial sectors. Different types of magnesium oxide are produced by using the dry process route, such as dead burned magnesia (DBM), caustic calcined magnesia (CCM), fused magnesia (FM).

The world’s production of MgO by using the dry process route was around 12.5 million tonnes in 2003. In the EU-27, about 2.3 million tonnes were produced in 2003 which was 18.4 % of the world’s production. In 2008 in the EU-27, on the basis of the information available, there were only nine producers of magnesium oxide (dry process route) using 14 plants. The number of kilns per plant was one to three, except for one producer who operates eight kilns in a single plant.

The manufacture of MgO is energy intensive as MgO, and particularly DBM, is manufactured at very high temperatures. The energy demand for MgO production ranges between 6 and 12 GJ/t MgO and is determined by different factors. In 2008, natural gas, petroleum coke and fuel oil were used as fuels.

The key environmental issues associated with magnesium oxide production are air pollution and the use of energy. The firing process is the main source of emissions and is also the principal user of energy. Depending on the specific MgO production processes, plants cause emissions to air, water and land (as waste). Additionally, the environment can be affected by noise and unpleasant smells. The key polluting substances emitted to air are dust, nitrogen oxides, sulphur dioxide and carbon oxides (CO, CO_2).

Applied processes and techniques

Raw magnesite is mined, crushed, ground or milled and sieved before being fired. More than 98 % of the mined magnesite is used for the production of the different magnesia products. The chemical reaction of oxidising magnesite is endothermic and depends on a high firing temperature. Several firing processes and firing steps are needed to produce the different types of magnesium oxide CCM, DBM and/or FM. Several kiln types are used, such as multiple hearth furnaces, shaft kilns or rotary sintering kilns. For the production of fused magnesia special electric arc kilns are used.

CEMENT, LIME AND MAGNESIUM OXIDE INDUSTRY

Techniques to consider in the determination of BAT

Important issues for the implementation of IPPC in the cement, lime and magnesium oxide industry are reduction of emissions to air, efficient energy and raw material usage, minimisation, recovery and recycling of process losses/waste, as well as effective environmental and energy management systems.

The issues above are addressed by a variety of process integrated measures/techniques and end-of-pipe techniques, taking into account their applicability in the cement, lime or magnesium oxide sectors. The measures/techniques that are included in this document are those that are considered to have the potential to achieve, or to contribute to, a high level of environmental protection. In this context, for the cement industry approximately 36 techniques to consider for pollution prevention and control are presented (Section 1.4), for the lime industry approximately 24 techniques (Section 2.4) and for the magnesium oxide industry using the dry process route approximately 16 techniques (Section 3.4).

Best available techniques

The BAT sections (Sections 1.5, 2.5 and 3.5) identify those techniques that are BAT for the cement, lime or magnesium oxide industries in a general sense, based mainly on the information from Sections 1.4, 2.4 or 3.4, taking into account the definition of best available techniques (Art. 2(12) of the IPPC Directive) and the considerations listed in Annex IV to the IPPC Directive. The BAT sections also suggest consumption and emission values that are associated with the use of BAT. As described in the Preface, the BAT sections do not propose emission limit values. For installation covered by the IPPC Directive, it is up to the competent authority to determine the emission limit values in the permit on the basis of BAT.

It has to be noted that in this Executive Summary, the BAT conclusions of this document are only presented as summaries. To read the relevant full BAT conclusion, see Sections 1.5, 2.5 and 3.5 of this document. Furthermore, it has generally to be noted, when co-incinerating waste, the requirements of the Waste Incineration Directive (WID) have to be met [59, European Commission, 2000].

Summary of BAT for the cement industry	
Environmental management (BAT 1 in Section 1.5.1)	• implement and adhere to an Environmental Management System (EMS) that incorporates, as appropriate to the local circumstances, the features as listed in BAT 1 in Section 1.5.1
General primary measures/techniques (BAT 2, 3, 4 in Section 1.5.2)	• achieve a smooth and stable kiln process, operating close to the process parameter set points, that is beneficial for all kiln emissions as well as the energy use by applying the measures/techniques listed in BAT 2 a, b in Section 1.5.2 • carry out a careful selection and control of all substances entering the kiln in order to avoid and/or reduce emissions (BAT 3 in Section 1.5.2) • carry out monitoring and measurements of process parameters and emissions on a regular basis which are listed in BAT 4 a – e in Section 1.5.2
Process selection (BAT 5 in Section 1.5.3.1)	• for new plants and major upgrades, apply a dry process kiln with multistage preheating and precalcination. Under regular and optimised operational conditions, the associated BAT heat balance value is 2900 – 3300 MJ/tonne clinker (BAT 5 in Section 1.5.3.1)
Energy consumption (BAT 6, 7, 8, 9 in Section 1.5.3.2)	• reduce/minimise thermal energy consumption by applying a combination of the measures/techniques as listed in BAT 6 a – f in Section 1.5.3.2 • reduce primary energy consumption by considering the reduction of the clinker content of cement and cement products (BAT 7 in Section 1.5.3.2) • reduce primary energy consumption by considering cogeneration/combined heat and power plants if possible, on the basis of useful heat demand, within energy regulatory schemes where economically viable (BAT 8 in Section 1.5.3.2) • minimise electrical energy consumption by applying the measures/techniques individually or in combination as listed BAT 9 a, b in Section 1.5.3.2
Waste quality control (BAT 10 a – c in Section 1.5.4.1)	• apply quality assurance systems to guarantee the characteristics of wastes and to analyse any waste that is to be used as raw material and/or fuel in a cement kiln for parameters/criteria listed in BAT 10 a I. – III. in Section 1.5.4.1 • control the amount of relevant parameters for any waste that is to be used as raw material and/or fuel in a cement kiln, such as chlorine, relevant metals (e.g. cadmium, mercury, thallium), sulphur, total halogen content (BAT 10 b in Section 1.5.4.1) • apply quality assurance systems for each waste load (BAT 10 c in Section 1.5.4.1)

<table>
<tr><th colspan="2">Summary of BAT for the cement industry</th></tr>
<tr><td>Waste feeding into the kiln (BAT 11 a – f in Section 1.5.4.2)</td><td>● use the appropriate feed points to the kiln in terms of temperature and residence time depending on kiln design and kiln operation (BAT 11 a in Section 1.5.4.2)
● feed waste materials containing organic components that can be volatilised before the calcining zone into the adequately high temperature zones of the kiln system (BAT 11 b in Section 1.5.4.2)
● operate in such a way that the gas resulting from the co-incineration of waste is raised in a controlled and homogeneous fashion, even under the most unfavourable conditions, to a temperature of 850 °C for 2 seconds (BAT 11 c in Section 1.5.4.2)
● raise the temperature to 1100 °C, if hazardous waste with a content of more than 1 % of halogenated organic substances, expressed as chlorine, is co-incinerated (BAT 11 d in Section 1.5.4.2)
● feed wastes continuously and constantly (BAT 11 e in Section 1.5.4.2)
● stop co-incinerating waste for operations such as start-ups and/or shutdowns when appropriate temperatures and residence times cannot be reached, as noted in BAT 11 a – d (BAT 11 f in Section 1.5.4.2)</td></tr>
<tr><td>Safety management for the use of hazardous waste materials (BAT 12 in Section 1.5.4.3)</td><td>● apply safety management for the handling, e.g. storage, and/or feeding of hazardous waste materials, such as using a risk based approach according to the source and type of waste, for the labelling, checking, sampling and testing of waste to be handled (BAT 12 in Section 1.5.4.3)</td></tr>
<tr><td>Diffuse dust emissions (BAT 13 a, b in Section 1.5.5.1)</td><td>● minimise/prevent diffuse dust emissions by applying the measures/techniques individually or in combination which are listed in BAT 13 a, b in Section 1.5.5.1 (measures/techniques for dusty operations and bulk storage areas)</td></tr>
<tr><td>Channelled dust emissions from dusty operations (BAT 14 in Section 1.5.5.2)</td><td>● apply a maintenance management system which especially addresses the performance of filters of these sources. Taking this management system into account, BAT is to reduce channelled dust emissions from dusty operations to less than 10 mg/Nm^3 (BAT-AEL), as the average over the sampling period (spot measurement, for at least half an hour) by applying dry exhaust gas cleaning with a filter.
For small sources (<10000 Nm^3/h) a priority approach has to be taken into account</td></tr>
<tr><td>Dust emissions from kiln firing processes (BAT 15 in Section 1.5.5.3)</td><td>● reduce dust (particulate matter) emissions from flue-gases of kiln firing processes by applying dry exhaust gas cleaning with a filter. The BAT-AEL is <10 – 20 mg/Nm^3, as the daily average value. When applying fabric filters or new or upgraded ESPs, the lower level is achieved</td></tr>
<tr><td>Dust emissions from cooling and milling processes (BAT 16 in Section 1.5.5.4)</td><td>● reduce dust (particulate matter) emissions from flue-gases of cooling and milling processes by applying dry exhaust gas cleaning with a filter. The BAT-AEL is <10 – 20 mg/Nm^3, as the daily average value or average over the sampling period (spot measurements for at least half an hour). When applying fabric filters or new or upgraded ESPs, the lower level is achieved</td></tr>
<tr><td>NO_x emissions (BAT 17, 18 in Section 1.5.6.1)</td><td>■ reduce the emissions of NO_x from the flue-gases of kiln firing processes by applying measures/techniques which are listed in BAT 17 a – d in Section 1.5.6.1 individually or in combination (i.e. primary measures/techniques and/or staged combustion (conventional or waste fuels), also in combination with a precalciner and the use of optimised fuel mix, SNCR, SCR, subject to appropriate catalyst and process development in the cement industry). The following emission levels of NO_x are BAT-AELs (BAT 17 in Section 1.5.6.1):
<table>
<tr><th>Kiln type</th><th>Unit</th><th>BAT-AEL
(daily average value)</th></tr>
<tr><td>Preheater kilns</td><td>mg/Nm^3</td><td><200 – 450[2) 3)]</td></tr>
<tr><td>Lepol and long rotary kilns</td><td>mg/Nm^3</td><td>400 – 800[1)]</td></tr>
<tr><td colspan="3">[1)] Depending on initial levels and ammonia slip
[2)] BAT-AEL is 500 mg/Nm^3, where after primary measures/techniques the initial NO_x level is >1000 mg/Nm^3
[3)] Existing kiln system design, fuel mix properties including waste, raw material burnability can influence the ability to be in the range. Levels below 350 mg/Nm^3 are achieved at kilns with favourable conditions. The lower value of 200 mg/Nm^3 has only been reported as monthly average for three plants (easy burning mix used)</td></tr>
</table>
● by applying SNCR (BAT 18 in Section 1.5.6.1),
○ apply measures/techniques which are listed in BAT 18 a and b in Section 1.5.6.1
○ keep the emissions of NH_3 slip from the flue-gases as low as possible, but below 30 mg/Nm^3, as the daily average value. The correlation between the NO_x abatement efficiency and the NH_3 slip has to be considered. Depending on the initial NO_x level and on the NO_x abatement efficiency, the NH_3 slip may be higher up to 50 mg/Nm^3. For Lepol and long rotary kilns, the level may be even higher (BAT 18 c in Section 1.5.6.1)</td></tr>
</table>

<table>
<tr><th colspan="2">Summary of BAT for the cement industry</th></tr>
<tr><td>SO_x emissions (BAT 19, 20 in Section 1.5.6.2)</td><td>

keep the emissions of SO_x low or reduce the emissions of SO_x from the flue-gases of kiln firing and/or preheating/precalcining processes by applying one of the measures/techniques which are listed in BAT 19 a (absorbent addition) and b (wet scrubber) in Section 1.5.6.2. The following emission levels of SO_x are BAT-AELs (BAT 19 in Section 1.5.6.2):
<table>
<tr><th>Parameter</th><th>Unit</th><th>BAT-AEL[1]
(daily average value)</th></tr>
<tr><td>SO_x expressed as SO_2</td><td>mg/Nm³</td><td><50 – <400</td></tr>
<tr><td colspan="3">[1] The range takes into account the sulphur content in the raw materials</td></tr>
</table>

optimise the raw milling processes (for the dry process) which act as SO_2 abatement for the kiln, as described in Section 1.3.4.3 (BAT 20 in Section 1.5.6.2)

</td></tr>
<tr><td>Reduction of CO trips (BAT 21 in Section 1.5.6.3.1)</td><td>

when applying ESPs or hybrid filters, minimise the frequency of CO trips and keep their total duration to below 30 minutes annually, by applying of the measures/techniques which are listed in BAT 21 a – c in Section 1.5.6.3.1 in combination

</td></tr>
<tr><td>Total organic carbon emissions (BAT 22 in Section 1.5.6.4)</td><td>

keep the emissions of TOC from the flue-gases of the kiln firing processes low by avoiding of feeding raw materials with a high content of volatile organic compounds into the kiln system via the raw material feeding route

</td></tr>
<tr><td>Hydrogen chloride (HCl) and hydrogen fluoride (HF) emissions (BAT 23, 24 in Section 1.5.6.5)</td><td>

keep the emissions of HCl below 10 mg/Nm³ (BAT-AEL), as the daily average value or average over the sampling period (spot measurements, for at least half an hour), by applying the measures/techniques which are listed in BAT 23 a and b in Section 1.5.6.5 individually or in combination
keep the emissions of HF below 1 mg/Nm³ (BAT-AEL) expressed as HF, as the daily average value or average over the sampling period (spot measurements, for at least half an hour), by applying the primary measures/techniques which are listed in BAT 24 a, b in Section 1.5.6.5 individually or in combination

</td></tr>
<tr><td>PCDD/F emissions (BAT 25 in Section 1.5.7)</td><td>

avoid emissions of PCDD/F or keep the emissions of PCDD/F from the flue-gases of the kiln firing processes low by applying the measures/techniques which are listed in BAT 25 a – f in Section 1.5.7 individually or in combination: The BAT-AELs are <0.05 – 0.1 ng PCDD/F I-TEQ/Nm³, as the average over the sampling period (6 – 8 hours)

</td></tr>
<tr><td>Metal emissions (BAT 26 in Section 1.5.8)</td><td>

minimise the emissions of metals from the flue-gases of the kiln firing processes by applying the measures/techniques which are listed in BAT 26 a – c in Section 1.5.8 individually or in combination. The following emission levels of metals are BAT-AELs:

<table>
<tr><th>Metals</th><th>Unit</th><th>BAT-AEL
(average over the sampling period
(spot measurements, for at least half an hour))</th></tr>
<tr><td>Hg</td><td>mg/Nm³</td><td><0.05[2]</td></tr>
<tr><td>Σ (Cd, Tl)</td><td>mg/Nm³</td><td><0.05[1]</td></tr>
<tr><td>Σ (As, Sb, Pb, Cr, Co, Cu, Mn, Ni, V)</td><td>mg/Nm³</td><td><0.5[1]</td></tr>
<tr><td colspan="3">[1] Low levels have been reported, see Sections 1.3.4.7, 1.3.4.7.1 and 1.4.7
[2] Low levels have been reported (see Sections 1.3.4.7, 1.3.4.7.1and 1.4.7). Values higher than 0.03 mg/Nm³ have to be further investigated. Values close to 0.05 mg/Nm³ require consideration of additional measures/techniques such as those described in Sections 1.3.4.13, 1.3.9.1 and 1.4.7</td></tr>
</table>
</td></tr>
<tr><td>Process losses/ waste (BAT 27 in Section 1.5.9)</td><td>

re-use collected particulate matter in the process, wherever practicable, or utilise these dusts in other commercial products, when possible

</td></tr>
<tr><td>Noise (BAT 28 in Section 1.5.10)</td><td>

reduce/minimise noise emissions from the cement manufacturing processes by applying a combination of the measures/techniques which are listed in BAT 28 a – h in Section 1.5.10

</td></tr>
</table>

<table>
<tr><th colspan="2">Summary of BAT for the lime industry</th></tr>
<tr><td>Environmental management (BAT 29 in Section 2.5.1)</td><td>

implement and adhere to an Environmental Management System (EMS) that incorporates, as appropriate to the local circumstances, the features as listed in BAT 29 in Section 2.5.1

</td></tr>
<tr><td>General primary measures/techniques (BAT 30, 31, 32 in Section 2.5.2)</td><td>

achieve a smooth and stable kiln process, operating close to the process parameter set points, that is beneficial for all kiln emissions as well as the energy use by applying the measures/techniques which are listed in BAT 30 a, b in Section 2.5.2
carry out a careful selection and control of substances entering the kiln in order to reduce and/or avoid emissions (BAT 31 in Section 2.5.2).
carry out monitoring and measurements of process parameters and emissions on a regular basis as listed in BAT 32 a – d in Section 2.5.2

</td></tr>
</table>

<table>
<tr><th colspan="2">Summary of BAT for the lime industry</th></tr>
<tr><td>Energy consumption (BAT 33, 34 in Section 2.5.3)</td><td>• reduce/minimise thermal energy consumption by applying a combination of the measures/techniques which are listed in BAT 33 a – c in Section 2.5.3. The following thermal energy consumption levels are associated with BAT (BAT 33 in Section 2.5.3):
<table>
<tr><th>Kiln type</th><th>Thermal energy consumption¹⁾
GJ/t</th></tr>
<tr><td>Long rotary kilns (LRK)</td><td>6.0 – 9.2</td></tr>
<tr><td>Rotary kilns with preheater (PRK)</td><td>5.1 – 7.8</td></tr>
<tr><td>Parallel flow regenerative kilns (PFRK)</td><td>3.2 – 4.2</td></tr>
<tr><td>Annular shaft kilns (ASK)</td><td>3.3 – 4.9</td></tr>
<tr><td>Mixed feed shaft kilns (MFSK)</td><td>3.4 – 4.7</td></tr>
<tr><td>Other kilns (OK)</td><td>3.5 – 7.0</td></tr>
<tr><td colspan="2">1) Energy consumption depends on the type of product, the product quality, the process conditions and the raw materials</td></tr>
</table>
• minimise electrical energy consumption by applying the measures/techniques which are listed in BAT 34 a – c in Section 2.5.3 individually or in combination (BAT 34 in Section 2.5.3)</td></tr>
<tr><td>Consumption of limestone (BAT 35 in Section 2.5.4)</td><td>• minimise limestone consumption by applying the measures/techniques which are listed in BAT 35 a, b in Section 2.5.4 individually or in combination</td></tr>
<tr><td>Selection of fuels (BAT 36 in Section 2.5.5)</td><td>• carry out a careful selection and control of fuels entering the kiln, such as selecting fuels with low contents of sulphur (for rotary kilns in particular), nitrogen and chlorine in order to avoid/reduce emissions</td></tr>
<tr><td>Waste quality control (BAT 37 a, b in Section 2.5.5.1.1)</td><td>• apply quality assurance systems to guarantee the characteristics of wastes and to analyse any waste that is to be used as fuel in a lime kiln for the parameters/criteria listed BAT 37 a I. – a III. in Section 2.5.5.1.1
• control the amount of relevant parameters for any waste that is to be used as fuel in a lime kiln, such as total halogen content, relevant metals (e.g. total chromium, lead, cadmium, mercury, thallium) and sulphur</td></tr>
<tr><td>Waste feeding into the kiln
(BAT 38 a – e in Section 2.5.5.1.2)</td><td>• use appropriate burners for feeding suitable wastes depending on kiln design and kiln operation (BAT 38 a in Section 2.5.5.1.2)
• operate in such a way that the gas resulting from the co-incineration of waste is raised in a controlled and homogeneous fashion and even under the most unfavourable conditions, to a temperature of 850 °C for 2 seconds (BAT 38 b in Section 2.5.5.1.2)
• raise the temperature to 1100 °C if hazardous wastes with a content of more than 1 % of halogenated organic substances, expressed as chlorine, are co-incinerated (BAT 38 c in Section 2.5.5.1.2)
• feed wastes continuously and constantly (BAT 38 d in Section 2.5.5.1.2)
• stop co-incinerating waste for operations such as start-ups and/or shutdowns when appropriate temperatures and residence times cannot be reached, as mentioned in BAT 38 b – c (BAT 38 e in Section 2.5.5.1.2)</td></tr>
<tr><td>Safety management for the use of hazardous waste materials (BAT 39 in Section 2.5.5.1.3)</td><td>• apply safety management for the handling, e.g. storage, and/or feeding of hazardous waste materials (see Section 2.4.4) (BAT 39 in Section 2.5.5.1.3)</td></tr>
<tr><td>Diffuse dust emissions (BAT 40 in Section 2.5.6.1)</td><td>• minimise/prevent diffuse dust emissions by applying the measures/techniques which are listed in BAT 40 a, b in Section 2.5.6.1 individually or in combination</td></tr>
<tr><td>Channelled dust emissions from dusty operations (BAT 41 in Section 2.5.6.2)</td><td>• apply a maintenance management system which especially addresses the performance of filters of these sources. Taking this management system into account, BAT is to reduce channelled dust emissions from dusty operations to less than 10 mg/Nm³ (BAT-AEL), as the average over the sampling period (spot measurements, for at least half an hour) by applying fabric filters or to <10 – 20 mg/Nm³ (BAT-AEL), as the average over the sampling period (spot measurements, for at least half an hour) by applying wet scrubbers.
Wet scrubbers are mainly used for hydrating lime plants. It has to be noted that for small sources (<10000 Nm³/h) a priority approach has to be taken into account</td></tr>
<tr><td>Dust emissions from kiln firing processes (BAT 42 in Section 2.5.6.3)</td><td>• reduce dust (particulate matter) emissions from the flue-gases of kiln firing processes by applying exhaust gas cleaning with a filter (see Section 2.4.5.3). By applying fabric filters, the BAT-AEL is less than 10 mg/Nm³, as the daily average value. By applying ESPs or other filters, the BAT-AEL is less than 20 mg/Nm³, as the daily average value.
In exceptional cases where the resistivity of dust is high, the BAT-AEL could be higher, up to 30 mg/Nm³, as the daily average value</td></tr>
</table>

<table>
<tr><th colspan="2">Summary of BAT for the lime industry</th></tr>
<tr><td>General primary measures/techniques for reducing gaseous compounds (BAT 43 in Section 2.5.7.1)</td><td>

- reduce the emissions of gaseous compounds (i.e. NO_x, SO_x, HCl, CO, TOC/VOC, metals) from the flue-gases of kiln firing processes by applying the primary measures/techniques which are listed in BAT 43 a – c in Section 2.5.7.1 individually or in combination

</td></tr>
<tr><td>NO_x emissions (BAT 44, 45 in Section 2.5.7.2)</td><td>

- reduce the emissions of NO_x from the flue-gases of kiln firing processes by applying the measures/techniques which are listed in BAT 44 a, b in Section 2.5.7.2 individually or in combination. The following emission levels of NO_x are BAT-AELs:

<table>
<tr><th>Kiln type</th><th>Unit</th><th>BAT-AEL (daily average value, stated as NO_2)</th></tr>
<tr><td>PFRK, ASK, MFSK, OSK</td><td>mg/Nm^3</td><td>100 – <350[1][3]</td></tr>
<tr><td>LRK, PRK</td><td>mg/Nm^3</td><td><200 – <500[1][2]</td></tr>
<tr><td colspan="3">[1] The higher ranges are related to the production of dolime and hard burned lime
[2] For LRK and PRK with shaft producing hard burned lime, the upper level is up to 800 mg/Nm^3
[3] Where primary measures as indicated in a) I. above are not sufficient and where secondary measures are not vailable to reduce the NO_x emissions to 350 mg/Nm^3, the upper level is 500 mg/Nm^3, especially for hard burned lime</td></tr>
</table>

- when SNCR is applicable,
  - apply measures/techniques which are listed in BAT 45 a, b in Section 2.5.7.2
  - keep the emissions of NH_3 slip from the flue-gases as low as possible, but below 30[1] mg/Nm^3, as the daily average value. The correlation between the NO_x abatement efficiency and the NH_3 slip has to be considered (see Section 2.4.6.1.4, Figure 2.50) (BAT 45 c in Section 2.5.7.2)

[1] This BAT-AEL is related to experiences taken from one lime installation (four kilns)

</td></tr>
<tr><td>SO_x emissions (BAT 46 in Section 2.5.7.3)</td><td>

- reduce the emissions of SO_x from the flue-gases of kiln firing processes by applying the measures/techniques which are listed in BAT 46 a – c in Section 2.5.7.3 individually or in combination. The following emission levels of SO_x are BAT-AELs:

<table>
<tr><th>Kiln type</th><th>Unit</th><th>BAT-AEL[1] (daily average value, SO_x expressed as SO_2)</th></tr>
<tr><td>PFRK, ASK, MFSK, OSK, PRK</td><td>mg/Nm^3</td><td><50 – 200</td></tr>
<tr><td>LRK</td><td>mg/Nm^3</td><td><50 – <400</td></tr>
<tr><td colspan="3">[1] The level depends on the initial SO_x level in the exhaust gas and on the reduction measure/technique used</td></tr>
</table>

</td></tr>
<tr><td>CO emissions (BAT 47 in Section 2.5.7.4.1)</td><td>

- reduce the emissions of CO by applying the primary measures/techniques which are listed in BAT 47 a, b in Section 2.5.7.4.1 individually or in combination. The following emission levels of CO are BAT-AELs:

<table>
<tr><th>Kiln type</th><th>Unit</th><th>BAT-AEL[1] (daily average value)</th></tr>
<tr><td>PFRK, OSK, LRK, PRK</td><td>mg/Nm^3</td><td><500</td></tr>
<tr><td colspan="3">[1] Level can be higher depending on raw materials used and/or type of lime produced, e.g. hydraulic lime</td></tr>
</table>

</td></tr>
<tr><td>Reduction of CO trips (BAT 48 in Section 2.5.7.4.2)</td><td>

- when using electrostatic precipitators (ESPs), minimise the frequency of CO trips by applying the measurements/techniques which are listed in BAT 48 a – c in Section 2.5.7.4.2

</td></tr>
<tr><td>Total organic carbon (BAT 49 in Section 2.5.7.5)</td><td>

- reduce the emissions of TOC from the flue-gases of the kiln firing processes by applying the measures/techniques which are listed in BAT 49 a, b in Section 2.5.7.5 individually or in combination. The following emission levels of TOC are BAT-AELs:

<table>
<tr><th>Kiln type</th><th>Unit</th><th>BAT-AEL (average over the sampling period)</th></tr>
<tr><td>LRK[1], PRK[1]</td><td>mg/Nm^3</td><td><10</td></tr>
<tr><td>ASK[1], MFSK[1][2], PFRK[2]</td><td>mg/Nm^3</td><td><30</td></tr>
<tr><td colspan="3">[1] Level can be higher depending on the raw materials used and/or the type of lime produced, e.g. hydraulic lime
[2] In exceptional cases, the level can be higher</td></tr>
</table>

</td></tr>
</table>

<table>
<tr><th colspan="2">Summary of BAT for the lime industry</th></tr>
<tr><td>Hydrogen chloride (HCl) and hydrogen fluoride (HF) emissions (BAT 50 in Section 2.5.7.6)</td><td>• when using wastes, reduce the emissions of HCl and the emissions of HF by applying the primary measures/techniques as listed in BAT 50 a, b in Section 2.5.7.6.
The BAT-AEL for HCl is <10 mg/Nm^3, as the daily average value or the average value over the sampling period (spot measurements, for at least half an hour) and the BAT for HF is <1 mg/Nm^3, as the daily average value or the average value over the sampling period (spot measurements, for at least half an hour)</td></tr>
<tr><td>PCDD/F emissions (BAT 51 in Section 2.5.8)</td><td>• prevent or reduce the emissions of PCDD/F by applying the primary measures/techniques which are listed in BAT 51 a – c in Section 2.5.8 individually or in combination.
The BAT-AELs are <0.05 – 0.1 ng PCDD/F I-TEQ/Nm^3, as the average over the sampling period (6 – 8 hours)</td></tr>
<tr><td>Metal emissions (BAT 52 in Section 2.5.9)</td><td>• minimise the emissions of metals from the flue-gases of the kiln firing processes by applying the measures/techniques which are listed in BAT 52 a – d in Section 2.5.9 individually or in combination. When using wastes, the following emission levels of metals are BAT-AELs:
<table>
<tr><th>Metals</th><th>Unit</th><th>BAT-AEL
(average over the sampling period
(spot measurements, for at least half an hour))</th></tr>
<tr><td>Hg</td><td>mg/Nm^3</td><td><0.05</td></tr>
<tr><td>∑ (Cd, Tl)</td><td>mg/Nm^3</td><td><0.05</td></tr>
<tr><td>∑ (As, Sb, Pb, Cr, Co, Cu, Mn, Ni, V)</td><td>mg/Nm^3</td><td><0.5</td></tr>
<tr><td colspan="3">Low levels were reported (see Sections 2.3.3.9, 2.3.3.10.1 and 4.3.4 when applying measures/techniques as mentioned in BAT 52)</td></tr>
</table>
</td></tr>
<tr><td>Process losses/waste (BAT 53 a, b in Section 2.5.10)</td><td>• re-use collected dust/particulate matter in the process wherever practicable (BAT 53 a in Section 2.5.10)
• utilise dust, off specification quicklime and hydrated lime in selected commercial products (BAT 53 b in Section 2.5.10)</td></tr>
<tr><td>Noise (BAT 54 in Section 2.5.11)</td><td>• reduce/minimise noise emissions from the lime manufacturing processes by applying a combination of the measures/techniques which are listed in BAT 54 a – o in Section 2.5.11</td></tr>
</table>

Summary of BAT for the magnesium oxide industry	
Environmental management (BAT 55 in Section 3.5.1)	• implement and adhere to an Environmental Management System (EMS) that incorporates, as appropriate to the local circumstances, the features as listed in BAT 55 in Section 3.5.1
General primary measures/techniques (BAT 56 in Section 3.5.2)	• carry out monitoring and measurements of process parameters and emissions on a regular basis as listed in BAT 56 a – c in Section 3.5.2
Energy consumption (BAT 57, 58 in Section 3.5.3)	• reduce thermal energy consumption depending on the process and the products to 6 – 12 GJ/t by applying a combination of the measures/techniques which are listed in BAT 57 a – c in Section 3.5.3 • minimise electrical energy consumption by applying the measures/techniques which are listed in BAT 58 a, b in Section 3.5.3 individually or in combination
Diffuse dust emissions (BAT 59 in Section 3.5.4.1)	• minimise/prevent diffuse dust emissions by applying measures/techniques for dusty operations individually or in combination
Channelled dust emissions from dusty operations (BAT 60 in Section 3.5.4.2)	• reduce channelled dust emissions from dusty operations to less than 10 mg/Nm^3 (BAT-AEL), as the average over the sampling period (spot measurements, for at least half an hour), by applying flue-gas cleaning with a filter. It has to be noted that for small sources (<10000 Nm^3/h), a priority approach has to be taken into account
Dust emissions from kiln firing process (BAT 61 in Section 3.5.4.3)	• reduce dust (particulate matter) emissions from the flue-gases of kiln firing processes to <20 – 35 mg/Nm^3 (BAT-AEL), as the daily average value or average over the sampling period (spot measurements, for at least half an hour), by applying exhaust gas cleaning with a filter
General primary measures/techniques for reducing gaseous compounds (BAT 62 in Section 3.5.5.1)	• reduce the emissions of gaseous compounds (i.e. NO_x, HCl, SO_x, CO) from flue-gases of kiln firing processes by applying the primary measures/techniques which are listed in BAT 62 a – c in Section 3.5.5.1 individually or in combination
NO_x emissions (BAT 63 in Section 3.5.5.2)	• reduce the emissions of NO_x from the flue-gases of kiln firing processes to <500 – <1500 mg/Nm^3 (BAT-AEL), as the daily average value stated as NO_2, by applying a combination of the measures/techniques which are listed in BAT 63 a, b in Section 3.5.5.2. The higher BAT-AEL values are related to the high temperature DBM process
CO emissions (BAT 64 in Section 3.5.5.3.1)	• reduce the emissions of CO from the flue-gases of kiln firing processes to <50 – 1000 mg/Nm^3 (BAT-AEL), as the daily average value by applying a combination of the measures/techniques which are listed in BAT 64 a – c in Section 3.5.5.3.1

<table>
<tr><th colspan="2">Summary of BAT for the magnesium oxide industry</th></tr>
<tr><td>Reduction of CO trips (BAT 65 in Section 3.5.5.3.2)</td><td>• by applying ESP, minimise the number of CO trips by applying the measures/techniques which are listed in BAT 65 a – c in Section 3.5.5.3.2</td></tr>
<tr><td>SO_x emissions (BAT 66 in Section 3.5.5.4)</td><td>• reduce the emissions of SO_x from the flue-gases of kiln firing processes by applying a combination of the primary and secondary measures/techniques which are listed in BAT 66 a – c in Section 3.5.5.4: The following emission levels of SO_x are BAT-AELs:
<table>
<tr><th>Parameter</th><th>Unit</th><th>BAT-AEL[1]
(daily average value)</th></tr>
<tr><td>SO_x expressed as SO_2
Sulphur content in the raw material <0.10 %</td><td>mg/Nm^3</td><td><50</td></tr>
<tr><td>SO_x expressed as SO_2
Sulphur content in the raw material 0.10 – 0.25 %</td><td>mg/Nm^3</td><td>50 – 250</td></tr>
<tr><td>SO_x expressed as SO_2
Sulphur content in the raw material >0.25</td><td>mg/Nm^3</td><td>250 – 400[2]</td></tr>
<tr><td colspan="3">[1] The ranges depend on the content of sulphur in the raw materials, e.g. for the use of raw materials with a lower content of sulphur, lower levels within the ranges are BAT and for the use of raw materials with a higher content of sulphur, higher levels within the ranges are BAT
[2] Related to raw material compositions, SO_2 emission levels could be higher than 400 mg/Nm^3 in exceptional cases.</td></tr>
</table>
</td></tr>
<tr><td>Process losses/waste (BAT 67, 68, 69 in Section 3.5.6)</td><td>• re-use collected particulate matter (various types of magnesium carbonate dusts) in the process wherever practicable (BAT 67 in Section 3.5.6)
• when various types of collected magnesium carbonate dusts are not recyclable utilise these dusts in other marketable products, when possible (BAT 68 in Section 3.5.6)
• re-use sludge resulting from the wet process of the flue-gas desulphurisation in other sectors (BAT 69 in Section 3.5.6)</td></tr>
<tr><td>Noise (BAT 70 in Section 3.5.7)</td><td>• reduce/minimise noise emissions from magnesium oxide manufacturing processes by applying a combination of the measures/techniques which are listed in BAT 70 a – j in Section 3.5.7</td></tr>
<tr><td>Use of wastes as fuels and/or raw materials (BAT 71 in Section 3.5.8)</td><td>• when using wastes,
○ select suitable wastes for the process and the burner (BAT 71 a in Section 3.5.8)
○ apply quality assurance systems to guarantee the characteristics of wastes and to analyse any waste that is to be used for the criteria which are listed in BAT 71 b in Section 3.5.8
○ control the amount of relevant parameters for any waste that is to be used, such as total halogen content, metals (e.g. total chromium, lead, cadmium, mercury, thallium) and sulphur (BAT 71 c in Section 3.5.8)</td></tr>
</table>

Conclusions, recommendations, research and technical development

The conclusions and recommendations for the cement, lime and magnesium oxide industry contain information on the milestones in developing this document, the degree of consensus reached on the BAT proposals for the cement, lime and magnesium oxide industries and the information gaps that still exist.

The EC is launching and supporting, through its RTD programmes, a series of projects dealing with clean technologies, emerging effluent treatment and recycling technologies and management strategies. Potentially these projects could provide a useful contribution to future BREF reviews. Readers are therefore invited to inform the European IPPC Bureau of any research results which are relevant to the Scope of this document (see also the Preface of this document).

PREFACE

1. Status of this document

Unless otherwise stated, references to 'the Directive' in this document means the Directive 2008/1/EC of the European Parliament and the Council concerning integrated pollution prevention and control (IPPC). As the IPPC Directive applies without prejudice to Community provisions on health and safety at the workplace, so does this document.

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

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

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

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

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

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

- 'techniques' shall include both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned
- 'available techniques' means those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator;
- 'best' means those most effective in achieving a high general level of protection of the environment as a whole.

Furthermore, Annex IV to the Directive contains a list of 'considerations to be taken into account generally or in specific cases when determining best available techniques ... bearing in mind the likely costs and benefits of a measure and the principles of precaution and prevention'. These considerations include the information published by the Commission pursuant to Article 17(2) of the Directive.

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

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

3. Objective of this document

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

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

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

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

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

4. Information sources

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

5. How to understand and use this document

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

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

As outlined in the Scope, this document is structured in a different way when compared with a standard BREF. This document contains three cornerstone chapters: Chapter 1 – cement industry, Chapter 2 – lime industry and Chapter 3 – magnesium oxide industry by using the dry process route.

Within these three chapters, standard BREF sections are built as follows:

- Sections 1 and 2 of each chapter provide general information on the industrial sector concerned and on the industrial processes used within the sector
- Section 3 of each chapter provides data and information concerning current consumption and emission levels reflecting the situation in existing installations in operation at the time of writing
- Section 4 of each chapter describes in more detail the emissions 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. It also includes the extent to which the technique is applicable to the range of installations requiring IPPC permits is also given, for example new, existing, changed, large or small installations. Techniques that are generally seen as obsolete are not included
- Section 5 of each chapter presents the techniques and the consumption and emission levels that are considered to be compatible with BAT in the sector (see for more details the introduction to Section 5 of each chapter). The purpose is thus to provide general indications regarding the consumption and emission 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) of the Directive. It should be stressed, however, that this document does not propose emission limit values. The determination of appropriate permit conditions will involve taking account of local, site-specific factors such as the technical characteristics of the installation concerned, its geographical location and the local environmental conditions. In the case of existing installations, the economic and technical viability of upgrading them also needs to be taken into account. Even the single objective of ensuring a high level of protection for the environment as a whole will often involve making trade-off judgements between different types of environmental impact, and these judgements will often be influenced by local considerations. Although an attempt is made to address some of these issues, it is not possible for them to be considered fully in this document. The techniques and levels presented in Sections 1.5, 2.5 and 3.5 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
- Section 6 of each chapter describes emerging techniques.

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

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

The original BREF on CL was adopted by the European Commission in 2001. This document is the result of the first review of the CL BREF.

Best Available Techniques Reference Document on The Cement, Lime and Magnesium Oxide manufacturing Industry

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SCOPE

This document addresses the industrial activities specified in Section 3.1 of Annex I to Directive 2008/1/EC, namely:

"3.1. Installations for the production of cement clinker in rotary kilns with a production capacity exceeding 500 tonnes per day or lime in rotary kilns with a production capacity exceeding 50 tonnes per day or in other furnaces with a production capacity exceeding 50 tonnes per day."

This document covers the processes involved in the production of cement and lime as well as the use of wastes as raw materials and/or fuels.

Additionally, this document covers the manufacture of magnesium oxide by using the dry process route based on mined natural magnesite (magnesium carbonate $MgCO_3$).

The wet process route using magnesium chloride as the starting material is not covered within this document because of the differences in the use of process structure, techniques and raw materials. This process is covered within the Reference Document on Best Available Technique for the Manufacture of Large Volume Inorganic Chemicals – Solids and Others Industry (LVIC-S) [108, European Commission, 2006].

The Waste Incineration Directive [59, European Commission, 2000] defines (in Article 3, point 5) a co-incineration plant as any stationary or mobile plant whose main purpose is the generation of energy or production of material products and:

- which uses wastes as a regular or additional fuel; or
- in which waste is thermally treated for the purpose of disposal.

However, the cement industry is capable of using:

- waste fuels with significant calorific value; and
- waste materials without significant calorific value but with mineral components used as raw materials that contribute to the intermediate product clinker; and
- waste materials that have both a significant calorific value and mineral components [104, HOLCIM/GTZ, 2006].

Therefore, the term 'co-incineration' is not fully adequate for the purpose of this document as it may not cover all the uses of waste within the cement sector. The terminology 'use of waste as fuel and/or raw material' is used to cover all three recovery processes mentioned above.

In addition to basic manufacturing activities of the three industrial activities mentioned above, i.e. cement, lime, magnesium oxide, this document covers the associated activities which could have an effect on emissions or pollution. Thus, this document includes activities from the preparation of raw materials to the dispatch of the finished products.

Certain activities are not covered because they are not considered to be directly associated with the primary activity. For example, quarrying and shaft kilns for cement clinker production are not covered.

The main operations covered by the descriptions are:

- raw materials – storage and preparation
- fuels – storage and preparation
- use of wastes as raw materials and/or fuels, quality requirements, control and preparation
- the kiln systems, kiln firing processes and emissions reduction techniques
- products – storage and preparation
- packaging and dispatch.

It has to be noted that in 2006 for the industrial sectors covered by this document (cement, lime and magnesium oxide), data were collected for the EU-25. Furthermore in 2007, information and data have partly been updated for the EU-27.

The structure of this document

Because of different products and processes involved, the structure of this document is described as follows:

Preliminary part: Executive Summary, Preface, Scope of the document
Chapter 1 General description of the cement industry including a generic part, a process part, and an emerging techniques part as well as a final part with conclusions and recommendations
Chapter 2 General description of the lime industry including a generic part, a process part, and an emerging techniques part as well as a final part with conclusions and recommendations
Chapter 3 General description of the magnesium oxide industry, dry process route including a generic part, a process part, and an emerging techniques part as well as a final part with conclusions and recommendations
Supplementary part: References, Glossary, Annexes

Within Chapters 1 to 3, standard BREF sections are built as described in the Preface.

1 CEMENT INDUSTRY

1.1 General information about the cement industry

Cement is a finely ground, non-metallic, inorganic powder, and when mixed with water forms a paste that sets and hardens. This hydraulic hardening is primarily due to the formation of calcium silicate hydrates as a result of the reaction between mixing water and the constituents of the cement. In the case of aluminous cements, hydraulic hardening involves the formation of calcium aluminate hydrates.

Cement is a basic material for building and civil engineering construction. In Europe the use of cement and concrete (a mixture of cement, aggregates, sand and water) in large civic works can be traced back to antiquity. Portland cement, the most widely used cement in concrete construction, was patented in 1824. Output from the cement industry is directly related to the state of the construction business in general and therefore tracks the overall economic situation closely.

As shown in Figure 1.1, world cement production has grown steadily since 1950, with increased production in developing countries, particularly in Asia, accounting for the lion's share of growth in world cement production in the 1990s.

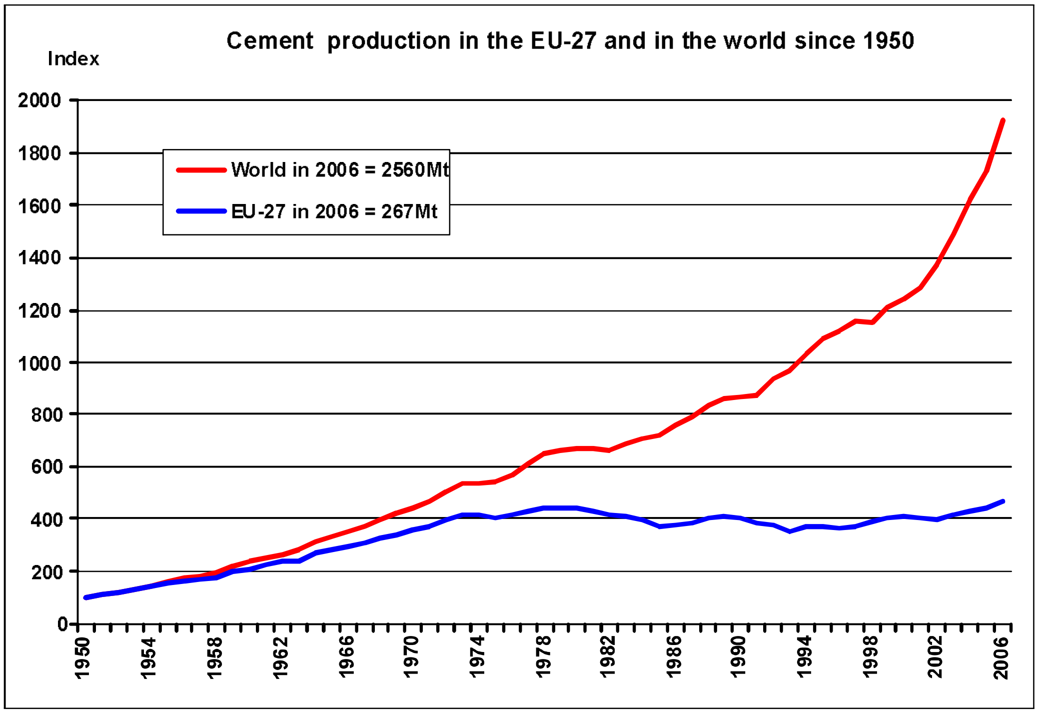


Figure 1.1: Cement production in the EU-27 and in the world from 1950 to 2006 [72, CEMBUREAU, 2006-2008,], [168, TWG CLM, 2007]

In 2006, world production of cement stood at 2540 million tonnes. Table 1.1 shows the distribution of cement production by geographic regions.

Region	Unit	2006	Region	Unit	2006
China	%	47.4	US	%	3.9
India	%	6.2	Other America	%	5.8
Japan	%	2.7	Africa	%	4.0
Other Asia	%	13.2	CIS	%	3.4
EU-27	%	10.5	Oceania	%	0.4
Other Europe	%	2.5			

Table 1.1: World cement production by geographic regions in 2006
[72, CEMBUREAU, 2006-2008,]

Producers in the European Union have increased cement output per man per year from 1700 tonnes in 1970 to 3500 in 1991. This increase in productivity is a result of the introduction of larger scale production units. These use advanced operation automation and therefore require fewer, but more highly qualified staff. The number of people employed in the cement industry in the European Union (EU-27) was about 54000 in 2005. Figure 1.2 shows the estimated workforce of the cement industry in the EU from 1975 to 2005 along with employment figures for the EU-25. The figures related to the years before 1991 do not include employees from the former East Germany.

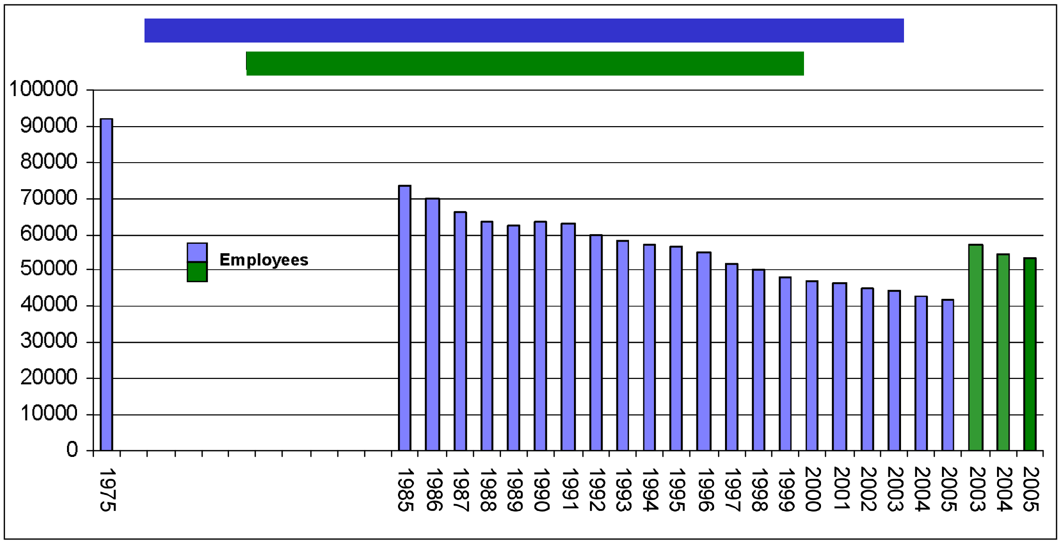


Figure 1.2: Estimated employment for the cement industry in the EU from 1975 to 2005
[72, CEMBUREAU, 2006-2008,]

In 2006, cement production in the EU-25 totalled 267.5 million tonnes and consumption 260.6 million tonnes. 38 million tonnes of cement were imported and 32 million tonnes exported. These figures include trade between EU countries.

Production and consumption of cement in the EU-25 in 2005 is shown in Figure 1.3.

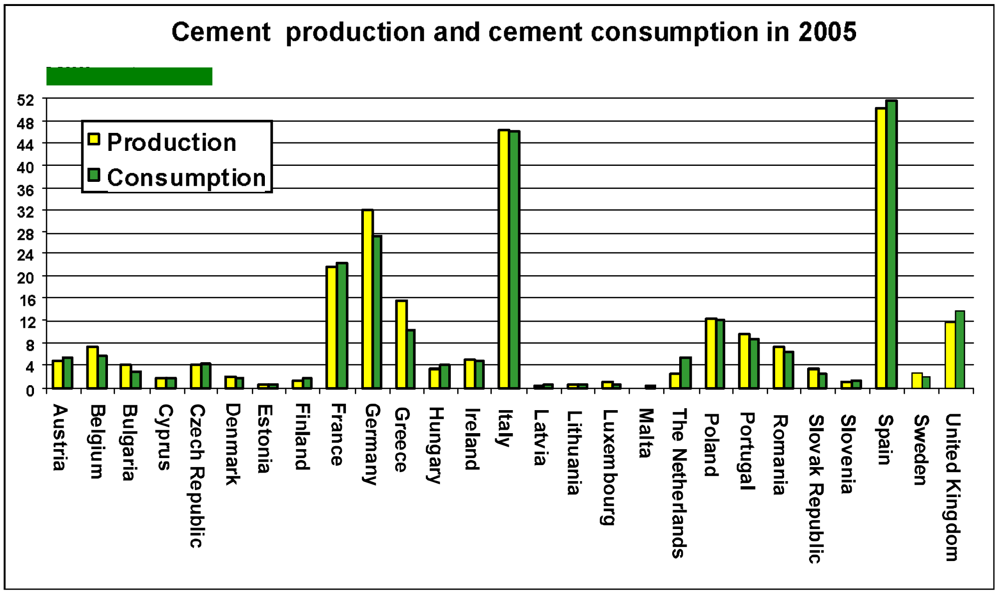


Figure 1.3: Cement production inclusive of exported clinker and cement consumption in the EU-25
[72, CEMBUREAU, 2006-2008,]

The world's five largest cement producers are Lafarge, Holcim, Cemex, HeidelbergCement and Italcementi. Apart from producing cement, these companies have also diversified into several other building material sectors such as aggregates, concrete products, plasterboard, etc.

Cement is mainly delivered by producers to their customers by road in the EU and there is a limit to the distance over which it can delivered by road under normal trading conditions due to costs of road transport and the relatively low unit selling price of cement. The maximum distance over which cement is transported by road is generally said to be between 200 and 300 km. However, where cement plants are located near water (sea, inland waterways), transport over longer distances is more common. Furthermore, having easy access to rail networks facilitates transport over longer distances in certain circumstances. Global trade does exist and in some cases it is economically viable to ship cement around the world. The presence of cement terminals (e.g. floating terminals) has contributed to the increase of imports of cement into EU markets from countries outside the EU. International competition is mainly a threat for individual plants, and within the EU increasing imports from Eastern Europe do affect local market conditions. It has been estimated that, in 2007, Greece, Italy, Portugal, Spain, southern France and the UK as a whole were regarded as areas open to imports. These areas represent 60 % of the EU's cement production in volume. Denmark, Norway and Sweden are also vulnerable. In 2005, 15.5 million tonnes were imported into the EU from countries with no carbon constraint compared to 13.5 million tonnes in 2004.

There are 268 installations producing cement clinker and finished cement in the EU-27. In addition, there are two clinker plants (kilns) without mills and 90 grinding plants (cement mills) without kilns (cement mills without kilns are not covered by this document), as shown in Table 1.2.

EU Member State		Cement plants – with kilns –	Cement plants – with cement mills only –
Belgium[1]	BE	5	4
Bulgaria	BG	5	-
Czech Republic	CZ	6	1
Denmark	DK	1	-
Germany	DE	38	20
Estonia	EE	1	-
Ireland	IE	4	-
Greece	EL	8	-
Spain	ES	37	13
France	FR	33	6
Italy	IT	59	35
Cyprus	CY	2	-
Latvia	LV	1	-
Lithuania	LT	1	-
Luxembourg[1)]	LU	1	1
Hungary	HU	4	-
Malta	MT		
Netherlands	NL	1	2
Austria	AT	9	3
Poland	PL	11	1
Portugal	PT	6	2
Romania	RO	8	1
Slovenia	SI	2	-
Slovakia	SK	6	-
Finland	FI	2	-
Sweden	SE	3	-
United Kingdom	UK	14	1
Total		268	90
[1)] Including one clinker plant			

Table 1.2: **Number of cement plants in the EU-27**
[72, CEMBUREAU, 2006-2008,]

There are a total of 377 kilns in the EU-27, but in 2007, not all were in operation. In recent years, typical kiln size has come to be around 3000 tonnes clinker per day, and although kilns of widely different sizes and ages exist, very few kilns have a capacity of less than 500 tonnes per day.

In 2007, about 90 % of Europe's cement production is from dry process kilns, a further 7.5 % of production is accounted for by semi-dry and semi-wet process kilns, with the remainder of European production – about 2.5 % – now coming from wet process kilns. The choice of manufacturing process is primarily motivated by the nature of the available raw materials.

The European standard (EN 197-1) for common cement, lists 27 different cement types into five groups. In addition, there is a range of special cements produced for particular applications. The European standard for cement produced in the EU-27 is shown in Table 1.4 while Table 1.3 shows the percentages of each type of cement supplied to domestic markets in 2005 in the EU-25. Furthermore, typical compositions of grey cement are shown in Table 1.5.

Type of cement	Unit	2005
CEM II Portland – composite	%	58.6
CEM I Portland	%	27.4
CEM III Blast furnace/slag	%	6.4
CEM IV Pozzolanic	%	6.0
CEM V Composite cement and other cements	%	1.6

Table 1.3: Domestic deliveries by type of cement in the EU-25
[72, CEMBUREAU, 2006-2008,]

Main types	Notation of the 27 products (types of common cement)		Composition (percentage by mass[1])										
			Main constituents										Minor additional constituents
			Clinker	Blast furnace slag	Silica fume	Pozzolana		Fly ash		Burnt shale	Limestone		
						Natural	Natural calcined	Siliceous	Calcareous				
			K	S	D[2]	P	Q	V	W	T	L[4]	LL[5]	
CEM I	Portland cement	CEM I	95 – 100	-	-	-	-	-	-	-	-	-	0 – 5
CEM II	Portland – slag cement	CEM II/A-S	80 – 95	6 – 20	-	-	-	-	-	-	-	-	0 – 5
		CEM II/B-S	65 – 79	21 – 35	-	-	-	-	-	-	-	-	0 – 5
	Portland – silica fume cement	CEM II/A-D	90 – 94	-	6 – 10	-	-	-	-	-	-	-	0 – 5
	Portland – pozzolana cement	CEM II/A-P	80 – 94	-	-	6 – 20	-	-	-	-	-	-	0 – 5
		CEM II/B-P	65 – 79	-	-	21 – 35	-	-	-	-	-	-	0 – 5
		CEM II/A-Q	80 – 94	-	-	-	6 – 20	-	-	-	-	-	0 – 5
		CEM II/B-Q	65 – 79	-	-	-	21 – 35	-	-	-	-	-	0 – 5
	Portland – fly ash cement	CEM II/A-V	80 – 94	-	-	-		6 – 20	-	-	-	-	0 – 5
		CEM II/B-V	65 – 79	-	-	-	-	21 – 35	-	-	-	-	0 – 5
		CEM II/A-W	80 – 94	-	-	-	-	-	6 – 20	-	-	-	0 – 5
		CEM II/B-W	65 – 79	-	-	-	-	-	21 – 35	-	-	-	0 – 5
	Portland – burnt shale	CEM II/A-T	80 – 94	-	-	-	-	-	-	6 – 20	-	-	0 – 5
		CEM II/B-T	65 – 79	-	-	-	-	-	-	21 – 35	-	-	0 – 5
	Portland – limestone cement	CEM II/A-L	80 – 94	-	-	-	-	-	-	-	6 – 20	-	0 – 5
		CEM II/B-L	65 – 79	-	-	-	-	-	-	-	21 – 35	-	0 – 5

Main types	Notation of the 27 products (types of common cement)		Composition (percentage by mass[1])										
			Main constituents										Minor additional constituents
			Clinker	Blast furnace slag	Silica fume	Pozzolana		Fly ash		Burnt shale	Limestone		
						Natural	Natural calcined	Siliceous	Calcareous				
			K	S	D[2]	P	Q	V	W	T	L[4]	LL[5]	
		CEM II/A-LL	80 – 94	-	-	-	-	-	-	-	-	6 – 20	0 – 5
		CEM II/B-LL	65 – 79	-	-	-	-	-	-	-	-	21 – 35	0 – 5
	Portland – composite cement	CEM II/A-M	80 – 94	6 – 20									0 – 5
		CEM II/B-M	65 – 79	21 – 35									0 – 5
CEM III	Blast furnace cement	CEM III/A	35 – 64	36 – 65	-	-	-	-	-	-	-	-	0 – 5
		CEM III/B	20 – 34	66 – 80	-	-	-	-	-	-	-	-	0 – 5
		CEM III/C	5 – 19	81 – 95	-	-	-	-	-	-	-	-	0 – 5
CEM IV	Pozzolanic cement[3]	CEM IV/A	65 – 89	-	11 – 35					-	-	-	0 – 5
		CEM IV/B	45 – 64	-	36 – 55					-	-	-	0 – 5
CEM V	Composite cement[3]	CEM V/A	40 – 64	18 – 30	-	18 – 30			-	-	-	-	0 – 5
		CEM V/B	20 – 38	31 – 50	-	31 – 50			-	-	-	-	0 – 5

[1] The values in this table refer to the sum of the major and minor additional constituents.

[2] The proportion of silica fumes is limited to 10 %.

[3] In Portland - composite cements CEM II/A-M and CEM II/B-M, in pozzolanic cements CEM IV/A and CEM IV/B and in composite cements CEM V/A and CEM V/B the main constituents other than clinker shall be declared by designation of the cement

[4] Limestone up to 50 % TOC

[5] Limestone up to 20 % TOC

Table 1.4: European standard in the EU-27 for types of cement and their composition
[149, CEN/EN 197-1, 2000]

	IUPAC nomencalature[1]	CAS number	EC number	Mol. formula Hill method	Mol. weight	Typical concentration (% w/w)	Concentration range (% w/w)
Composition information – main constituents							
A	Tricalcium silicate	12168-85-3	235-336-9	$3CaO \bullet SiO_2$	228	65	40 – 80
B	Dicalcium silicate	10034-77-2	233-107-8	$2CaO \bullet SiO_2$	172	15	10 – 50
C	Tricalcium aluminate	12042-78-3	234-932-6	$3CaO \bullet Al_2O_3$	270	10	0 – 15
D	Tetracalcium aluminoferrite	12068-35-8	235-094-4	$4CaO \bullet Al_2O_3 \bullet Fe_2O_3$	486	10	0 – 20
Composition information – Impurities and additives							
E[2]	Calcium oxide	1305-78-8	215-138-9	CaO		1	0 – 3
F	Magnesium oxide	1309-48-4	215-171-9	MgO		2	0 – 5
G	Dipotassium sulphate	10233-01-9	233-558-0	K_2SO_4		1	0 – 2
H	Disodium sulphate	7757-82-6	231-820-9	Na_2SO_4		0.5	0 – 1
Number of non-specified impurities: Total concentration of non-specified impurities:				<1 w/w %			
Additives				not available			

[1] International Union of Pure and Applied Chemistry nomenclature

[2] Calcium oxide is found in free form as 'free lime'. CaO is also present bound in the four main phases A-B-C-D

Note: Cements containing Portland cement clinker may release, upon reaction with water, traces of soluble chromate. Measures to prevent harmful dermatological effects are described in Commission Directive 2005/53/EC of 16 September 2005 amending Council Directive 91/414/EEC to include chlorothalonil, chlorotoluron, cypermethrin, daminozide and thiophanate-methyl as active substances.

Table 1.5: Chemical composition of grey cement
[103, CEMBUREAU, 2006]

Besides grey Portland cement, other specifications of cement are also produced, such as white cement. Except for colour, this type of cement has the same properties as grey cement. For white cement production, only materials which do not have a negative effect on the colour of this special type of cement are used. Table 1.6 shows some examples of parameters corresponding to white cement of the American and European markets. The local demand for whiteness will influence these parameters. Furthermore, the great difference is shown in the Fe_2O_3 content with respect to the range of grey cement.

Characteristics		White cement
Chemical composition (%)	SiO_2	22.5 – 23.8
	Al_2O_3	2.3 – 6.2
	Fe_2O_3	0.19 – 0.4
	CaO	66.3 – 68.0
	MgO	0.48 – 1.0
	SO_3	0.65 – 2.8
	F	0.24 – 0.85
	K_2O	0.12 – 0.14
Loss on ignition (%)		0.50 – 1.7
Na_2O		0.17
Potential compound composition (%)	C_3S (3 CaO SiO_2)	69.89
	C_2S (2 CaO SiO_2)	19
	C_3A (3 CaO Al_2O_3)	8.08
	C_4AF (4 CaO Al_2O_3 Fe_2O_3)	1
Blaine fineness (m^2/kg)		464

Table 1.6: Examples of chemical compositions of white cement clinker
[103, CEMBUREAU, 2006], [118, Germany, 2007], [119, Sobolev, 2001]

The whiteness of this type of cement is one of the most important characteristics. Different specifications are used for the whiteness of this cement according to different national standards [118, Germany, 2007], [119, Sobolev, 2001].

The cement industry is an energy intensive industry with energy typically accounting for about 40 % of operational costs, i.e. excluding capital costs but including electricity costs. Traditionally, the primary solid fossil fuel used was coal. A wide range of other solid, liquid or gaseous fossil fuels are used, such as petroleum coke, lignite, natural gas and oil (heavy, medium or light fuel oil). In addition to these traditional types of fossil fuels, the cement industry has been using large quantities of waste fuels or biomass fuels, for more than 15 years.

Type of fuel	Unit	2006
Petcoke (fossil)	%	38.6
Coal (fossil)	%	18.7
Petcoke and coal (fossil)[1)]	%	15.9
Fuel oil including HVFO[2)]	%	3.1
Lignite and other solid fuels (fossil)	%	4.8
Natural gas (fossil)	%	1.0
Waste fuels	%	17.9
Excluded: IE, CY, LT, SL Estimated: IT, PT, SE [1)] Reported by the EU-23+ members [2)] HVFO = highly viscous fuel oil		

Table 1.7: Fuel consumption expressed as a percentage of heat generation by the cement industry in the EU-27
[72, CEMBUREAU, 2006-2008,], [168, TWG CLM, 2007]

The emissions from cement plants which cause greatest concern and which need to be dealt with are dust, nitrogen oxides (NO_x) and sulphur dioxide (SO_2). Other emissions to be considered are volatile organic compounds (VOCs), polychlorinated dibenzo-p-dioxins (PCDDs) and dibenzofurans (PCDFs) as well as hydrogen chloride (HCl). Also emissions of carbon oxides (CO, CO_2), hydrogen fluoride (HF), ammonia (NH_3), benzene, toluene, ethylbenzene and xylene (BTEX), polyaromatic hydrocarbons (PAH), metals and their compounds, noise and odour may be considered under special circumstances.

Conventional raw materials and fuels are replaced by suitable waste and/or biomass and are used in the cement manufacturing process.

The cement industry is also a capital intensive industry. The cost of a new cement plant is equivalent to around three years' turnover, which ranks the cement industry among the most capital intensive industries. The profitability of the cement industry is around 10 % as a proportion of turnover (on the basis of pre-tax profits before interest repayments).

1.2 Applied processes and techniques in cement manufacturing

The basic chemistry of the cement manufacturing process begins with the decomposition of calcium carbonate ($CaCO_3$) at about 900 °C to leave calcium oxide (CaO, lime) and liberated gaseous carbon dioxide (CO_2); this process is known as calcination. This is followed by the clinkering process in which the calcium oxide reacts at a high temperature (typically 1400 - 1500 °C) with silica, alumina, and ferrous oxide to form the silicates, aluminates, and ferrites of calcium which comprise the clinker. The clinker is then ground or milled together with gypsum and other additives to produce cement.

There are four main process routes for the manufacture of cement – the dry, semi-dry, semi-wet and wet processes:

- in the dry process, the raw materials are ground and dried to raw meal in the form of a flowable powder. The dry raw meal is fed to the preheater or precalciner kiln or, more rarely, to a long dry kiln
- in the semi-dry process, dry raw meal is pelletised with water and fed into a grate preheater before the kiln or to a long kiln equipped with crosses
- in the semi-wet process, the slurry is first dewatered in filter presses. The filter cake is extruded into pellets and fed either to a grate preheater or directly to a filter cake dryer for raw meal production
- in the wet process, the raw materials (often with a high moisture content) are ground in water to form pumpable slurry. The slurry is either fed directly into the kiln or first to a slurry dryer.

The choice of process is, to a large extent, determined by the state of the raw materials (dry or wet). A large part of world clinker production is still based on wet processes. However, in Europe, more than 90 % of production is based on dry processes thanks to the availability of dry raw materials. Wet processes are more energy consuming, and thus more expensive. Plants using semi-dry processes are likely to change to dry techniques whenever expansion or major improvement is required. Plants using wet or semi-wet processes normally only have access to moist raw materials, as is the situation in Denmark and Belgium, and to some extent in the UK.

All processes have the following sub-processes in common:

- raw materials – storage and preparation
- fuels – storage and preparation
- use of wastes as raw materials and/or fuels, quality requirements, control and preparation
- the kiln systems, kiln firing processes and emissions reduction techniques
- products – storage and preparation
- packaging and dispatch.

The process of manufacturing white cement is similar to grey Portland cement production. The process includes the selection of raw materials, storage and preparation, fuel storage and preparation, firing of clinker in a kiln system, whitening/cooling, and grinding under precisely controlled conditions through the stages of the process in order to avoid contamination and undesired changes of the product. However, the combination of cooling and whitening is the main technological difference. These steps are used and needed in order to improve the whiteness of this special type of cement and to provide a uniform colour.

A typical process flow diagram from a cement plant is shown in Figure 1.4.

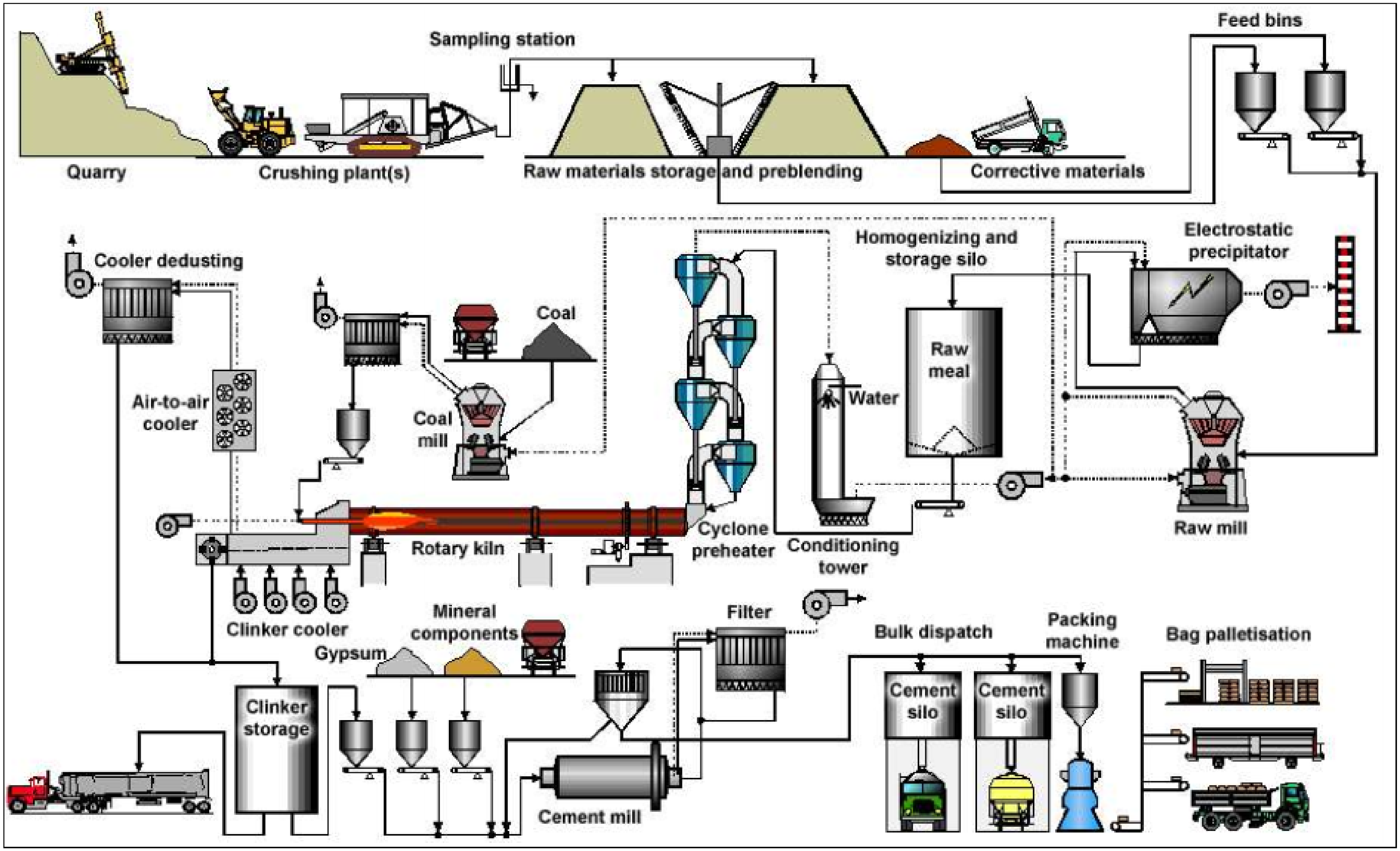


Figure 1.4: General overview of a cement manufacturing process
[103, CEMBUREAU, 2006]

1.2.1 Raw materials and their winning

Naturally occurring calcareous deposits, such as limestone, marl or chalk, provide the source for calcium carbonate. Silica, iron oxide and alumina are found in various ores and minerals, such as sand, shale, clay and iron ore.

Winning of nearly all of the natural raw materials involves mining and quarrying operations. The materials are most often obtained from open surface quarries. The operations necessary include rock drilling, blasting, excavation, hauling and crushing. Useful information regarding mining/quarrying can be found in the Reference Document on Best Available Techniques for Management of Tailings and Waste-Rock in Mining Activities [47, European Commission, 2004].

The main raw materials, like limestone, chalk, marl and shale or clay, are extracted from quarries. In most cases, the quarry is close to the plant. After primary crushing, the raw materials are transported to the cement plant for storage and further preparation. Other raw materials, such as bauxite, iron ore, blast furnace slag or foundry sand, are brought in from elsewhere.

Raw materials have to show and meet characteristics, chemical elements and components which are necessary for the clinker burning process and they may affect the production process and clinker quality. Table 1.8 shows example ranges from chemical analyses and characteristics of raw materials and cement raw meals for the production of cement clinker. Apart from the main components, these raw materials also contain a number of metals that are listed in Table 1.9.

Components	Limestone, lime marl, chalk	Clay	Sand	PFA 2)	Fe source	Raw meal
	(mass %)					
SiO_2	0.5 – 50	33 – 78	80 – 99	40 – 60	0.5 – 30	12 – 16
Al_2O_3	0.1 – 20	7 – 30	0.5 – 7	20 – 30	0.2 – 4	2 – 5
Fe_2O_3	0.2 – 5.9	4.0 – 15	0.0 – 4	5 – 15	50 – 93	1.5 – 2.5
Mn_2O_3	0.02 – 0.15	0.090	0.051	0.127	0.1 – 4	0.0 – 0.5
Fe_2O_3 and Mn_2O_3	0.1 – 10	2 – 15	0.5 – 2		19 – 95	≤2
CaO	20 – 55	0.2 – 25	0.1 – 3	2 – 10	0.1 – 34	40 – 45
MgO	0.2 – 6	0.3 – 5	0.3 – 0.5	1.0 – 3	0.5 – 7	0.3 – 5
K_2O	0 – 3.5	0.4 – 5	0.2 – 3	1 – 5	0.1 – 1	0.1– 1.5
Na_2O	0.0 – 1.5	0.1 – 1.5	0.0 – 1	0.2 – 1.5	0.1 – 1	0.1 – 0.5
SO_3 1)	0.0 – 0.7	0.0 – 4	0.0 – 0.5	0.0 – 1	0 – 3	0 – 1.5
Cl	0.0 – 0.6	0.0 – 1	Traces		0.0 – 0.5	0.0 – 0.3
TiO_2	0.0 – 0.7	0.2 – 1.8	0.0 – 0.5	0.5 – 1.5	0.0 – 3	0.0 – 0.5
P_2O_5	0.0 – 0.8	0.0 – 1.0	0.0 – 0.1	0.5 – 1.5	0.0 – 1	0.0 – 0.8
ZrO_2		0.02				
$CaCO_3$	96					
Loss on ignition (CO_2 + H_2O), LOI 950 3)	2 – 44	1 – 20	≤5	6.74	0.1 – 30	32 – 36

1) Total content of sulphur, expressed as SO_2
2) Pulverised fly ash
3) LOI 950 = loss on ignition

Table 1.8: Chemical analyses of raw materials and cement raw meal for the production of cement clinker
[60, VDI 2094 Germany, 2003], [81, Castle Cement UK, 2006], [90, Hungary, 2006], [103, CEMBUREAU, 2006]

Elements		**Clay and argillite**	**Limestone, marl and chalk**	**Raw meal**
		mg/kg DS$^{1)}$		
Antimony	Sb	No data available	1 – 3	<3
Arsenic	As	13 – 23	0.2 – 20	1 – 20
Beryllium	Be	2 – 4	0.05 – 2	0.1 – 2.5
Lead	Pb	10 – 40	0.3 – 21	4 – 25
Cadmium	Cd	0.02 – 0.3	0.04 – 0.7	004 – 1
Chromium	Cr	20 – 109	1.2 – 21	10 – 40
Cobalt	Co	10 – 20	0.5 – 5	3 – 10
Copper	Cu	No data available	3 – 12	6 – 60
Manganese	Mn	No data available	≤250	100 – 360
Nickel	Ni	11 – 70	1.5 – 21	10 – 35
Mercury	Hg	0.02 – 0.15	<0.01 – 0.13	0.01 – 0.5
Selenium	Se	No data available	1 – 10	<10
Tellurium	Te	No data available	<4	<4
Thallium	Tl	0.7 – 1.6	0.05 – 1.6	0.11 – 3
Vanadium	V	98 – 170	4 – 80	20 – 102
Tin	Sn	No data available	<1 – 5	<10
Zinc	Zn	59 – 115	10 – 40	20 – 47
$^{1)}$ DS: dry substance				

Table 1.9: Metals in raw materials and raw meal
[60, VDI 2094 Germany, 2003]

Waste also can replace conventional raw materials. Regarding the use of wastes as raw material see Section 1.2.4.2.

For white cement production, the availability of highly pure raw material, such as purity of Si, Ca and Al sources, is essential. Raw materials, e.g. highly pure limestone, types of white clays, kaolin, quartz sand, feldspar, diatomaceous earth, are selected with low contents of metals such as iron and manganese. The metal oxides influence the whiteness of the product and are one of the determining factors. For the production of high-grade white cement, the chemical composition of the raw materials is essential and examples are shown in Table 1.10. However, the proportions of these components also need to meet the requirements of the firing process. To improve the burnability, sometimes mineralised clinker is produced and used in small amounts, e.g. 2 – 3 % and even 0.1 % to be effective in some cases. Mineralisers known and used are fluxing agents, such as fluoride (F), fluorosilicates (SiF, NaSiF), phosphoric slag and different forms of chlorine (Cl) [119, Sobolev, 2001], [120, Spain, 2007].

Raw materials	**Chemical components in the raw materials (%)**						
	Fe_2O_3	**MgO**	**SiO_2**	**TiO_2**	**Al_2O_3**	**Cr_2O_3**	**Mn_2O_3**
Limestone	<0.15	<0.015					
Clay	≤1.0	Traces	65 – 80	<0.8			
Kaolin (suitable)	0.4 – 1.0	0	70 – 73	0 – 0.80	18 – 20		
Quartz sand (pure)	≤0.2		<96				
Others$^{1)}$	<0.5	<3.0		<0.2		<30 ppm	<0.05
$^{1)}$ Italy							

Table 1.10: Examples of chemical compositions of raw materials for white cement clinker production
[119, Sobolev, 2001], [120, Spain, 2007], [138, Italy, 2007]

1.2.2 Raw materials – storage and preparation

Preparation of the raw materials is of great importance to the subsequent kiln system both in getting the chemistry of the raw feed right and in ensuring that the feed is sufficiently fine.

1.2.2.1 Storage of raw materials

The need to use covered storage depends on climatic conditions and the amount of fines in the raw material leaving the crushing plant. In the case of a 3000 tonnes/day plant these buildings may hold between 20000 and 40000 tonnes of material. An example of covered raw material storage is shown in Figure 1.5.

Figure 1.5: Example of covered raw material storage
[81, Castle Cement UK, 2006]

The raw material fed to a kiln system needs to be as chemically homogeneous as practicable. This is achieved by controlling the feed into the raw grinding plant. When the material from the quarry varies in quality, initial preblending can be achieved by stacking the material in rows or layers along the length (or around the circumference) of the store and extracting it by taking cross-sections across the pile. When the material from the quarry is fairly homogeneous, simpler stacking and reclaiming systems can be used.

Raw materials used in relatively small quantities, mineral additions for example, may alternatively be stored in silos or bunkers. Any raw materials with potentially harmful properties to public health and to the environment must be stored and prepared according to individual specific requirements.

1.2.2.2 Grinding of raw materials

Accurate metering and proportioning of the mill feed components by weight is important for achieving a consistent chemical composition. This is essential for steady kiln operation and a high quality product. Metering and proportioning are also important factors in the energy efficiency of the grinding system. The predominant metering and proportioning equipment for raw material feed to mills is the apron feeder followed by the belt weigh feeder.

For white cement production, care has to be maintained during milling operations in order to prevent introduction of different pieces or small quantities of metals providing colour. Furthermore, the selection of grinding media and mill liners is important in order to avoid contamination of the raw mix with iron. Special steels or ceramic materials are used for the essential parts of the equipment. To improve the whiteness, humidity control of the raw mix is used and the grinding time is reduced by using any accelerating/surface active admixtures, which, however, could be different from commercially available grinding aids. In some cases, granulating equipment is recommended for the final stage of the raw mix preparation process, especially when using a fluidised bed kiln for firing [119, Sobolev, 2001], [120, Spain, 2007].

1.2.2.2.1 Grinding of raw materials – dry and semi-dry kiln systems

The raw materials, in controlled proportions, are ground and mixed together to form a homogeneous blend with the required chemical composition. For dry and semi-dry kiln systems, the raw material components are ground and dried to a fine powder, making use mainly of the kiln exhaust gases and/or cooler exhaust air. For raw materials with a relatively high moisture content, and for start-up procedures, an auxiliary furnace may be needed to provide additional heat.

Typical dry grinding systems used are:

- tube mill, centre discharge
- tube mill, airswept
- vertical roller mill
- horizontal roller mill (only a few installations in operation).

Other grinding systems are used to a lesser extent. These are:

- tube mill, end discharge in closed circuit
- autogenous mill
- roller press, with or without crushers (dryers).

The fineness and particle size distribution of the product leaving a raw grinding system is of great importance for the subsequent burning process. The target given for these parameters is achieved by adjusting the separator used for classifying the product leaving the grinding mill. For dry classification, air separators are used. The newest generation, rotor cage type separators, have several advantages. These are:

- lower specific energy consumption of the grinding system (less over-grinding)
- increased system throughput (efficiency of particle separation)
- more favourable particle size distribution and product uniformity.

1.2.2.2.2 Grinding of raw materials – wet or semi-wet kiln systems

Wet grinding is only used in combination with wet or semi-wet kiln systems. The raw material components are ground with added water to form a slurry. To achieve the slurry fineness required and in order to comply with modern quality demands, closed circuit milling systems are the main option.

The wet process is normally preferred whenever the raw material has a moisture content of more than 20 % by weight. Raw materials such as chalk, marl or clay, which are sticky and have an inherently high moisture content, are soft and as a first stage of preparation they may be ground in a wash mill. Water and crushed material are fed to the wash mill and broken down into slurry by shearing and impact forces imparted by the rotating harrows. When sufficiently fine, the material passes through screens in the wall of the wash mill and is pumped to storage. To achieve the required slurry fineness, further grinding in a tube mill is usually required, especially if an additional raw material such as sand is to be added.

To reduce kiln fuel consumption, water addition during raw material grinding is controlled so that the amount used is the minimum necessary to achieve the required slurry flow and pumpability characteristics (32 to 40 % w/w water). Chemical additives may act as slurry thinners permitting the water content to be reduced.

1.2.2.2.3 Raw meal or slurry homogenisation and storage

Raw meal or slurry leaving the raw grinding process requires further blending/homogenisation to achieve optimum consistency of the raw mix prior to being fed to any type of kiln system. The raw meal is homogenised and stored in silos, the raw slurry in either tanks or silos.

For raw meal transport to storage silos, pneumatic and mechanical systems are used. Mechanical conveyors normally require a higher investment cost but have much lower operating costs than pneumatic conveying systems. A combination of air-slide or screw/chain conveyors with a belt bucket elevator is the most commonly used conveying system.

1.2.3 Fuels – storage and preparation

Various fuels (conventional and waste) can be used to provide the heat and the energy required for the process. Different types of conventional fuels are mainly used in cement kiln firing; such as:

- solid fuels, e.g. coal as well as petcoke and lignite, and in some cases oil shale
- liquid fuels, e.g. fuel oil including highly viscous fuel oil (HVFO)
- gaseous fuels, e.g. natural gas.

The main ash constituents of these fuels are silica and alumina compounds. Furthermore, ashes may also contain traces of metals. These combine with the raw materials to become part of the clinker. This needs to be allowed for in calculating the raw material proportion and so it is desirable to use fuel with a consistent, though not necessarily low, ash content. Examples of chemical analyses of metals in coal used in Germany are shown in Table 1.11.

Elements		**Hard coal/brown coal**
		mg/kg DS[1)]
Antimony	Sb	0.4 – 2
Arsenic	As	1 – 50
Beryllium	Be	<0.1 – 3.3
Lead	Pb	1.5 – 273
Cadmium	Cd	<0.1 – 10
Chromium	Cr	1.5 – 81
Cobalt	Co	<1 – 40
Copper	Cu	1 – 100
Manganese	Mn	82 – 250
Nickel	Ni	<1 – 100
Mercury	Hg	0.1 – 3.3
Selenium	Se	0.6 – 2
Tellurium	Te	0.2 – 1
Thallium	Tl	0.1 – 5.5
Vanadium	V	1 – 200
Tin	Sn	0.8 – 2.3
Zinc	Zn	6 – 220
1) DS: dry substance		

Table 1.11: Chemical analyses of metals in coal
[60, VDI 2094 Germany, 2003]

The main fossil fuels used in the European cement industry are petcoke and coal. Costs normally preclude the use of natural gas or oil, but the selection of fuels depends on the local situation (such as the availability of domestic coal). However, the high temperatures and long residence times in the kiln system implies considerable potential for the destruction of organic substances (see Section 1.2.4.1). This makes a wide variety of less expensive fuel options possible, in particular different types of wastes. The use of wastes has been increasing over the last few years (see Section 1.2.4).

In order to keep heat losses to a minimum, cement kilns are operated at the lowest reasonable excess oxygen levels. This requires highly uniform and reliable fuel metering and fuel presentation in a form allowing easy and complete combustion. These conditions are fulfilled by all liquid and gaseous fuels. For pulverised solid fuels, good design of hoppers, conveyors and feeders is essential to meet these conditions. The main fuel input (65 – 85 %) has to be of this easily combustible type, whereas the remaining 15 – 35 % may be fed in coarsely crushed or lump form.

For white cement production, fuel selection has to be made very carefully in order to avoid elements in the fuel ash that could be incorporated in the clinker and could therefore alter the desired colour of the white cement. In 2007, selected waste fuels were used on a limited scale for white cement production.

1.2.3.1 Storage of conventional fuels

Raw coal and petcoke are stored similarly to raw materials; thus, in many cases, in covered stores. Outside storage in large, compacted stockpiles is used for long term stocks. Such stockpiles may be seeded with grass to prevent rainwater and wind erosion. Drainage to the ground from outside storage has shown to be a problem. However, sealed concrete floors under the stockpiles make it possible to collect and clean the water that drains off. Normal good practice in terms of compaction and stockpile height needs to be observed when storing coal with a relatively high volatile matter content in order to avoid the risk of spontaneous ignition when stored for long periods.

Pulverised coal and petcoke are stored exclusively in silos. For safety reasons (i.e. the danger of explosions being triggered by smouldering fires and static electricity spark-overs), these silos have to be of the mass flow extraction type and have to be equipped with standard safety devices.

Fuel oil is stored in vertical steel tanks. These are sometimes insulated to help keep the oil at a pumpable temperature (50 to 60 °C). They may also be equipped with heatable suction points to maintain the oil at the correct temperature locally.

Natural gas is not stored at the cement plant. The international high pressure gas distribution network acts as a gas storage facility.

1.2.3.2 Preparation of conventional fuels

Solid conventional fuel preparation (crushing, grinding and drying) is usually carried out on site. Coal and petcoke are pulverised to about raw meal fineness in grinding plants using equipment similar to the raw material grinding plants. The fineness of the pulverised fuel is important – too fine and flame temperatures can be excessively high, too coarse and poor combustion can occur. Low volatility or low volatiles contents of the solid fuel will need finer grinding. If sufficient hot air for drying is not available from the kiln or from the cooler, an auxiliary furnace may be needed. Special features have to be incorporated to protect the equipment from fires and explosions.

Three main types of coal milling and grinding systems are used:

- tube mill, airswept
- vertical roller or ring-ball mill
- impact mill.

Ground solid fuel may be fired directly into the kiln, but in modern installations it is usually stored in silos to allow the use of more thermally efficient burners (indirect firing) using low primary air.

Solid fuel grinding, storage and firing systems have to be designed and operated so as to avoid the risk of explosion or fire. The primary requirements are to control air temperatures properly, and to avoid the accumulation of fine material in dead spots exposed to heat.

Fuel oil preparation: In order to facilitate metering and combustion, the fuel oil is brought to 120 – 140 °C, resulting in a viscosity reduction to 10 – 20 cSt. Additionally, the pressure is increased to 20 – 40 bar.

Natural gas preparation: Prior to combustion the gas pressure has to be brought from the pipeline pressure of 30 – 80 bar down to the plant's network pressure of 3 – 10 bar and then reduced again to the burner's supply pressure of around 1 bar (overpressure). The first pressure reduction step is accomplished in the gas transfer station where consumption metering also takes place. To avoid freezing of the equipment as a result of the Joule-Thompson effect, the natural gas is preheated before passing through the pressure reduction valve.

Alternatively, the pressure reduction can be accomplished by passing the gas through a gas expansion turbine connected to a power generator. Thus, some of the energy required for gas compression can be recovered.

1.2.4 Use of waste

The European cement industry recovers a substantial amount of waste-derived fuels, which replace fossil fuels up to a level of more than 80 % in some plants. This enables the cement industry to contribute further to the reduction of greenhouse gas emissions and to the use of fewer natural resources.

The ban on the landfilling of unprocessed waste in some EU Member States has led to an increasing number of mechanical and mechanical biological waste treatment plants being put into operation. As a consequence, the utilisation of pretreated waste fractions is an issue of growing concern. After suitable treatment, individual waste fractions can meet the requirements for environmentally compatible re-use in cement plants. The cement industry of the EU-27 has been involved in the recovery of selected waste streams in cement plants for many years. This industry, traditionally a substantial user of non-renewable natural resources, minerals and fossil fuels, is committed to using waste for the conservation of these resources without, at the same time, producing final wastes [103, CEMBUREAU, 2006], [168, TWG CLM, 2007].

Since waste treatment is not covered in this document, useful information regarding waste treatment can be found in the Reference Document on the Best Available Techniques for the Waste Treatments Industries [48, European Commission, 2005]. Furthermore, the requirements of existing European and national regulations have to be considered, e.g. when co-incinerating waste, the requirements of the Waste Incineration Directive (WID) have to be met [59, European Commission, 2000].

1.2.4.1 General aspects

Different types of waste materials can replace primary raw materials and/or fossil fuels in cement manufacturing and will contribute to saving natural resources. Basically, characteristics of the clinker burning process itself allow environmental beneficial waste-to-energy and material recycling applications. The essential process characteristics for the use of waste can be summarised as follows:

- maximum temperatures of approx. 2000 °C (main firing system, flame temperature) in rotary kilns
- gas retention times of about 8 seconds at temperatures above 1200 °C in rotary kilns
- material temperatures of about 1450 °C in the sintering zone of the rotary kiln
- oxidising gas atmosphere in the rotary kiln
- gas retention time in the secondary firing system of more than 2 seconds at temperatures of above 850 °C; in the precalciner, the retention times are correspondingly longer and temperatures are higher
- solids temperatures of 850 °C in the secondary firing system and/or the calciner
- uniform burnout conditions for load fluctuations due to the high temperatures at sufficiently long retention times
- destruction of organic pollutants due to the high temperatures at sufficiently long retention times
- sorption of gaseous components like HF, HCl, SO_2 on alkaline reactants
- high retention capacity for particle-bound heavy metals
- short retention times of exhaust gases in the temperature range known to lead to 'de-novo-synthesis' of PCDD/F
- complete utilisation of fuel ashes as clinker components and hence, simultaneous material recycling (e.g. also as a component of the raw material) and energy recovery
- product specific wastes are not generated due to a complete material utilisation into the clinker matrix; however, some cement plants in Europe dispose of bypass dust
- chemical-mineralogical incorporation of non-volatile heavy metals into the clinker matrix [60, VDI 2094 Germany, 2003], [76, Germany, 2006], [168, TWG CLM, 2007].

Investigations show that in rotary kilns hazardous substances are better absorbed by material and clinker than in other types of kilns, e.g. shaft kilns [75, Estonia, 2006], [76, Germany, 2006].

A wide range of different types of wastes are used as raw materials and/or as fuels. Before considering the use of waste materials, different basic principles have to be considered, such as appropriate selection of waste materials and an extensive analysing procedure of wastes and pretreatment. Treatment of these wastes has to be carried out in order to keep quality standards of the clinker, because the fuel ashes are fully captured in the clinker. The decision on what type of waste can finally be used in a certain plant cannot be answered uniformly.

Considerations and decisions have to be based on the clinker production process and the operation conditions, the raw materials and fuel compositions, the feeding points, the flue-gas cleaning technique used, the given waste management problems and the requirements of existing European and national regulations, e.g. the Waste Incineration Directive (WID) [59, European Commission, 2000].

As a basic rule, wastes accepted as fuels and/or raw materials must give the following added value to the cement kiln:

- calorific value from waste material
- material value from waste material.

Furthermore, volumes and categories of wastes have to be considered as well as physical and chemical compositions, characteristics and pollutants. Waste-derived fuels used by the cement industry are derived exclusively from selected waste streams, which usually require a pretreatment, e.g. shredding, blending, grinding and homogenisation, and an appropriate quality assurance. Preparation of waste materials is usually carried out at waste treatment plants.

Feed points for inserting waste into the kiln

Wastes used as raw materials are typically fed to the kiln system in the same way as conventional raw materials, e.g. via the normal raw meal supply.

As described in Section 1.2.5.1, different feed points can be used to insert fuels into the cement kiln. These feed points can also be used for feeding wastes as fuels and/or raw materials into the cement production process. It has to be noted that the way the fuels are fed into the kiln is very important because this can have an effect on the emissions. Of these feed points, there is, in general, only one way in which the flue-gases from fuels pass the highest temperature zone of the kiln, namely by feeding them through the main burner. Related to other feed points, temperature and residence time depends on kiln design and kiln operation, as described above.

Wastes, which are fed through the main burner, will be decomposed in the primary burning zone, at high temperatures of up to 2000 °C. Multi-channel burners are designed for the use of different types of fuels including waste fuels. Wastes fed to a secondary burner, preheater or precalciner will be burned at lower temperatures, which is not always enough to decompose halogenated organic substances. Volatile components in material that is fed at the upper end of the kiln or as lump fuel can evaporate. These components do not pass the primary burning zone and may not be decomposed or bound in the cement clinker. Therefore, the use of waste containing volatile metals (mercury, cadmium, thallium) or volatile organic compounds can result in an increase of the emissions of mercury, cadmium, thallium or organic emissions (e.g. VOCs) when improperly used. Consideration should be given to these waste materials containing components that can be volatilised at lower temperatures before the calcining zone (e.g. hydrocarbons, solvents, waste oils). They have to be fed into the adequately high temperature zones of the kiln system.

Energy efficiency by using waste

The cement industry has achieved an improvement in energy efficiency regarding fuels used in the cement manufacturing processes and will continue to develop alternative means for improvements. However, the calorific values of the waste fuels which are used in the process are very important quality requirements necessary to receive an improvement in energy efficiency and a positive input to the thermal process that supports calcination [76, Germany, 2006], [89, ERFO, 2005], [103, CEMBUREAU, 2006].

Impacts by using wastes

Information about impacts on the emissions behaviour by using waste materials can be found in Section 1.3.4.13 and information about impacts on product quality can be found in Section 1.3.4.14 of this document.

The monitoring of parameters and emissions for using wastes as fuels and/or raw materials can be found in Section 1.3.9. Furthermore, plant specific data for, e.g. using wastes, can be found in Section 4.2.2 of this document.

1.2.4.2 Use of wastes as raw materials

The chemical suitability of wastes used as raw materials is important and they have to provide the constituents required for the production of clinker. Primary desired chemical elements are lime, silica, alumina and iron as well as sulphur, alkalis and others which can be classified into different groups according to their chemical composition. The use of wastes as raw materials as in the clinker burning process involves the substitution of sulphur and the oxides contained in the wastes used as raw materials. These include calcium oxide (CaO), silica (SiO_2), alumina (Al_2O_3) or iron oxide (Fe_2O_3) for the respective raw material constituents. Power station ash (fly ash), blast furnace slag, and other process residues can be used as partial replacements for the natural raw materials. Table 1.12 shows the types of wastes most frequently used as raw materials in the production of cement in Europe in 2006.

Fly ash	Blast furnace slag	Silica fume
Iron slag	Paper sludge	Pyrite ash
Spent foundry sand	Soil containing oil	
Artificial gypsum (from flue-gas desulphurisation and phosphoric acid production)		

Table 1.12: Types of waste frequently used as raw materials in the European cement industry [8, CEMBUREAU, 2001], [91, CEMBUREAU, 2006]

Other waste materials are supplied as so-called 'inter-ground' additions to the grinding plants. Fly ash can be used both as raw material in the production of clinker (mainly for its content of alumina) and as an inter-ground addition for cement. Fly ash can replace up to 50 % of the Portland cement clinker; however, it may contain mercury. Furthermore, suitable industrial gypsum lends itself for use as a sulphate component. An overview of wastes used as raw materials classified into different groups according to their chemical composition is shown in Table 1.13.

Raw material group	Examples of wastes used as raw materials
Ca group	Industrial lime (waste limestone) Lime slurries Carbide sludge Sludge from drinking water treatment
Si group	Spent foundry sand Sand
Fe group	Blast furnace and converter slag Pyrite ash Synthetic hematite Red mud
Al group	Industrial sludge
Si-Al-Ca group	Fly ash Slags Crusher fines Soil
S group	Industrial gypsum
F group	CaF_2 Filter sludge

Table 1.13: Example list of wastes used as raw materials classified to their chemical composition and used in cement kilns in the EU-25
[76, Germany, 2006], [91, CEMBUREAU, 2006], [103, CEMBUREAU, 2006]

Like ash from conventional fuels, the ash from waste fuels provides mineral components for the cement clinker. The ternary diagram in Figure 1.6 shows the composition of different fuel ash and wastes used as raw materials, for which the contents of the main components CaO, SiO_2, Fe_2O_3 and Al_2O_3 are represented. As shown, the clinker has a defined composition which is crucial to the characteristic hydraulic properties of the cement. This means that all raw materials and fuel ash must be carefully matched in terms of mineral composition and feed rate to obtain the desired clinker composition.

The wastes used as raw materials enter the clinker burning process or the calciner via the raw meal path or via the kiln inlet and/or the calciner. During the preheating phase in the preheater, organic components may be released from the kiln feed, because of lower temperatures, which are not always enough to decompose halogenated organic substances. When processing these waste raw materials, these must be checked for potential emissions of volatile organic constituents and the feed point selected accordingly, e.g. kiln burner.

Spent foundry sand with a high volatile content, for example, should be fed to the kiln inlet. The residual organic binder used in chemically bonded sand cast systems can be decomposed in the preheater. However, a short residence time of the material in the low temperature phase of the preheater ensures that volatiles are not emitted. Pretreatment of spent foundry sand, such as the separation of dust, can reduce the content of heavy metals. By using industrial gypsum and fly ash, the feeding of gypsum takes place in the grinding plant. The recoverable calorific value of carbon rich ash, i.e. up to 20 % of carbon is possible, can be used in the cement clinker process [76, Germany, 2006], [91, CEMBUREAU, 2006], [168, TWG CLM, 2007].

Requirements to consider in the selection and use of waste as raw material:

- the waste consists primarily of the clinker components
- low volatile heavy metal concentration, i.e. mercury, thallium and other types of metals have to be taken into account
- regular monitoring of inputs, e.g. used waste materials by sampling and analysis.

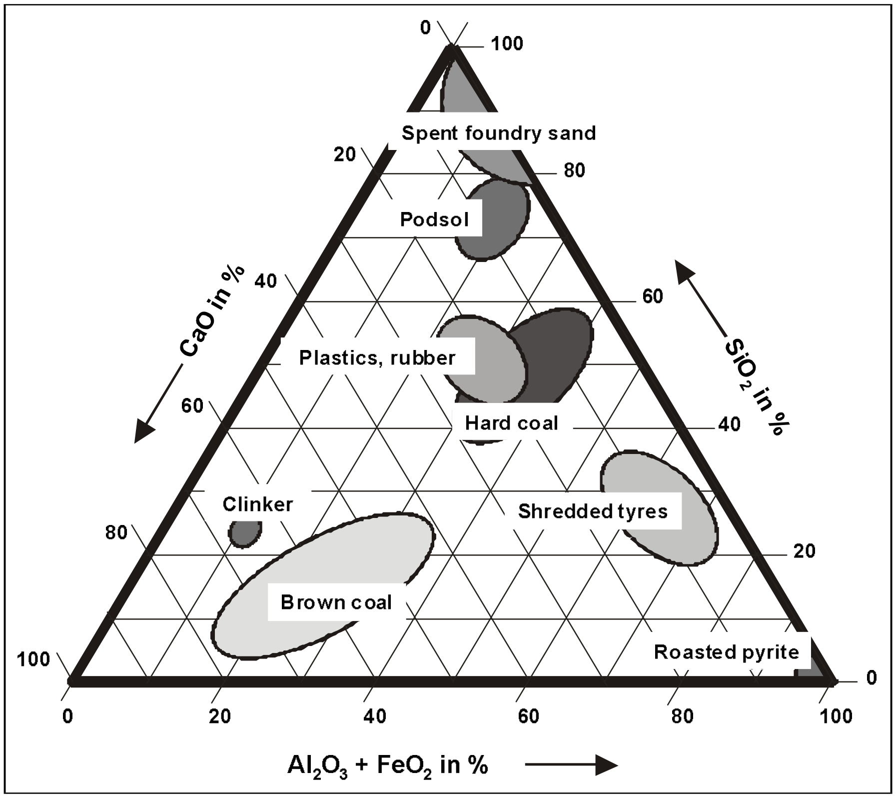


Figure 1.6: Ternary CaO, SiO_2 and Al_2O_3+Fe_2O_3 diagram for cement clinker and the ash constituents of different raw materials and fuels

[76, Germany, 2006]

1.2.4.3 Use of wastes as fuels

Conventional fuels, such as fossil fuels, can be replaced by waste fuels, i.e. waste fuels derived from pretreated and sorted waste fractions including solid and liquid recovered fuels, and/or biomass. A wide range of different types of wastes are used as fuels including the remaining ashes. Waste materials can be solid, liquid or pasty and are defined by their origin, e.g. industrial, agricultural and municipal sources. Consumption of waste fuels is described in Section 1.3.3.3 and impacts on the emissions behaviour are described in Section 1.3.4.13.

1.2.4.3.1 Types of waste fuels

The clinker burning process offers good conditions for using different types of waste materials replacing parts of conventional fuels (see Section 1.2.4.1). As listed in Table 1.14, different types of wastes are used as fuels in European cement kilns which are categorised as hazardous and non-hazardous wastes. As these calorific waste materials can replace primary fuel in cement kilns, a consistent waste quality is essential (e.g. sufficient calorific value, low metal, halogen (e.g. chlorine) and ash content, the waste has to be suitable for the burners). There is a constant increase in the use of waste fuels in clinker production; however, the increase in the use of non-hazardous waste is more significant than in the use of hazardous waste [74, CEMBUREAU, 2006], [75, Estonia, 2006], [76, Germany, 2006], [92, Austria, 2006].

Table 1.14 presents a list of the use of waste fuels clustered into 14 groups. These groups span several EWC listings and a full list of the whole grouping structure along with waste categories and waste descriptions can be found in Table 4.1 of Section 4.2.1. Furthermore, examples of calorific values of several types of wastes can be found in Table 1.20 of Section 1.3.3.3 [74, CEMBUREAU, 2006], [98, European Commission, 2000], [103, CEMBUREAU, 2006], [168, TWG CLM, 2007].

Group Nr.[1]	Types of waste fuels (hazardous and non-hazardous)
1	Wood, paper, cardboard
2	Textiles
3	Plastics
4	Processed fractions (e.g. RDF)
5	Rubber/tyres
6	Industrial sludge
7	Municipal sewage sludge
8	Animal meal, fats
9	Coal/carbon waste
10	Agricultural waste
11	Solid waste (impregnated sawdust)
12	Solvents and related waste
13	Oil and oily waste
14	Others

[1] Each grouping spans several EWC listings, see Table 4.1 in Section 4.2.1

Table 1.14: Different types of wastes used as fuels in EU-27 cement kilns in 2003 and 2004 [74, CEMBUREAU, 2006], [168, TWG CLM, 2007]

1.2.4.3.1.1 Solid waste fuels

Not every combustible solid waste is suitable as fuel in the clinker burning process. Solid waste can be a homogenous or an inhomogeneous mixture of very diverse origins and components, such as:

- combustible fractions, e.g. paper, cardboard, plastics, rubber, and wood residues
- varying amounts of inert materials containing organic fractions, e.g. sand, stone, ceramics, ferrous/non-ferrous metals and organic wet materials
- hazardous fractions, e.g. tar, resins, impregnated sawdust, or non hazardous materials.

Waste, like mixed municipal waste, mixed commercial waste or mixed construction, demolition waste and some solid hazardous waste has to be pretreated in waste management facilities before being used as fuels. The extent of the waste treatment operation, such as sorting, crushing, and pelletising, depends on the waste fuel application.

Solid fuel preparation techniques vary considerably depending on the source and type of the waste, and on the requirements of the cement industry. One important requirement results from the used transfer and firing system to convey waste fuel into a kiln:

- the main firing system (at the kiln head/outlet, injection of waste fuels via lances): highly abrasive wastes such as dried sludge and unusual particle shapes and sizes can produce operational problems. When pneumatic transfer systems are used to convey solid waste fuel in the kiln, plugging and damage to rotating parts can be avoided (the system functions entirely without moving parts). The amount of conveying air injected into the kiln along with the waste is negligible in terms of kiln combustion stoichiometry. Greater particle sizes dictate large pneumatic conveyor lines and blowers. Therefore, important processing steps are the size reduction and the soft pelletising of the waste fuel. (Typically, the particle size is no larger than 25 mm). The advantage of compacting by soft pelletising is the improvement of flow and dosage characteristics of the fuel

- the secondary firing system (the fuel is fed via the kiln inlet, the riser between the rotary kiln inlet and the lowest cyclone stage or the calciner): the size restriction for solid waste fuels is not important for the secondary firing system. Even whole tyres can be introduced via the kiln inlet or via mid kiln technology. Furthermore, waste with a high ash content can be used.

Different types of solid wastes are used, e.g.:

- non-hazardous waste as listed in Table 1.14, group number 1 – 10
- hazardous waste listed in Table 1.14, group number 11 – 13.

Figure 1.7, Figure 1.8 and Figure 1.9 show examples of pretreated waste mixtures used in cement plants, such as:

- hazardous waste impregnated sawdust
- waste fuel based on paper, textiles both pre and post consumer which is manufactured from polythene film, photographic film, paper, polypropylene, packaging materials and plastics
- waste fuel consisting of household waste, screened paper, cardboard, wood, carpet, textiles and plastics which is a solid, clean and non-hazardous fuel.

The wastes are analysed and especially prepared for the use in cement kilns [45, Schorcht, 2006], [81, Castle Cement UK, 2006], [107, Belgium, 2006].

Figure 1.7: Hazardous waste – impregnated sawdust
[168, TWG CLM, 2007]

Figure 1.8: Specially prepared waste fuel based on, e.g. paper, plastics, textiles
[81, Castle Cement UK, 2006]

Figure 1.9: Specially prepared household waste used as fuel in cement kilns
[82, CEMEX Rugby UK, 2006]

1.2.4.3.1.2 Liquid waste fuels

Liquid waste fuels can be prepared by blending or preheating different wastes like used solvents, paint residues or waste oil with suitable calorific values in special waste management facilities. More useful information regarding waste treatment can be found in the Reference Document on the Best Available Techniques for the Waste Treatments Industries [48, European Commission, 2005].

Consideration has to be given to some liquid hazardous wastes (e.g. solvents) when handling liquid waste fuels, e.g. storage, feeding, in order to avoid emissions of organic compounds. Several techniques exist, e.g. vapour recovery which is used where required. Vapour recovery systems are operated in a way which ensures that the flow of organic substances is permitted only upon connection of the vapour recovery system, and that the vapour recovery system and attached facilities release no gas to the air during normal operation, with the exception of releases necessary for safety reasons [76, Germany, 2006], [81, Castle Cement UK, 2006], [168, TWG CLM, 2007].

1.2.4.3.2 Quality requirements of waste and input control

Waste materials used as raw materials and/or as fuels in cement kilns have to reach different quality standards because the fuel ashes are fully captured in the clinker to minimise negative effects on clinker compositions and air emissions. A constant waste quality is essential. To guarantee the characteristics of the waste fuel, a quality assurance system is required. In particular, this includes provisions for the sampling, the sample preparation, the analysis and the external monitoring. More useful information can be found in the technical specifications of the European Committee for Standardisation, such as CEN/TC 343 ‘Solid Recovered Fuels’. Furthermore, the requirements of existing European and national regulations have to be considered. When co-incinerating waste, the requirements of the Waste Incineration Directive (WID) have to be met, e.g. requirements regarding reception procedures carried out by the operator when using hazardous waste [59, European Commission, 2000]. As a basic rule for quality requirements, wastes accepted as fuels and/or raw materials have to give the following added values to the cement kiln:

- calorific value from waste material
- material value from waste material.

Waste with sufficient calorific value can replace primary fuel in cement kilns. It has to be noted that the calorific values of these wastes vary widely (see Section 1.3.3.3).

Preparation of different types of combustible wastes or wastes with separable calorific fractions for use as fuel is usually performed outside the cement plant. These wastes are normally prepared by the supplier or by waste treatment specialists' organisations in special waste management facilities in such a way that they can directly be used in cement kilns without any additional treatment on the cement plant. Additionally, before being used in the cement kiln, the delivered waste material is checked and analysed regularly by the cement plant personnel as well. Special laboratory equipment is used for checking different quality characteristics.

The techniques used to prepare and blend certain waste fuel qualities depend on the characteristics of the material input and the requirements of the users. Even waste materials like production specific wastes, are treated and blended prior to use in waste facilities to ensure a homogeneous mixture with nearly constant qualities, such as thermal properties and chemical composition. Only in some cases can wastes be just used as they are delivered without further processing, for example used tyres or used oil. Any inhomogeneous wastes, like mixed solid wastes from different sources or separated fractions from mixed municipal waste, require higher monitoring efforts to attain a reliable quality with a constant low pollutant input.

Important characteristics and parameters for waste fuels are calorific value along with a content of water, ash, sulphur, chlorine and heavy metals (especially mercury, cadmium and thallium). Additionally, the suitability for the burners is important. Chlorine may have a negative impact on the production process. The acceptable chlorine concentration therefore depends on the individual situation on site; however, this concentration is kept as low as possible in order to avoid operational problems in the kiln system, e.g. blockage in the preheater. In cases when a high volume of chlorine is input, usually a chlorine bypass might be necessary to avoid corrosion, blockings, shutdown, etc. (see Section 1.2.5.4.1). Typical chlorine concentrations range from <0.5 – 2 %. Individual systems and specifications have been developed in the EU-27 to assess and control the suitability of waste fuels, e.g. lists have been developed of maximum pollutant values allowed for selected wastes to be used for the clinker burning process. Plant specific aspects have been taken into consideration for the specifications which are based both on requirements of plant specific processes and permits. Furthermore, specifications determine technical norms for delivering liquid waste fuels. An example of an internal specification for waste fuels is described in Section 4.2.2.1 and Table 4.9. Furthermore, examples of input criteria for different substances for suitable waste fuels being accepted in some EU countries are given in Section 4.2.2.1.1.

Other systems used are mainly focused on the content of metals (see Section 1.2.4.3.2.1). It has to be noted that other materials can be used as well which do not meet all of these conditions. In the case of using sewage sludge or waste wood, the mercury input has to be monitored regularly because of the possible mercury emissions.

Furthermore, the waste fuel has to be available in a sufficient quantity. Source selection is the first action to take into account for mono streams to reduce materials that might cause operation or quality problems in the cement process.

The quality requirements of the products should be considered regarding the selection of fuels (conventional or waste). There are consequently limits on the types and amounts of waste fuels suitable for use in the production of cement which is highly dependent on site-specific circumstances [75, Estonia, 2006], [76, Germany, 2006], [89, ERFO, 2005], [103, CEMBUREAU, 2006], [168, TWG CLM, 2007].

Useful information regarding waste treatment can be found in the Reference Document on Best Available Techniques for the Waste Treatments Industries, where, e.g. examples of specifications of a waste that can be accepted as fuel in some countries' cement kilns are described [48, European Commission, 2005].

1.2.4.3.2.1 *Metal concentrations of wastes*

Concentrations of metals vary with the waste origin. In many European countries, regulators and/or industry have produced lists of the maximum allowable substance values for different wastes that can be used as fuels and/or raw materials. Examples of typical metal concentration ranges and typical input criteria regarding different substances for suitable waste fuels from different countries in Europe can be found in Section 4.2.2.1.1. Different values may also be found in other authorised environmental performance covering specific wastes. However, no agreed threshold limit value exists, as different criteria are applied, depending on the local situation. The criteria applied may include:

- national environmental policies and legislation
- significance of the impact of the cement industry in the context of regional industrial development
- efforts to harmonise regional environmental laws and standards
- levels of substances in traditional raw materials and wastes
- plant conditions and emissions
- treatment alternatives for available wastes
- required minimum calorific values
- requirements for cement quality.

1.2.4.3.3 Storage and handling of waste

Usually, waste fuels are prepared in special waste management facilities. The delivered wastes need to be stored at the cement plant and then proportioned for feeding to the cement kiln. Since supplies of waste suitable for use as fuel tend to be variable whilst waste material markets are rapidly developing, it is advisable to design multipurpose storage/preparation plants.

Liquid waste fuels are mostly hazardous wastes. This has to be taken into account when handling liquid waste fuels, e.g. storage, feeding (see Section 1.2.4.3.1.2) [76, Germany, 2006]. Furthermore, safety management for potentially self igniting materials may be considered when using waste fuels derived from pretreated and sorted waste fractions.

Useful information regarding storage of materials can also be found in the Reference Document on Best Available Techniques on Emissions from Storage [96, European Commission, 2006].

1.2.5 Clinker burning

This part of the process is the most important in terms of emissions potential and of product quality and cost. In clinker burning, the raw meal (or raw meal slurry in the wet process) is fed to the rotary kiln system where it is dried, preheated, calcined and sintered to produce cement clinker. The clinker is cooled with air and then stored.

In the clinker burning process, high process temperatures are required to convert the raw material mix into cement clinker. It is essential to maintain kiln charge temperatures in the sintering zone of the rotary kilns at between 1400 and 1500 °C, and the flame temperature at about 2000 °C. Also, the clinker needs to be burned under oxidising conditions. Therefore, an excess of air is required in the sintering zone of a cement clinker kiln.

For white cement production, the firing process leads to temperatures in the sintering zone of up to 1600 °C, depending on the composition of the raw material mix and the desired composition of the final product. Flame temperatures of higher than 2000 °C are required because of the absence of fusing elements in the raw materials which could alter the colour of the product. Generally, reducing conditions are kept in order to avoid oxidation of some elements that could colour the clinker. Furthermore, the selection of a no-ash fuel and talc-magnesite or other magnesite based refractories with spinel binder is essential to avoid the contamination of the clinker. The quality of a white cement is strongly affected by the production technique [119, Sobolev, 2001], [120, Spain, 2007], [138, Italy, 2007].

Since the rotary kiln was introduced in around 1895 it has become the central part of all modern clinker producing installations. The vertical shaft kiln is still used for the production of lime, but only in a few countries is it in use for the production of cement clinker, and in these cases only at small-scale plants.

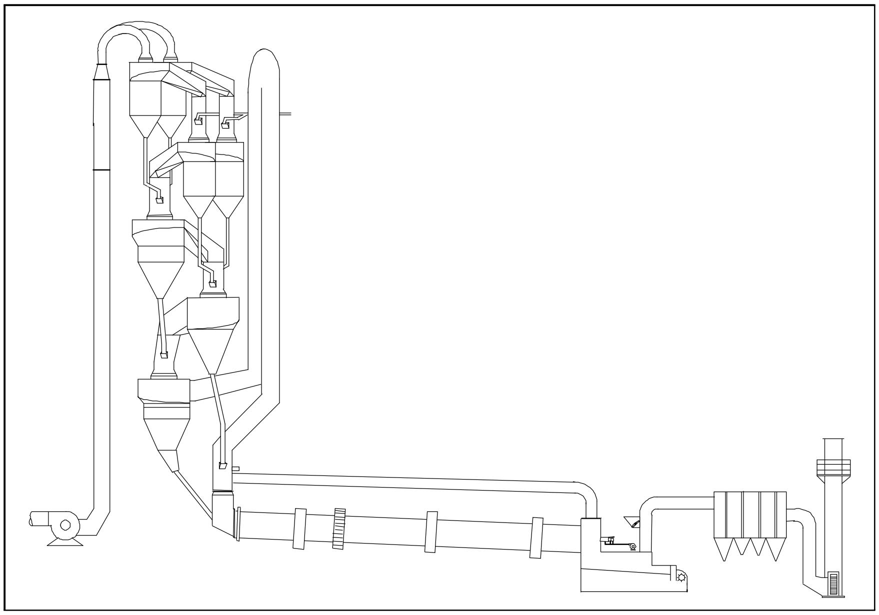


Figure 1.10: Schematic few of a preheater/precalciner/grate cooler kiln
[72, CEMBUREAU, 2006-2008,]

The first rotary kilns were long wet kilns, where the whole heat consuming thermal process takes place in the kiln itself. With the introduction of the dry process, optimisation led to techniques which allowed drying, preheating and calcining to take place in a stationary installation rather than in the rotary kiln, as shown in Figure 1.10 above.

The rotary kiln consists of a steel tube with a length to diameter ratio of between 10:1 and 38:1. The tube is supported by two to seven (or more) support stations, has an inclination of 2.5 to 4.5 % and a drive rotates the kiln about its axis at 0.5 to 5.0 revolutions per minute. The combination of the tube's slope and rotation causes material to be transported slowly along it. In order to withstand the very high peak temperatures, the entire rotary kiln is lined with heat resistant bricks (refractories). All long and some short kilns are equipped with internals (chains, crosses, lifters) to improve heat transfer.

Transient build-ups of material can occur around the inner surface of the kiln depending on the process and raw materials, etc. These are known as rings and can occur at the feed end (gypsum rings), near the sintering zone (clinker rings) or the product exit end (ash rings). The latter two types can break away suddenly and cause a surge of hot, poor quality material to leave the kiln which may be reprocessed or have to be rejected as waste. The cyclones and grates of preheater kilns may also be subject to the build-up of material which can lead to blockages.

1.2.5.1 Kiln firing

The fuel introduced via the main burner produces the main flame with flame temperatures of around 2000 °C. For process optimisation reasons, the flame has to be adjustable within certain limits. In a modern indirectly fired burner, the flame is shaped and adjusted by the primary air (10 – 15 % of total combustion air).

Potential feed points for supplying fuel to the kiln system are:

- via the main burner at the rotary kiln outlet end
- via a feed chute at the transition chamber at the rotary kiln inlet end (for lump fuel)
- via secondary burners to the riser duct
- via precalciner burners to the precalciner
- via a feed chute to the precalciner (for lump fuel)
- via a mid kiln valve in the case of long wet and dry kilns (for lump fuel)
- via the end of the Lepol grid.

Coal/petcoke firing plants are of both indirect- and direct-firing types. Direct-firing plants operate without fine-coal storage and fine-coal metering. The pulverised fuel is blown directly into the kiln with the mill sweeping air acting as the carrier and as (flame shaping) the primary air. Direct firing plants have a number of drawbacks. In particular, kiln system heat losses are around 200 – 250 MJ/tonne clinker (6 to 8 % higher on modern kiln systems). Thus, direct firing is seldom installed today.

Fuel oil is, at adequate viscosity and pressure, discharged via an atomiser nozzle into the kiln in order to form, e.g. the main flame. Flame shaping is mainly accomplished via multi-channel burners with the oil atomiser head in a central location.

Kiln burners for natural gas, too, are designed according to the multi-channel principle, the gas thereby replacing not only coal or fuel oil, but also primary air.

Multi-channel burners are also designed for the use of different types of waste fuels (see Section 1.2.4). An example is shown in Figure 1.11.

Figure 1.11: Example of a multi-channel burner
[107, Belgium, 2006]

1.2.5.2 Long rotary kilns

Long rotary kilns can be fed with slurry, crushed filter cakes, nodules or dry meal and are thus suitable for all process types. The largest long kilns have a length to diameter ratio of 38:1 and can be more than 200 m long. These huge units produce around 3600 tonnes/day using the wet process (Belgium, US, Commonwealth of Independent States (CIS)). Long rotary kilns are designed for drying, preheating, calcining and sintering, so that only the feed system and cooler have to be added. The upper part of the long kilns is equipped with chain curtains and fixed installations to improve heat transfer.

Wet process kilns, used since 1895, are the oldest type of rotary kilns in use for producing cement clinker. Wet raw material preparation was initially used because homogenisation was easier with liquid material. Wet kiln feed typically contains 32 to 40 % water. This is necessary to maintain the liquid properties of the feed. This water must then be evaporated in the specially designed drying zone at the inlet section of the kiln where a significant portion of the heat from fuel combustion is used. This technique has high heat consumption with the resulting high quantities of combustion gas and water vapour emissions.

Long dry kilns were developed in the US based on batch type dry homogenising systems for raw material preparation. Because of the high fuel consumption, only a few have been installed in Europe.

1.2.5.3 Rotary kilns equipped with preheaters

Rotary kilns equipped with preheaters have a typical length to diameter ratio of between 10:1 and 17:1. There are two types of preheaters: grate preheaters and suspension preheaters. For these types of kilns it has to be noted that problems may be encountered in cases where an excessive input of circulating elements (chlorides, sulphur, alkalis) from the feed and/or fuel (see Sections 1.2.4.3.2 and 1.2.5.3.4).

1.2.5.3.1 Grate preheater technique

Grate preheater technique, perhaps better known as the Lepol kiln, was invented in 1928. It represented the first approach to letting part of the clinkering process take place in a stationary installation outside the kiln. This allowed the rotary kiln to become shorter and so reduced the heat losses and increased energy efficiency.

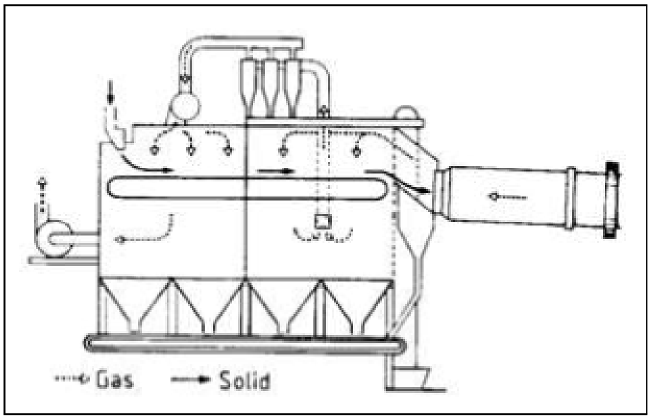


Figure 1.12: Grate preheater
[39, Ullmann's, 1986]

In the grate preheater (see Figure 1.12), nodules made from dry meal on a noduliser disc (semi dry process) or from wet slurry filter cakes in an extruder (semi-wet process) are fed onto a horizontal travelling grate which travels through a closed tunnel. The tunnel is divided into a hot gas chamber and a drying chamber by a partition with an opening for the grate. A fan draws the exhaust gas from the rotary kiln into the top of the preheater, through the nodules layer in the hot gas chamber, and then through the cyclones of the intermediate dust collector. In these cyclones large dust particles, which would otherwise cause wear to the fan, are removed. The next fan then draws the gas into the top of the drying chamber, through the moist layer of nodules, and finally pushes it out into the dust collector. In order to achieve optimum thermal efficiency, the semi-wet grate preheaters can be equipped with triple-pass gas systems, and cooler waste air is used for raw material drying. The maximum unit size to have been built is 3300 tonnes/day for a semi-wet kiln system.

The rotary kiln exhaust gas enters the preheater with a temperature of 1000 – 1100 °C. As it flows through the layer of material in the hot gas chamber, the exhaust gas cools down to 250/300 °C, and it leaves the drying chamber at 90 – 150 °C. The material to be burned reaches a temperature of about 150 °C in the drying chamber and 700 – 800 °C in the heating chamber.

1.2.5.3.2 Suspension preheater technique

The invention of the suspension preheater in the early 1930s was a significant development. Preheating and even partial calcination of the dry raw meal (dry/semi-wet processes) takes place by maintaining the meal in suspension with hot gas from the rotary kiln. The considerably larger contact surface allows almost complete heat exchange, at least theoretically.

Various suspension preheater systems are available. Examples are shown in Figure 1.13 and Figure 1.14. They usually have between four and six cyclone stages, which are arranged one above the other in a tower 50 – 120 m high. The uppermost stage may comprise two parallel cyclones for better dust separation. The exhaust gases from the rotary kiln flow through the cyclone stages from the bottom upwards. The dry powdery raw material mixture is added to the exhaust gas before the uppermost cyclone stage. It is separated from the gas in the cyclones and rejoins it before the next cyclone stage. This procedure repeats itself at every stage until finally the material is discharged from the last stage into the rotary kiln. This alternate mixing, separation and remixing at a higher temperature is necessary for optimal heat transfer.

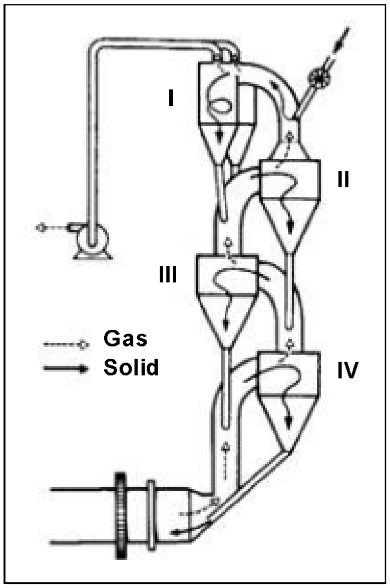


Figure 1.13: Suspension preheater [39, Ullmann's, 1986]

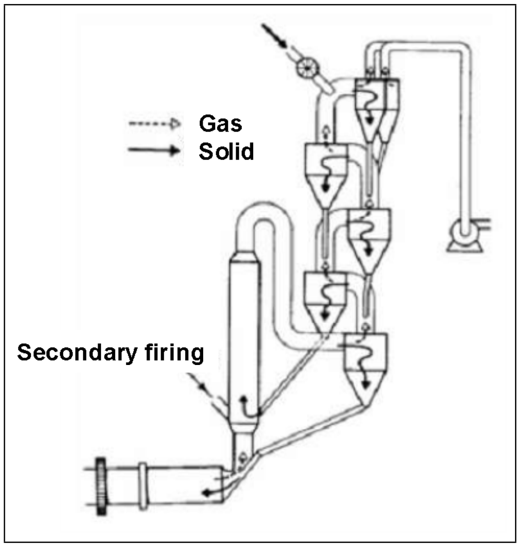


Figure 1.14: Suspension preheater with precalciner [39, Ullmann's, 1986]

1.2.5.3.3 Shaft preheaters

A considerable number of shaft preheaters were built following the introduction of suspension preheater technique, given its theoretically superior heat exchange properties. However, the difficulty of ensuring an even distribution of meal to gas meant that actual performance was far worse than expected, and technique using shaft stages alone was eventually abandoned in favour of hybrid systems with cyclone stages or pure multistage cyclone preheaters. Some of those hybrids are still in operation; however, most of them have been converted to pure cyclone preheaters.

A shaft stage is considerably less sensitive to build-up problems than a cyclone stage, which can be an advantage for the bottom stage in cases where excessive quantities of circulating elements (chlorides, sulphur, and alkalis) are present. Hybrid preheaters with a bottom shaft stage are still available for new plants.

Typical capacities of shaft preheater kilns are up to 1500 tonnes/day, whereas hybrid systems can produce 3000 tonnes/day or more.

1.2.5.3.4 Four stage cyclone preheater

The four stage cyclone preheater kiln system (suspension preheater, see Figure 1.13) was standard technique in the 1970s when many plants were built in the 1000 to 3000 tonnes/day range. The exhaust gas, which has a temperature of around 300 – 400 °C at the top preheater cyclone stage is normally used for raw material drying.

When the meal enters the rotary kiln, calcination is already about 30 % completed because the kiln feed is already heated to a temperature of approx. 850 °C by using the exhaust gases. Severe problems have been encountered with four stage preheaters in the past in cases where inputs of circulating elements (chlorides, sulphur, alkalis) from the feed and/or fuel were excessive. Highly enriched cycles of these elements lead to build-ups in cyclones and duct walls, which frequently cause blockages and kiln stops lasting several days. A kiln gas bypass, i.e. extraction of part of the particulate laden gas stream leaving the kiln so that it bypasses the cyclone system, is frequently used as a solution to the problem. This bypass gas is cooled to condense the alkalis and is then passed through a dust collector before discharge. Whilst in some regions it is necessary for the control of clinker alkali levels to send the bypass dust and part of the kiln dust to landfill, in all other cases it is fed back into the production process.

Almost all four stage suspension preheaters operate with rotary kilns with three supports. This has been the standard design since around 1970. Kilns with diameters from 3.5 to 6 m have been built with length to diameter ratios in the range 13:1 to 16:1. Mechanically simpler than the long wet and dry kilns, it is probably the most widely used kiln type today.

1.2.5.4 Rotary kilns with preheater and precalciner

The precalcination technique has been available to the cement industry since about 1970. In this procedure, the heat input is divided between two points. Primary fuel combustion occurs in the kiln burning zone. Secondary burning takes place in a special combustion chamber between the rotary kiln and the preheater. In this chamber up to 65 % of the total fuel can be burned in a typical precalciner kiln. This is because of the significantly longer retention time of the hot meal, the kiln exhaust gases in the bottom area of the cyclone preheater and the use of additional tertiary air. The energy is basically used to calcine the raw meal, which is almost completely calcined when it enters the kiln. Calcination levels of well above 90 % can be achieved. Hot air for combustion in the calciner is ducted from the cooler. Material leaves the calciner at about 870 °C. Gas and solids temperature profiles in a cyclone preheater kiln system are shown in Figure 1.15.

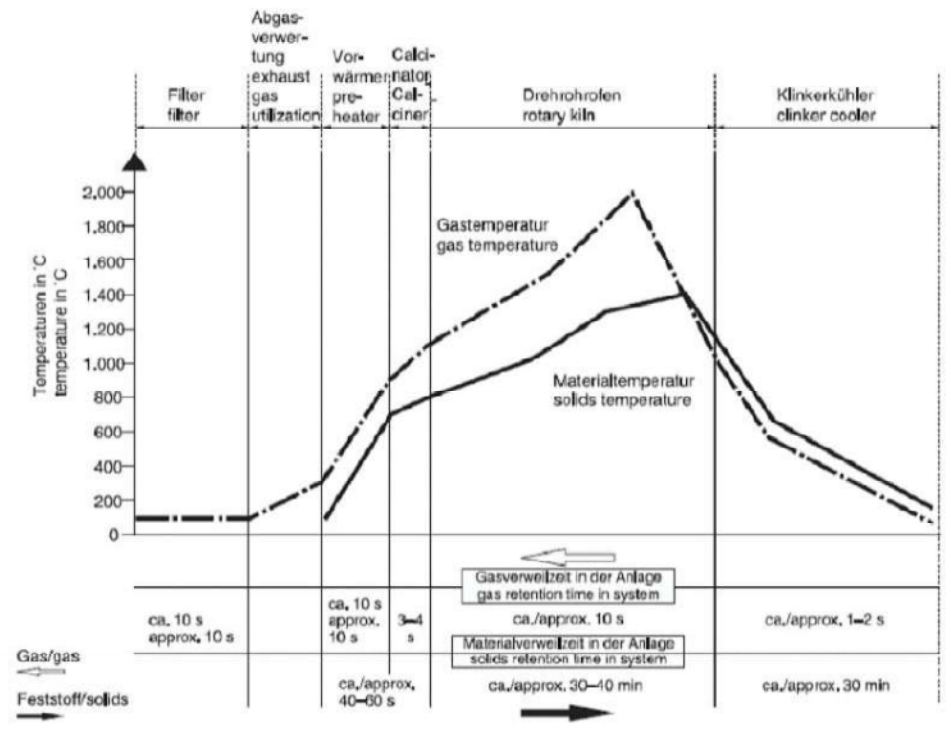


Figure 1.15: Gas and solids temperature profiles in a cyclone preheater kiln system
[60, VDI 2094 Germany, 2003]

Figure 1.14 shows this procedure applied to a kiln with a suspension preheater. In principle, secondary burning can also be applied in a kiln with a grate preheater. For a given rotary kiln size precalcining increases the clinker capacity.

Kiln systems with up to five cyclone preheater stages and a precalciner are considered standard technique for new dry process plants. An example is shown in Figure 1.16. For the use of waste as fuels, the calciner technique is shown in Figure 1.17.

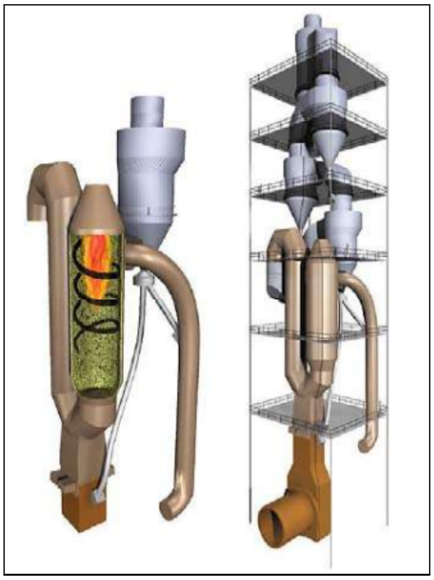


Figure 1.16: Example of a separate line/calciner downdraft
[81, Castle Cement UK, 2006]

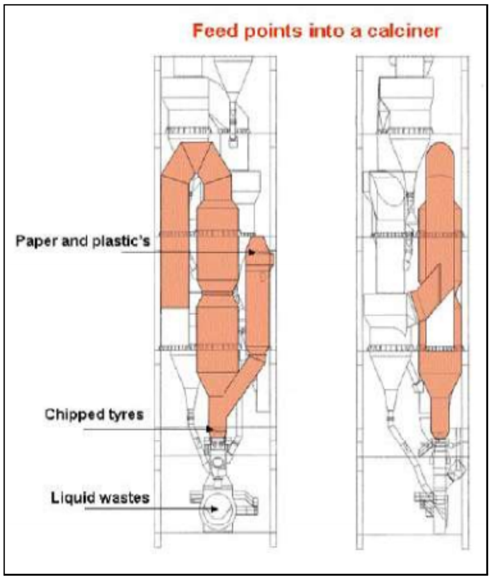


Figure 1.17: Example of waste feed points into a calciner
[81, Castle Cement UK, 2006]

The size of a new plant is primarily determined by predicted market developments, but also by the economy of scale. A typical unit capacity for new plants in Europe today is from 3000 to 5000 tonnes/day. Technically, larger units up to 15000 tonnes/day are possible, and in 2007, several 10000 tonnes/day kilns are in operation in Asian markets.

Earlier precalciner systems had only four preheater stages with accordingly higher exhaust gas temperatures and fuel consumption. Where natural raw material moisture is low, six stage preheaters can be the preferred choice, particularly in combination with fabric filter dedusting.

Where excessive input of circulating elements is present, a kiln gas bypass is required to maintain continuous kiln operation. However, due to the different gas flow characteristics, a bypass in a precalciner kiln is much more efficient than in a straight preheater kiln.

In spite of the fact that the meal enters the kiln 75 to 95 % calcined, most precalciner kilns are still equipped with a rotary kiln with a calcining zone, i.e. with an L/D ratio of 13:1 to 16:1 as in the case of the straight preheater kilns.

1.2.5.4.1 Bypass systems

With raw materials as well as with fuels (including wastes) containing chlorine, sulphur and alkalis being fed to the kiln system, the internal circulation between the kiln and the preheater acts as an enrichment cycle. At higher concentrations, such a cycle causes deposit formation in the area of the kiln inlet, the calciner and the two bottom stages. As a uniform kiln operation with minimised disturbances is the basis for energy efficient clinker production, shutdowns resulting from coating formation should be avoided. Hence a high circulation of alkalis, chlorine and, to a lower extent, sulphur enforces the use of a gas bypass at the kiln inlet. By removing part of the process gas not only are chlorine, sulphur and alkalis discharged, but also other substances. The removal of hot raw material and hot gas leads as a consequence, to a higher specific energy consumption of about 6 – 12 MJ/tonne clinker per per cent of removed kiln inlet gas. Typical bypass rates are of up to 15 % for chlorine bypass and of up to 70 % for a sulphur bypass. The inherent scrubbing of SO_x extracted along with the bypass gas is governed by:

- the amount of reactive lime
- the retention time at higher temperatures of >300 °C
- the retention time at lower temperatures of <200 °C in the presence of water (vapour).

The bypass might create additional emissions depending on its configuration and additional thermal energy may be used [76, Germany, 2006], [86, EURITS, 2006], [89, ERFO, 2005], [103, CEMBUREAU, 2006].

1.2.5.5 Shaft kilns

A few shaft kilns are used for cement production in Europe. Kilns of this type consist of a refractory-lined, vertical cylinder 2 – 3 m in diameter and 8 – 10 m high. They are fed from the top with raw meal pellets and fine grained coal or coke. The material being burned travels through a short sintering zone in the upper, slightly enlarged part of the kiln. It is then cooled by the combustion air blown in from the bottom and leaves the lower end of the kiln on a discharge grate in the form of clinker.

Shaft kilns produce less than 300 tonnes of clinker a day. They are only economic for small plants, and for this reason their number has been diminishing.

1.2.5.6 Kiln exhaust gases

In all kiln systems, the exhaust gases are finally passed through an air pollution control device (electrostatic precipitator or fabric filter) for separation of the dust before going to the main stack.

In the dry processes, the exhaust gases can be at a relatively high temperature and may provide heat for the raw mill when it is running (compound operation). If the raw mill is not running (direct operation), the gases are normally cooled with water sprays in a conditioning tower before going to the dust collector, both to reduce their volume and to improve their precipitation characteristics.

1.2.5.6.1 CO trips

Carbon monoxide can arise from any organic content in the raw materials and, occasionally, due to the incomplete combustion of fuel. The contribution from the raw materials, due to preheating, will be exhausted with the kiln gases.

Control of CO levels is critical in cement (and lime) kilns when ESPs are used for particulate abatement, to ensure concentrations are kept well below the lower explosive limit. If the level of CO in the ESP rises above a certain level as shown in Table 1.38 (see Section 1.4.5.3), then the electrical system is tripped (switched off) to eliminate the risk of explosion. This leads to unabated particulate releases from the kiln. CO trips can be caused by unsteady state operation of the combustion system. This sometimes occurs when feeding solid fuels, so solid fuel feeding systems must be designed to prevent surges of fuel into the burner. The moisture content of solid fuels is a particularly critical factor in this respect and must be carefully controlled to prevent hold ups or blockages in the fuel preparation and feeding systems.

A guideline concerning the control of CO trips can be found in Section 4.2.6.

1.2.5.7 Clinker coolers

The clinker cooler is an integral part of the kiln system and has a decisive influence on performance and economy of the pyroprocessing plant. The cooler has two tasks: to recover as much heat as possible from the hot (1450 °C) clinker so as to return it to the process; and to reduce the clinker temperature to a level suitable for the equipment downstream.

Heat is recovered by preheating the air used for combustion in the main and secondary firing as close to the thermodynamic limit as possible. However, this is hindered by high temperatures, the extreme abrasiveness of the clinker and its wide granulometric range. Rapid cooling fixes the mineralogical composition of the clinker to improve the grindability and optimise cement reactivity.

Typical problems with clinker coolers are thermal expansion, wear, incorrect airflows and poor availability, which work against the above requirements. There are two main types of coolers: rotary and grate.

For white cement production, other types of coolers are used, tailor made to the specificities of the plant in order to retain the reducing conditions during clinker cooling. An oxygen-free atmosphere in the first stage of whitening and the rapid cooling by water spray are used for improvement of the clinker quality. Rapid cooling of white clinker in water proceeds a significant improvement of whiteness. The contamination of white clinker with chromophore elements and the strong oxidation during the cooling phase has to be avoided [119, Sobolev, 2001], [120, Spain, 2007], [138, Italy, 2007].

1.2.5.7.1 Rotary coolers

1.2.5.7.1.1 Tube coolers

The tube cooler uses the same principle as the rotary kiln, but for reversed heat exchange. Arranged at the outlet of the kiln, often in reverse configuration, i.e. underneath the kiln, a second rotary tube with its own drive is installed. After kiln discharge, the clinker passes a transition hood before it enters the cooler, which is equipped with lifters to disperse the product into the airflow. Cooling of the airflow is determined by the air required for fuel combustion. Apart from the speed, only the internals can influence the performance of the cooler. Optimisation of lifters must consider heat exchange (dispersion pattern) versus dust cycle back to the kiln.

1.2.5.7.1.2 Planetary (or satellite) coolers

The planetary or satellite cooler is a special type of rotary cooler. Several cooler tubes, typically 9 to 11, are attached to the rotary kiln at the discharge end as shown in Figure 1.18. The hot clinker enters through openings in the kiln shell arranged in a circle at each point where a cooler tube is attached. The quantity of cooling air is determined by the air required for fuel combustion and enters each tube from the discharge end, allowing countercurrent heat exchange. As for the tube cooler, internals for lifting and dispersing the clinker are essential. There are no variable operating parameters. High wear and thermal shock, in conjunction with dust cycles, mean high clinker exit temperatures and sub-optimum heat recovery are not unusual. The clinker exit temperature can only be further reduced by water injection into the cooler tubes or onto the shell.

Because it is practically impossible to extract tertiary air, the planetary cooler is not suitable for precalcination. However, secondary firing with up to 25 % fuel in the kiln riser area is possible.

Figure 1.18: Example of a planetary cooler
[45, Schorcht, 2006], [90, Hungary, 2006]

1.2.5.7.2 Grate coolers

Cooling in grate coolers is achieved by passing a current of air upwards through a layer of clinker (clinker bed) lying on an air-permeable grate. Two ways of transporting the clinker are applied: travelling grate and reciprocating grate (steps with pushing edges).

Since the hot air from the aftercooling zone is not used for combustion, it is available for drying purposes, e.g. raw materials, cement additives or coal. If not used for drying, this cooler waste air must be properly dedusted.

1.2.5.7.2.1 Travelling grate coolers

In this type of cooler, clinker is transported by a travelling grate. This grate has the same design features as the preheater grate (Lepol). Cooling air is blown by fans into compartments underneath the grate. Advantages of this design are an undisturbed clinker layer (no steps) and the possibilities of exchanging plates without a kiln stop. Due to its mechanical complexity and poor recovery resulting from limited bed thickness (caused by the difficulty of achieving an effective seal between the grate and walls), this design ceased to be used in new installations in around 1980.

1.2.5.7.2.2 Reciprocating grate coolers

Clinker transport in the reciprocating grate cooler is affected by stepwise pushing of the clinker bed by the front edges of alternate rows of plates. Relative movement of front edges is generated by hydraulic or mechanical (crankshaft) drives connected to every second row. Only the clinker travels from the feed end to the discharge end, but not the grate.

The grate plates are made from heat resistant cast steel and are typically 300 mmWG wide and have holes for the air to pass through them.

Cooling air is insufflated from fans at 300 – 1000 mmWG via compartments located underneath the grate. These compartments are partitioned from one another in order to maintain the pressure profile. Two cooling zones can be distinguished:

- the recuperation zone, from which the hot cooling air is used for combustion of the main burner fuel (secondary air) and the precalciner fuel (tertiary air)
- the aftercooling zone, where additional cooling air cools the clinker to lower temperatures.

Key features of modern cooler technique are (depending on supplier):

- modern plates with built-in, variable or permanent, pressure drop, permeable to air but not to clinker
- forced plate aeration via ducts and beams
- individually adjustable aeration zones
- fixed inlet
- fewer and wider grates
- roller crusher
- heat shields.

The largest units in operation have an active surface of about 280 m^2 and a cooling capacity of 10000 tonnes clinker per day. Typical operational challenges with these coolers are segregation and uneven clinker distribution leading to an air-clinker imbalance, fluidisation of fine clinker (red river) and also build-ups (snowmen) and less than ideal lifetime of the plates.

1.2.5.7.2.3 Third generation of grate coolers

Introduction and development of modern technique reciprocating grate coolers started around 1983. The design aimed to eliminate the difficulties with conventional coolers thus coming a step closer to optimum heat exchange and also more compact coolers using less cooling air and smaller dedusting systems.

In the 2000s, a new generation representing a completely new concept of cooling clinker emerged in the cement industry. The basic idea was to develop a cooler in which the conveying of clinker and air distribution systems are separated and optimised. Compared with the reciprocating grate coolers, sealing air is eliminated and the distribution of air is optimised for all modes of operation.

Key features of these types of coolers are (depending on supplier):

- one inclined or horizontal fixed grate
- clinker conveying by cross bars, tracks, walking floors or similar devices, separate from air distribution
- clinker stays in place and does not fall through to the under grate compartment
- elimination of sealing air and automatic control of air distribution
- clinker transport efficiency is improved with a better control of difficulties related to fluidisation of fine clinker (red river).

These types of coolers are suitable to be in operation with the largest clinker capacities of cement kilns.

1.2.5.7.3 Vertical coolers

A dust free aftercooler called a gravity cooler or a G-cooler was developed to be installed after a planetary cooler or short grate recuperator/cooler. The cooling air never comes into contact with the clinker as heat exchange is effected by the clinker descending over transverse steel tubes in the clinker bed, which in turn are cooled by air blown through them.

1.2.5.8 Cogeneration

Generation of electrical power and using excess heat from the cement production process can be applied in cement plants.

Normally the majority of heat emitted from a cement clinker kiln is used for the drying and dry grinding processes as follows:

- raw material drying and grinding/milling
- slag drying
- sand drying
- fuel drying and grinding.

Multistage suspended cyclone preheater plants – with or without a precalciner – are designed to suit the nature of the available raw materials. When the raw materials are very wet, the off-gas of the grate clinker cooler is also used for material processing.

The lime-based raw materials need, depending on geology and seasonal rainfall, varying levels of heat for driving off the moisture. At times though, some heat is in excess for the above-mentioned process needs. It has to be noted that the excess heat availability and subsequently the heat recovery technique has to take this variability into account.

Besides district heating, excess heat can also be used for electrical power generation. Normally, these processes are operated with water which needs to operate economically at relatively high steam temperature/pressure if electrical power is to be generated.

For the first time in a German cement kiln, the Organic Rankine Cycle (ORC) process for the cogeneration of power from low temperature waste heat has been applied. This process is essentially based on the use of pentane as the motive medium which evaporates to steam at significantly lower temperatures than water. The particular advantages are the simple operation, the compact structure and the relatively high levels of efficiency which can be achieved with heat sources below 275 °C. Therefore, generation of electrical power by using excess heat from the cement production process can be regarded as a technically feasible alternative to power generating plants using steam if certain preconditions are applied.

The results available from the one German cement plant indicate that 1.1 MW electrical power can be generated with the given mode of operation. This was achieved by a clinker cooler with a waste heat output of exhaust air of 14 MW and an exhaust gas temperature of 300 °C [76, Germany, 2006], [78, E. Baatz + G. Heidt, 2000], [79, Germany, 2001], [133, CEMBUREAU/Federhen, 2007].

Example plants and more information concerning the recovery of excess heat from clinker coolers or kiln off-gases for district heating, the cogeneration of electric power via the conventional steam cycle process, as well as the ORC process in operation can be found in Section 1.4.2.4 and in Section 4.2.3.

1.2.6 Cement grinding and storage

1.2.6.1 Clinker storage

Clinker and other cement components are stored in silos or in closed sheds. Larger stocks can be stored in the open if the necessary precautions against dust formation are taken.

The most common clinker storage systems are:

- longitudinal stores with gravity discharge (limited live stock)
- circular stores with gravity discharge (limited live stock)
- clinker storage silos (high live stock; problems with ground vibrations can occur during clinker withdrawal from the silo at certain silo levels)
- clinker storage domes (limited live stock).

1.2.6.2 Cement grinding

Portland cement is produced by intergrinding cement clinker and sulphates such as gypsum and anhydrite. In blended cements (composite cements) there are other constituents, such as granulated blast furnace slag, fly ash, natural or artificial pozzolanas, limestone, or inert fillers. These will be interground with the clinker or may need to be dried and ground separately. (Grinding plants may be at separate locations from clinker production plants.)

The kind of cement grinding process and the plant concept chosen at a specific site depend on the cement type to be produced. Of special importance are the grindability, the humidity and the abrasive behaviour of the compounds of the cement type produced.

Most mills work in a closed circuit, that is, they can separate cement with the required fineness from the material being ground and return coarse material to the mill.

For white cement production, final grinding is one of the most essential steps along with the selection of appropriate types of gypsum with high purity. For increasing the fineness and for decreasing the grinding time, an appropriate grinding aid (up to 1 %) is used, which results in an increase of whiteness of between 5 – 7 %. Furthermore, finely ground microfillers like white marble or quartz glass, pure silica gel, mica or talc, kaolin (or metakaolin) or powders with traces of TiO_2 could be used in relatively small quantities [119, Sobolev, 2001].

1.2.6.2.1 Metering and proportioning of the mill feed

The accuracy and reliability of metering and proportioning of the mill feed components by weight is of great importance for maintaining a high energy efficiency of a grinding system. The predominant metering and proportioning equipment for the material feed to mills is the belt weigh feeder.

1.2.6.2.2 Grinding of cement

Due to the variety of cement types required by the market, the latest grinding systems equipped with a dynamic air separator predominate.

Commonly used finish grinding systems are:

- tube mills, closed circuit (mineral addition is rather limited, if not dry or pre-dried)
- vertical roller mills (best suited for high mineral additions due to its drying capacity, best suited for separate grinding of mineral addition)
- roller presses (mineral addition is rather limited, if not dry or pre-dried).

Other finish grinding systems used are:

- tube mill, end discharge in open circuit
- tube mill, end discharge in closed circuit with mechanical air separator or cyclone air separator of older generations
- horizontal roller mills.

Ball mills (type of a *tube mill*) are available in tube diameters of up to 6 m and tube lengths of up to 20 m. Steel balls of different sizes are used depending on the expected grinding fineness. This type of mill is relatively easy to operate under stable operating conditions and has a high operating reliability and availability. To a limited extent also mineral additions with certain moisture contents can be dried by passing hot gases to the mill and using the heat from the grinding process. However, compared with other mill types, ball mills have a higher specific energy consumption and rank last in energy efficiency.

The working principle of *vertical roller mills* is based on the action of two to four grinding rollers supported on hinged arms and riding on a horizontal grinding table or grinding bowl. It is suited especially for simultaneous grinding and drying of cement raw materials or slag since vertical roller mills can handle relatively high moisture contents in the mill feeds. The transition time for materials through the mill is short enough to prevent prehydration of the cement clinker, e.g. in the case of slag cement grinding.

The *high pressure twin roller mill* still needs a comparatively high degree of maintenance. High pressure twin roller mills are often used in conjunction with ball mills.

A more recent development in cement grinding is the *horizontal roller mill*. This consists of a short horizontal shell supported on hydrodynamic or hydrostatic bearings. The shell is rotated via a girth gear. Inside the shell is a horizontal roller which is free to rotate and can be pressed hydraulically onto the shell. The material to be ground is fed into one or both ends of the shell, and passes between the roller and the shell several times. The crushed material leaving the mill is transported to a separator, with the oversize fraction being returned to the mill.

A comparison of key characteristics from grinding technique examples are shown in Table 1.19 in Section 1.3.3.2.

1.2.6.2.3 Grinding of mineral additions

Mineral additions are usually ground together with the clinker and gypsum. The decision to grind them separately basically depends upon the following factors:

- the percentage of mineral additives in the final product and in cement production as a whole
- whether a spare mill system is available
- whether there is a considerable difference in the grindability of the clinker and mineral additives
- the moisture content of the mineral additives.

If pre-drying of the mineral additives is required, dryer systems can be employed using either kiln exhaust gases and/or cooler exhaust air or an independent hot gas source.

Intergrinding systems

Any of the grinding systems mentioned for the dry/semi-dry grinding of raw materials can be used for intergrinding mineral additives with clinker and gypsum. However, most systems place limits on the moisture content of the feed mixture – 2 % maximum or 4 % if a hot gas source is used. For higher moisture contents, the systems require pre-drying of the mineral additives in a dryer. An exception is the vertical roller system, which is capable of handling moisture contents of up to 20 %, but still requires a hot gas source.

Separate grinding

For separate grinding of mineral additives, the systems for the dry/semi-dry grinding of raw materials can be used. However, the same applies for the systems with regard to the moisture content of the additive mixtures and pre-drying may be required.

1.2.6.2.4 Separation by particle size distribution

The particle size distribution of the product leaving the cement grinding system is of great importance for the cement quality. The specification of these parameters is achieved by adjusting the separator. The latest separators of the rotor cage type have several advantages over previous designs, such as:

- lower specific energy consumption by the system (less overgrinding)
- increase of system throughput (efficiency)
- possibility of product cooling
- higher flexibility for adjustments in product fineness
- better control of particle size distribution, better product uniformity.

1.2.6.2.5 Reduction of chromates – chromium (VI)

Since cement is produced from natural raw materials, its chromium content may vary considerably, depending on the circumstances, but it is unavoidable. The main sources of chromium in Portland cement are the natural raw materials like limestone, sand and in particular, clay. Minor sources include fuels (conventional (fossil) and waste). Consequently, as a result of natural variations in the chemical composition of the earth's crust, the chromium content may vary considerably. A part of the chromium will be present in a water soluble form, the so-called hexavalent chromium (chromium (VI)).

In 2003, an epidemiological assessment from the National Institute of Occupational Health regarding the occurrence of allergic dermatitis in workers in the construction industry related to the content of chromium (VI) in cement was made. This assessment said that 'the main sources of chromium in finished cement are the raw materials, the refractory bricks in the kiln and the chromium grounding media. The relative contribution from these sources may vary, depending on the chromium content of the raw materials and on the manufacturing conditions. In a study of clinker grinding with chrome alloy balls of 17 – 28 % chromium, the hexavalent chromium of the cement increased to over twice that present in the original clinker.'

When dissolved in water, chromium (VI) may penetrate unprotected skin. This water soluble chromium (VI) may cause allergic dermatitis, also called 'cement eczema'. 'Cement eczema' also covers another type of dermatitis: irritant dermatitis, caused by the alkaline nature of cement mixed with water.

The EU Directive on chromates (2003/53/EC) restricted the marketing and use of cement with more than 0.0002 % (2 ppm) soluble chromium (VI). In general for the cement industry, it is not possible to reduce the chromate content in cement at the input phase, as the main sources are the raw materials. Therefore in 2007, the only way to reduce the water soluble chromium (VI) in cement is to add a reducing agent to the finished products. The main reducing agents used in Europe are ferrous sulphate and tin sulphate [86, EURITS, 2006], [103, CEMBUREAU, 2006], [111, European Commission, 2003].

1.2.6.3 Storage of cement

Both pneumatic and mechanical conveying systems can be used for transporting cement to storage silos. Mechanical systems normally have a higher investment cost but a much lower operating cost than pneumatic transport. A combination of air-slide or screw/chain conveyors with a chain bucket elevator is the most commonly used conveying system.

Different cements are stored separately in silos. Usually various silos are required for the storage of cements. However, new silo designs allow the storage of more than one type of cement in the same silo. The silo configurations used for cement storage are:

- single-cell silos with a discharge hopper
- single-cell silos with a central cone
- multi-cell silos
- dome silos with a central cone.

Compressed air is used to initiate and maintain the cement discharge process from these silos via aeration pads located at the bottom of the silo.

1.2.7 Packaging and dispatch

Cement is transferred from the silos either directly into bulk road, rail or ship tankers, or to a bag packaging station.

1.3 Current consumption and emission levels

It has to be noted that, if not otherwise mentioned in this document, for this section concerning the cement industry, the standard conditions for measurements of volume flows and concentrations of flue-gases are related to the following definitions which are also stated in the Glossary:

m^3/h	volume flow: if not otherwise mentioned in this document, the volume flows refer to 10 vol-% oxygen and standard state
mg/Nm^3	concentration: if not otherwise mentioned in this document, the concentrations of gaseous substances or mixtures of substances refer to dry flue-gas at 10 vol-% oxygen and standard state
standard state	refers to a temperature of 273 K, a pressure of 1013 hPa and dry gas

In addition, it has to be noted that the emissions ranges refer to a reference oxygen level of 10 % although the actual oxygen level within the firing process is much lower than 10 %, e.g. 3 %. The calculation formula for calculating the emissions concentration is shown below:

$$E_R = \frac{21 - O_R}{21 - O_M} * E_M$$

E_R (mg/Nm^3): emissions concentration related to the reference oxygen level O_R
O_R (vol %): reference oxygen level
E_M (mg/Nm^3): emissions concentration related to the measured oxygen level O_M
O_M (vol %): measured oxygen level

Additional useful information on monitoring can be found in the Reference Document on the General Principles of Monitoring (MON) [151, European Commission, 2003].

The main environmental issues associated with cement production are emissions to air and energy use. Waste water discharge is usually limited to surface run off and cooling water only and causes no substantial contribution to water pollution. The storage and handling of fuels is a potential source of contamination of soil and groundwater.

The purpose of a mass balance is to evaluate the mass components entering and exiting the system taking into account the law of mass conservation. The evaluation of all mass balance items requires a previous knowledge of process data like raw materials and fuel compositions, gas streams, atmospheric data, etc. In a cement plant, with a system consisting of raw mill, preheater, kiln and cooler, the following input and output flows are important:

- input flows:
  - raw materials (conventional and/or waste)
  - energy (fuels (fossil and/or waste and/or biomass), electrical energy)
  - water (including fuel moisture, raw material moisture, air moisture and water injection in raw mill)
  - air (primary air, transport air, cooling air and leak air)
  - auxiliary agents (mineral additions, packaging material)

- output flows:
  - clinker
  - process losses/waste (filter dusts)
  - emissions to air (e.g. dust,NO_x, SO_x, noise; see also mass balance Figure 1.19)
  - emissions to water (e.g. wet process).

The input data are the following:

- dry process; five stage preheater, precalciner, grate cooler, vertical raw mill
- fuel: 100 % petroleum coke
- heat consumption: 3300 kJ/kg clinker
- petcoke (net) calorific value (NCV): 33500 kJ/kg fuel
- kiln feed: 1.66 kg/kg clinker; standard kiln feed chemical composition
- raw material factor: 1.52 kg/kg clinker and 5 % moisture
- air moisture: 1 %
- raw mill:
  - leak air: 30 %
  - water injection: 0.5 % kiln feed
- clinker/cement factor: 0.8.

A mass balance for the production of 1 kg of cement using the dry process with petcoke as the fuel is shown in Figure 1.19.

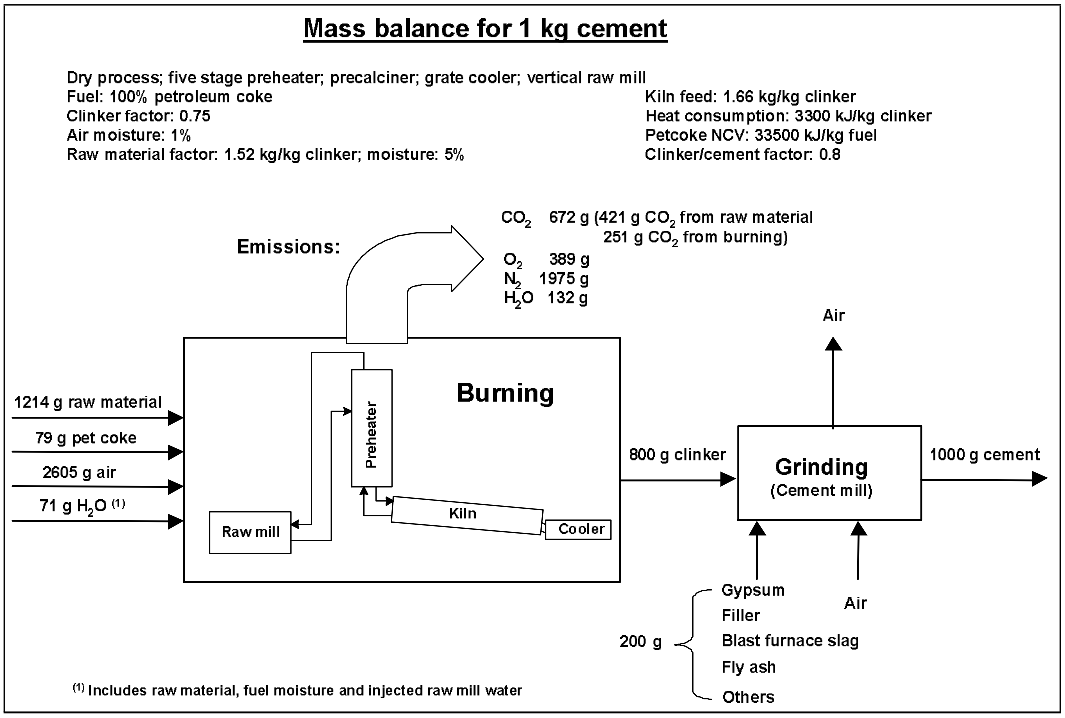


Figure 1.19: Mass balance for the production of 1 kg cement using the dry process [103, CEMBUREAU, 2006]

1.3.1 Consumption of water

Water is used at a number of stages during the production process. In some cases, water only is used for the preparation of raw material, in clinker burning and cooling processes, such as the cooling of gases, as well as in the technological process for slurry production. In the semi-dry process, water is used for pelletising the dry raw meal. Plants using the wet process use more water (per tonne of cement produced) in preparing the kiln feed slurry and a typical water consumption of 100 – 600 litres water per tonne clinker is reported. Furthermore, for special applications, water is used for clinker cooling and a water usage of around 5 m^3/hour has been reported. In most cases, the water consumed is not potable water [45, Schorcht, 2006], [75, Estonia, 2006], [81, Castle Cement UK, 2006], [103, CEMBUREAU, 2006], [120, Spain, 2007].

1.3.2 Consumption of raw materials

Cement manufacture is a high volume process. The figures in Table 1.15 indicate typical average consumptions of raw materials for the production of cement in the European Union. The figures in the final column are for a plant with a clinker production of 3000 tonnes/day or 1 million tonnes/year, corresponding to 1.23 million tonnes cement per year based on the average clinker content in European cement.

Materials (dry basis)	Per tonne clinker	Per tonne cement	Per year per Mt clinker
Limestone, clay, shale, marl, other	1.57 t	1.27 t	1568000 t
Gypsum, anhydrite	-	0.05 t	61000 t
Mineral additions	-	0.14 t	172000 t

Table 1.15: Consumption of raw materials in cement production
[9, CEMBUREAU, 1997 November]

1.3.2.1 Consumption of wastes as raw materials

The use of wastes as raw materials in the clinker burning process can replace a relatively large amount of raw materials (see also Section 1.2.4). The quantities of wastes used as raw materials in clinker production have more than doubled since 2001. In 2004, waste raw materials used in clinker production allowed the cement industry to make a direct saving of almost 14 million tonnes of conventional raw materials, which is equivalent to about 6.5 % of the natural raw materials needed.

However, these waste raw materials have to show and meet characteristics, chemical elements and components which are necessary for the clinker burning process. These waste materials may have an impact on the emissions behaviour of the process and an effect on the emissions. Impacts on emissions are discusses in Section 1.3.4.13. Table 1.16 lists the consumption of wastes used as raw materials characterised by chemical elements used by the EU-27 in 2003 and 2004 for clinker production. Figure 1.20 shows the share used by 20 countries of the EU-27.

Wastes used as raw materials			
Desired (primary) chemical elements	**Examples of waste streams**	**Quantities 2003 (million tonnes)**	**Quantities 2004 (million tonnes)**
Si	Spent foundry sand	1.52	1.50
Ca	Industrial lime Lime slurries Carbide sludge Sludge from drinking water treatment	2.20	2.44
Fe	Pyrite cinder Synthetic hematite Red mud	3.29	3.37
Al		0.71	0.69
Si-Al-Ca-Fe	Fly ash Slags Crusher fines	3.37	3.78
Soil		0.45	0.50
S group	Industry by-product gypsum		
F group	CaF_2 Filter sludge		
Others		1.56	1.71
Total		13.10	13.89

Table 1.16: Wastes used as raw materials characterised by chemical elements used in cement manufacturing in the EU-27 in 2003 and 2004
[74, CEMBUREAU, 2006], [103, CEMBUREAU, 2006]

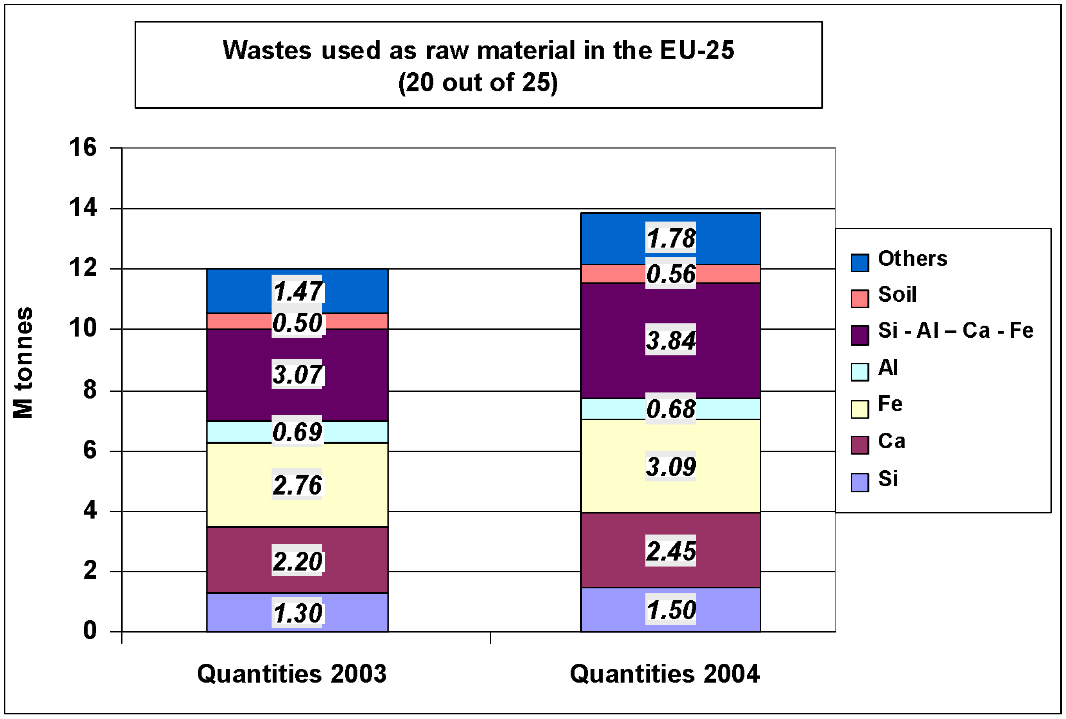


Figure 1.20: Wastes used as raw materials in 20 countries of the EU-27
[74, CEMBUREAU, 2006]

For cement grinding, the consumption of wastes as raw materials has increased. As an example, it was reported that the use of oil shale fly ash doubled up to 100 kt/yr from 2000 to 2005 [75, Estonia, 2006].

1.3.3 Use of energy

The cement industry is a highly energy consuming industry, depending on the process used. The use of fuels and electricity are the two main types of energy used in cement manufacture. Energy efficiency (both thermal and electrical) has been a priority for many decades for the European cement industry as part of the overall business decisions which are driven by economic and technological needs [103, CEMBUREAU, 2006].

1.3.3.1 Thermal energy demand

The theoretical thermal (fuel) energy demand for cement clinker production is determined by the energy required for the chemical/mineralogical reactions of the clinker burning process (1700 to 1800 MJ/tonne clinker) and the thermal energy required for raw material drying and preheating, mainly depending on the moisture content of the raw material as given by the examples shown in Table 1.17. In modern preheater kilns, the number of cyclones can be limited by the chemical composition of the raw material.

Characteristics	Unit	Raw material moisture (% w/w)			
		3	6	9	12
Number of cyclone stages	-	6	5	4	3
Enthalpy required for drying	MJ/t $_{\text{clinker}}$	150	290	440	599

Table 1.17: Examples of thermal energy required for drying the raw meal
[137, Klein/Hoenig, 2006]

The actual thermal (fuels) demand for different kiln systems and kiln sizes is within the ranges shown in Table 1.18, as well as the fuel energy use for special cement production. Practical experience shows that the energy consumption of plants using the dry process, with multistage cyclone preheaters and precalcining kilns starts at about 3000 and can reach more than 3800 MJ/tonne clinker (as an annual average). The variations in this range are due to shutdowns and start-ups of the systems and e.g. because of different raw material properties. Table 1.17 gives an estimation of the influence of the raw material moisture on the thermal energy demand for cyclone preheater kilns

Specific thermal energy demand (MJ/tonne clinker)	Process
3000 – <4000	For the dry process, multistage (three to six stages) cyclone preheaters and precalcining kilns
3100 – 4200	For the dry process rotary kilns equipped with cyclon preheaters
3300 – 5400	For the semi-dry/semi-wet processes (Lepol kiln)
up to 5000	For the dry process long kilns
5000 – 6400	For the wet process long kilns
3100 – 6500 and higher	For shaft kilns and for the production of special cements

Table 1.18: Fuel energy use in cement manufacturing in the EU-27
[75, Estonia, 2006], [76, Germany, 2006], [84, CEMBUREAU, 2006], [92, Austria, 2006], [120, Spain, 2007], [168, TWG CLM, 2007]

Figure 1.21 shows the fuel energy use in the cement industry in the EU-27 in 2004 without a distinction being made between the different processes (dry, semi-dry/-wet or wet) and fuels (fossil and/or waste) used. Approximately 30 cement plants in the EU-27 are high consumers of fuel energy with more than 5000 MJ/tonne clinker, e.g. for the production of special cement such as white cement (see also Table 1.18). Energy consumption for white cement production is affected by a higher temperature which is needed for producing this type of white clinker in comparison to the production of other types of clinker (grey clinker) [75, Estonia, 2006], [84, CEMBUREAU, 2006], [120, Spain, 2007].

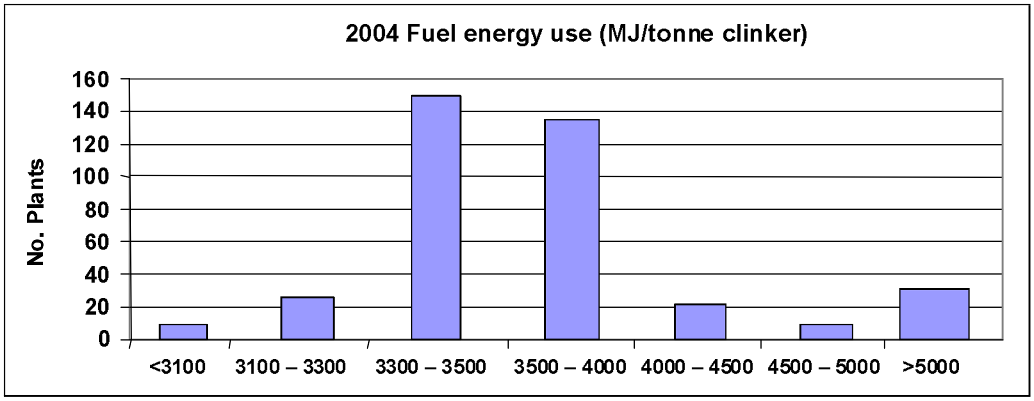


Figure 1.21: Fuel energy use in the EU-25 cement industry in 2004
[84, CEMBUREAU, 2006]

Different parameters can influence the specific energy consumption, such as [92, Austria, 2006]:

- size and plant design
  - three to six cyclone stages
  - calciner
  - tertiary air
  - compound operation of the mill
  - length to diameter ratio of the kiln
  - type of clinker cooler
- throughput of the kiln
- moisture content of raw materials and fuels
- raw material properties, such as burnability
- specific calorific value of the fuels
- type of clinker
- homogenising and precise metering of kiln feed material and fuels
- optimisation of process control including flame cooling
- bypass rate.

When changing the fuel mix used, the specific energy consumption per tonne of clinker can vary due to various reasons, depending on the type of fuels (conventional or waste fuel), their parameters, e.g. moisture content, reactivity or coarseness, and the calorific value of the fuels used.

One of the main impacts on energy consumption is due to the preparation of fossil fuels like coal or lignite which are, in many cases, partly or completely dried outside of the kiln system, even outside of the cement plant. Lignite, for example, can be extracted with a moisture content of above 50 % and needs to be dried before delivery to the cement plant. When replacing dried fuels by fuels having a higher moisture content, an increase of the energy consumption per tonne of clinker in the kiln system is possible, but can be globally compensated by the energy saved from the avoided drying and transport of fossil fuels.

On the issue of fuel moisture, the efficiency of the process varies depending on the type of fuel drying used, such as fuel drying by using waste heat from the process or effectively drying the fuel inside of the kiln, which will require more energy for removing the moisture content. Some fuels also partly contain wet minerals used as the raw material. These minerals are dried into the kiln system, and can also increase the specific energy consumption per tonne of clinker.

Furthermore, a high substitution rate of waste fuels in combination with different parameters, e.g. lower calorific values of these waste fuels, high moisture content, design of the plant, can relate to a higher energy use as shown in examples from Austria and the UK (see Section 1.3.3.3). In cases where plants are suitable and designed especially for the co-incineration of certain types of waste fuels, thermal energy consumption can still be in the range of between 3120 – 3400 MJ/t clinker. Austrian cement plants reported results from a 48 hours test trial with a considerable amount of low calorific value that included rather humid plastics achieving 3400 MJ/t clinker. Furthermore, in the UK, energy consumption of 3473 kJ/kg has been reported for a five stage precalciner kiln. However, potentials for improvements have been stated [81, Castle Cement UK, 2006], [92, Austria, 2006], [163, Castle Cement UK, 2006], [168, TWG CLM, 2007], [171, A TEC, 2007].

1.3.3.2 Electrical energy demand

The main users of electricity are the mills (finish grinding and raw grinding) and the exhaust fans (kiln/raw mill and cement mill) which together account for more than 80 % of electrical energy usage. On average, energy costs – in the form of fuel and electricity – represent 40 % of the total production cost involved in producing a tonne of cement. Electrical energy represents up to 20 % of this overall energy requirement. The electricity demand ranges from 90 to 150 kWh/tonne cement. Between 2004 and 2006, electricity costs increased from 14 % of total cement production cost to 25 %. The wet process is more energy intensive than the semi-wet or the dry process [20, Rother, 1996 January,], [84, CEMBUREAU, 2006].

Electricity use is also determined by the nature of the products, through the use of milling requirements. In some cases, the use of electricity was minimised by replacing old raw material mills with new ones. Table 1.19 gives an overview of the relationship between the energy consumption of the different grinding techniques. It has to be noted that it is not always possible to replace one mill by another grinding device. Furthermore, it is worth mentioning that an assessment of the most appropriate grinding technique should always also consider the economic aspects.

Grinding process	Energy consumption	Maintenance requirements	Drying capacity	Suitability for grinding to great fineness
Ball mill	100 %	Minor	Average	Good
Gutbett roller mill	65 to 50 %	Minor to major	Low[1)]	Average
Vertical roller mill	75 to 70 %	Average	High	Average
[1)] Drying in classifier				

Table 1.19: Comparison of grinding techniques based on key characteristics [60, VDI 2094 Germany, 2003], [76, Germany, 2006]

1.3.3.3 Consumption of waste fuels

To cover the necessary energy demand, waste fuels as well as conventional fuels are used and the consumption of waste fuels has consistently increased over the last few years. In 2004 in Europe, 6.1 million tonnes of different types of wastes were used as fuels in cement kilns. Of these wastes, about one million tonnes were hazardous. In EU-23+ counties (see Glossary), substitution of traditional fuels by waste fuels is increasing sharply, rising from 3 % in 1990 to about 17 % in 2007, equivalent to saving about 4 million tonnes of coal [74, CEMBUREAU, 2006].

However, great differences can be observed between Member States with similar opportunities to increase substitution. In 2007, individual plants were already reaching substitution rates of more than 80 %. Up to 100 % of the energy consumption can be utilised by waste fuels, e.g. at a dry process kiln system, which consists of a rotary kiln with a four stage, two-string preheater and planetary cooler. An example is shown in Section 4.2.2.1.

It has to be noted that of these wastes, the calorific values vary very widely, from 3 to 40 MJ/kg. Literature shows that conventional fuels have calorific values (average, net) of, e.g. 26 – 30 MJ/kg for typical coal, 40 – 42 MJ/kg for typical fuel oil while solid waste can have a calorific value of 8.5 MJ/kg, and plastic material has a calorific value of up to 40 MJ/kg [143, Williams, 2005]. Waste fuels with sufficient calorific values can replace fossil fuels and leads to fossil fuel savings. However, kilns have to be suitable for burning wastes and circumstances have to be optimised in order to be able to contribute to a high energy efficiency (see Sections 1.3.3.1 and 1.4.2.1.3). Table 1.20 shows examples of typical calorific values of different waste materials:

Examples of types of waste fuels (hazardous and non-hazardous)	Examples of calorific values (MJ/kg)
Wood	Approx. 16
Paper, cardboard	3 – 16
Textiles	up to 40
Plastics	17 – 40
Processed fractions (RDF)	14 – 25
Rubber/tyres	approx. 26
Industrial sludge	8 – 14
Municipal sewage sludge	12 – 16
Animal meal, fats	14 – 18, 27 – 32
Animal meal (carcase meal)	14 – 21.5
Coal/carbon waste	20 – 30
Agricultural waste	12 – 16
Solid waste (impregnated sawdust)	14 – 28
Solvents and related waste	20 – 36
Oil and oily waste	25 – 36
Oil-shale based fuel mix (85 – 90 % oil-shale)	9.5
Sewage sludge (moisture content >10 %)	3 – 8
Sewage sludge (moisture content <10 to 0 %)	8 – 13

Table 1.20: Examples of calorific values for different types of wastes used as fuels in the EU-27 [75, Estonia, 2006], [168, TWG CLM, 2007], [180, Mauschitz, 2004]

It has to be noted that depending on the different parameters (see Section 1.4.2.1.3), the annual average specific thermal energy demand also can increase, as shown in examples from the UK and Austria given below.

In example plants in the UK, the (net) calorific value of waste fuels used, e.g. derived from municipal, commercial and/or industrial wastes, can vary between 15 and 23 MJ/kg. However, in one plant a thermal substitution rate of 25 % of the total fuel used was reported which is equivalent to 30000 tonnes of coal. Since the waste fuels have a lower calorific value, the quantity of waste fuels required is 44118 t [153, Castle Cement UK, 2007], [154, CEMEX UK, 2006]. Another example shows that 125000 t waste fuels have to be used to replace 100000 t coal. This refers to 20 % more waste fuels used [81, Castle Cement UK, 2006].

In Austria between 1997 and 2004, the use of fossil fuels was constantly decreasing whereas the waste input increased from 19 % in 1997 to 47 % in 2004. The thermal energy demand first decreased from 3554 to 3481 MJ/t clinker in 2000. However, during the period 2000 to 2004 the fuel mix significantly changed (see Section 4.2.2.2, Table 4.21), with a significant decrease of coal (from 44.9 to 17.6 %) and, at the same time, a significant increase in using petcoke (from 3.2 to 16.0 %) and wastes, such as plastics (from 9.1 to 17.6 %) and other waste fuels (from 2.4 to 10.2 %) [92, Austria, 2006].

Furthermore, information regarding the examples of calorific values calculated for different types of waste treated and calculation examples for calorific values from waste can be found in the Reference Document on Best Available Techniques for Waste Incineration [57, European Commission, 2005].

The increase in the use of non-hazardous wastes is more significant than the increase in the use of hazardous wastes. This reflects societal evolution (increase in sewage sludge, animal meal, processed urban waste), as well as their increased focus on waste classification. With a thermal substitution rate of 17 % on average, which is as high as 100 % at times in some countries, considered that the use of wastes as fuels and raw materials in the clinker burning process is to be common practice. Out of the 6 million tonnes, about 10 % is biomass. Substitution rates of waste fuels used in EU-23+ countries are shown in Table 1.22 [74, CEMBUREAU, 2006], [75, Estonia, 2006], [76, Germany, 2006], [81, Castle Cement UK, 2006], [92, Austria, 2006], [107, Belgium, 2006], [112, Czech Republic, 2006].

Consumptions of different hazardous and non-hazardous wastes used as fuels for firing in EU-27 cement kilns are shown in Table 1.21 and Figure 1.22. The total consumption of waste fuels in EU-27 cement kilns increased from 2003 to 2004 [74, CEMBUREAU, 2006].

Types of waste fuels					
Group Nr.[1]	**Type of waste**	**Quantities in 1000 tonnes**			
		2003		**2004**	
		Hazardous	**Non-hazardous**	**Hazardous**	**Non-hazardous**
1	Wood, paper, cardboard	0.000	214.991	1.077	302.138
2	Textiles	0.000	19.301	0.000	8.660
3	Plastics	0.000	354.070	0.000	464.199
4	RDF	4.992	570.068	1.554	734.296
5	Rubber/tyres	0.000	699.388	0.000	810.320
6	Industrial sludge	52.080	161.660	49.597	197.720
7	Municipal sewage sludge	0.000	174.801	0.000	264.489
8	Animal meal, fats	0.000	1313.094	0.000	1285.074
9	Coal/carbon waste	1.890	137.213	7.489	137.013
10	Agricultural waste	0.000	73.861	0.000	69.058
11	Solid waste (impregnated sawdust)	164.931	271.453	149.916	305.558
12	Solvents and related waste	425.410	131.090	517.125	145.465
13	Oil and oily waste	325.265	181.743	313.489	196.383
14	Others	0.551	199.705	0.000	212.380
Total		975.119	4502.435	1040.247	5133.353
[1] Each grouping spans several EWC listings, see Table 4.1 in Section 4.2.1					

Table 1.21: Consumption of different types of waste used as fuels in EU-27 cement kilns in 2003 and 2004
[74, CEMBUREAU, 2006]

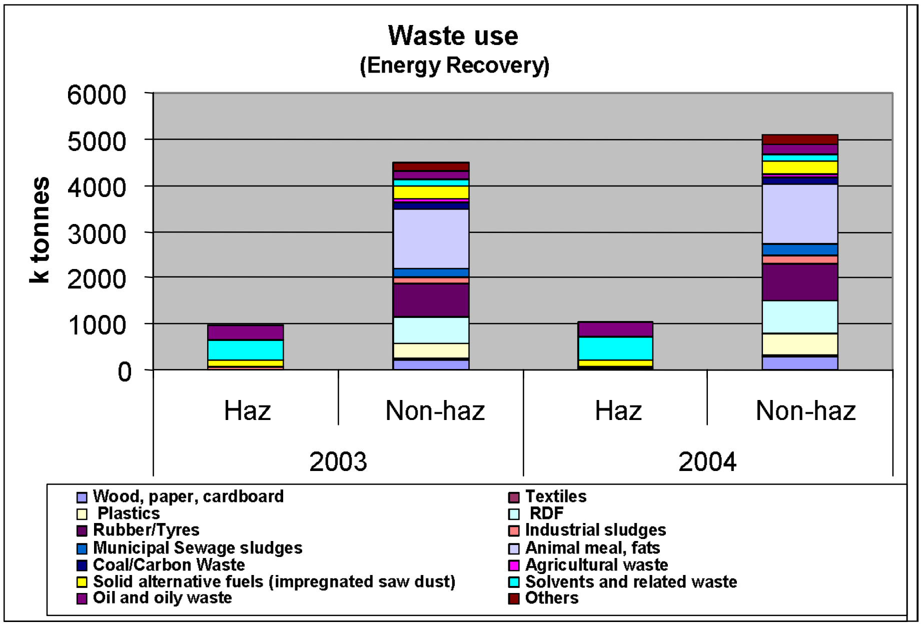


Figure 1.22: Consumption of different types of hazardous and non-hazardous waste used as fuel in cement kilns in the EU-27
[74, CEMBUREAU, 2006]

Country	Permitted capacities for waste fuels (t/yr)		Amount of waste fuels used (t/yr)		Percentage of heat release (%)			
					Hazardous waste		Non-hazardous waste	
	National range$^{1)}$	National average	National range$^{1)}$	National average	National range$^{1)}$	National average	National range$^{1)}$	National average
Austria$^{3)}$	10000 – 35000	-	9500 – 39000	30000	30 – 45	12	15 – 50	35
Belgium, Netherlands, Luxembourg	-	-	58500 – 402000	138930	0 – 25	11	21 – 30	24
Czech Republic	90000$^{2)}$	-	-	40000	0 – 40	15	0 – 100	37
Denmark, Finland, Sweden, Norway, Ireland	300000$^{2)}$	-	22000 – 120000	75000	2 – 20	15	24 – 35	32
Estonia, Latvia, Poland, Hungary	15000 – 380000	125000	8000 – 67369	27271	13.4 – 14	13.7	16 – 26.1	17.5
France	125000 – 265000	-	300 – 113000	37374	0 – 41.2	14	0.4 – 52	14.6
Germany	-	-	218157$^{2)}$	56857	0 – 25	5.2	76$^{2)}$	43.6
Greece, Portugal, Romania, Slovenia	20000–500000	20506	640 – 60000	9196	0 – 3.8	0.7	0.4 – 15.6	2
Italy	5000 – 115000	28000	5300 – 90600	13100	1.3 – 21	12	0.9 – 37	11.3
Spain	8800 – 100000	43000	2000 – 36000	15500	0 – 27.8	4.8	2 – 25	8.5
United Kingdom	25000 – 788400	182337	0 – 55960	24086	0 – 27.6	6	0 – 40	7.8

Note: Figures are aggregated from EU-23+ countries' replies
$^{1)}$ Minimum – maximum
$^{2)}$ Maximum
$^{3)}$ Only 2004 figures

Table 1.22: Substitution of waste fuels for cement production in EU-23+ countries
[168, TWG CLM, 2007], [178, CEMBUREAU, 2008]

1.3.4 Emissions to air

Emissions to air and noise emissions arise during the manufacture of cement. Furthermore with regard to the use of waste, odour can arise, e.g. from the storage and handling of waste (see Section 1.3.8). In this section, ranges of air pollutant emissions are presented for the process of cement production, including other process steps, such as the storage and handling of, e.g. raw materials, additives and fuels including waste fuels.

The IPPC Directive includes a general indicative list of the main air-polluting substances to be taken into account, if they are relevant for fixing emission limit values. Relevant to cement manufacture including the use of waste are:

- oxides of nitrogen (NO_x) and other nitrogen compounds
- sulphur dioxide (SO_2) and other sulphur compounds
- dust
- total organic compounds (TOC) including volatile organic compounds (VOC)
- polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDDs and PCDFs)
- metals and their compounds
- hydrogen fluoride (HF)
- hydrogen chloride (HCl)
- carbon monoxide (CO).

Not mentioned on the list, but considered to be relevant for cement production is carbon dioxide (CO_2). Regarding CO_2 emissions and the emissions trading scheme, general information can be found in the Directive 2003/87/EC of the European Parliament and the Council of 13 October 2003 establishing a scheme for greenhouse gas emissions allowance trading within the Community and amending Council Directive 96/61/EC [99, European Commission, 2003]. Furthermore, emissions of NH_3 may be considered to be relevant, especially when using secondary measures/techniques for NO_x reduction, e.g. SNCR.

The main emissions from the production of cement are emissions to air from the kiln system. These derive from the physico-chemical reactions involving the raw materials and the combustion of fuels. The main constituents of the exit gases from a cement kiln are nitrogen from the combustion air; CO_2 from calcination of $CaCO_3$ and combustion of fuel; water vapour from the combustion process and from the raw materials; and excess oxygen.

In all kiln systems, the solid material moves countercurrently to the hot combustion gases. This countercurrent flow affects the emissions of pollutants, since it acts as a built-in circulating fluidised bed. Many components that result from the combustion of the fuel or from the transformation of the raw material into clinker remain in the gas phase only until they are absorbed by, or condensed on, the raw material flowing countercurrently.

The adsorptive capacity of the material varies with its physico-chemical state. This, in turn, depends on its position within the kiln system. For instance, material leaving the calcination stage of a kiln process has a high calcium oxide content and therefore has a high absorptive capacity for acid species, such as HCl, HF and SO_2.

Emission data from kilns in operation is given in Table 1.23. The emissions ranges within which kilns operate depend largely on the nature of the raw materials; the fuels; the age and design of the plant; and also on the requirements laid down by the permitting authority. For example, the concentration of impurities and the behaviour of the limestone during firing/calcination can influence emissions, e.g. the variation of the sulphur content in the raw material plays an important role and has an effect on the range of the sulphur emissions in the exhaust gas.

Reported emissions from European cement kilns[1]			
Pollutant	**mg/Nm^3**	**kg/tonne clinker**	**tonnes/year**
NO_x (as NO_2)	145 – 2040	0.33 – 4.67	334 – 4670
SO_2	up to 4837[2]	up to 11.12	up to 11125
Dust	0.27 – 227[3]	0.00062 – 0.5221	0.62 – 522
CO	200 – 2000[4]	0.46 – 4.6	460 – 11500
CO_2	-	approx. 672 g/t_{cement}	1.5456 million
TOC/VOC	1 – 60[5]	0.0023 – 0.138	2.17 – 267
HF	0.009 – 1.0	0.021 – 2.3 g/t	0.21 – 23.0
HCL	0.02 – 20.0	0.046 – 46 g/t	0.046 – 46
PCDD/F	0.000012 – 0.27 ng I-TEQ/Nm^3	0.0276 – 627 ng/t	0.0000276 – 0.627 g/year
Metals[7]			
Hg	0 – 0.03[6]	0 – 69 mg/t	0 – 1311 kg/year
∑ (Cd, Tl)	0 – 0.68	0 – 1564 mg/t	0 – 1564 kg/year
∑ (As, Sb, Pb, Cr, Co, Cu, Mn, Ni, V)	0 – 4.0	0 – 9200 mg/t	0 – 9200 kg/year

[1] Mass figures are based on 2300 m^3/tonne clinker and one million tonnes clinker per year. Emissions ranges are yearly averages and are indicative values based on various measurement techniques. The reference O_2 content is normally 10 %

[2] Values from SO_2 measurements in the clean gas of 253 rotary kilns. 11 measurements are above the scale. Of these, 7 are of '0' substitution rate, 3 are '0 – 10', and one is 'above 40'. High SO_2 emissions are to be expected when the raw materials contain volatile sulphur compounds (e.g. pyrite). Indeed, these oxidisable compounds may be converted to SO_2 as early as in the upper cyclone stages. This SO_2 can be captured in the raw mill by the finely ground raw material

[3] The figures are values from continuous dust measurements in the clean gas of 253 rotary kilns. 8 measurements are above the scale. The emission levels largely depend on the state of the abatement equipment

[4] In some cases, CO emissions can be higher than 2000 mg/Nm^3 and up to 5000 mg/Nm^3 (11.5 kg/tonne clinker), e.g. due to NO_x reduction

[5] Daily average values from 120 measurements; only a few values range above 60 mg/Nm^3 (up to 122.6 mg/Nm^3 or 0.28 kg/tonne clinker)

[6] Collected from 306 spot measurements with an average value of 0.02 mg/Nm^3 and an upper value of 0.57 mg/Nm^3 (1311 mg/tonne clinker)

[7] '0' implies LOD=level of detection

Table 1.23: Data of emissions ranges from European cement kilns
[8, CEMBUREAU, 2001], [9, CEMBUREAU, 1997 November], [12, Netherlands, 1997], [19, Haugh, 2001], [29, Lohse, 2001], [97, CEMBUREAU, 2007], [168, TWG CLM, 2007]

Typical kiln exhaust gas volumes expressed as m^3/tonne of clinker (dry gas, 101.3 kPa, 273 K) are between 1700 and 2500 for all types of kilns [8, CEMBUREAU, 2001]. Suspension preheater and precalciner kiln systems normally have exhaust gas volumes of around 2300 m^3/tonne of clinker (dry gas, 101.3 kPa, 273 K).

There are also channelled emissions of dust from other sources, such as grinding (milling) and handling operations, raw materials, solid fuel and product. There is a potential for the diffuse emissions of dust from any outside storage of raw materials and solid fuels as well as from any materials transport systems, including cement product loading. The magnitude of these emissions can be significant if these aspects are not well engineered or maintained and being released at a low level can lead to local nuisance problems.

1.3.4.1 Dust (particulate matter)

1.3.4.1.1 Channelled dust emissions

Traditionally, the emissions of dust (PM), particularly from kiln stacks, have been one of the main environmental concerns in relation to cement manufacture. The main sources of dust emissions are the raw material preparation process (raw mills), grinding and drying units, the clinker burning process (kilns and clinker coolers), the fuel preparation and cement grinding unit (mills). Subsidiary processes of a cement plant lead to dust emissions, independent of whether waste is used or not, such as:

- crushing of raw materials
- raw material conveyors and elevators
- storage for raw materials and cement
- grinding mills for raw materials, cement and coal
- storage of fuels (petcoke, hard coal, lignite) and
- dispatch of cement (loading).

In all these processes, large volumes of gases flow through dusty materials. In cases like crushing, grinding and dispatch, equipment is kept under slight suction and these sources are normally equipped with fabric filters. The design and reliability of modern electrostatic precipitators and fabric filters ensure dust emissions can be reduced to levels where they cease to be significant; emission levels of below 10 mg/Nm^3 (daily average values) are achieved in 37 % of the reported installations. Examples of system types and the amount of filter dust and dust extraction are shown in Table 1.24.

Total dust emissions are continuously measured at 253 rotary kilns and spot dust measurements are collected from 180 rotary kilns, as shown in Figure 1.23 and Figure 1.24. These measurements are all taken from different plants located in EU-27 and EU-23+ countries (see Glossary). The thermal substitution is marked in this figure by using different colours. Most of the dust emissions range between 0.27 and less than 30 mg/Nm^3. Continuously measured emissions were reported as the annual average of 24 hour averages [97, CEMBUREAU, 2007]. Measured values relate to 1 m^3 of dry gas under standard conditions.

Furthermore, typical clean gas dust contents (daily average values) are attained by rotary kiln systems equipped with an ESP range of between <10 and 30 mg/Nm^3. After flue-gas abatement with fabric filters, reported dust emissions ranges from <10 to 20 mg/Nm^3, as a daily average value [92, Austria, 2006], [75, Estonia, 2006], [76, Germany, 2006], [90, Hungary, 2006], [112, Czech Republic, 2006].

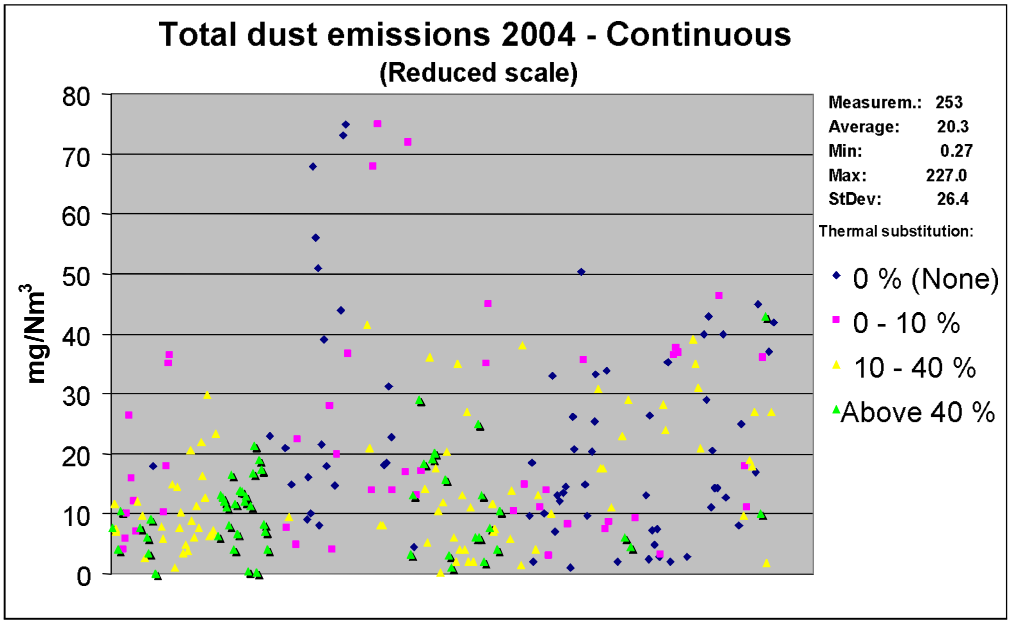


Figure 1.23: Ranges of emission values from continuous dust measurements in the clean gas from 253 rotary kilns in the EU-27 and EU 23+ countries
[97, CEMBUREAU, 2007]

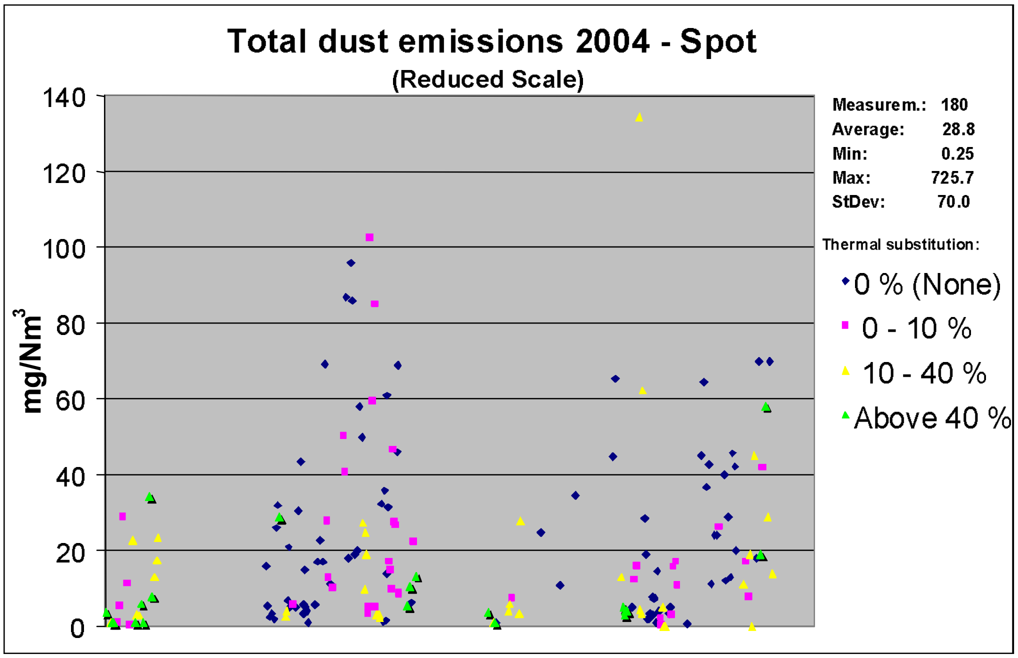


Figure 1.24: Dust emission values from 180 spot dust measurements in the clean gas of rotary kilns in the EU-27 and EU 23+ countries
[97, CEMBUREAU, 2007]

Table 1.24 shows examples of some types of ESPs and fabric filters. The values represent typical ranges and the values in brackets refer to extreme values that have been reported in some individual cases. The overview also shows an estimation of filter dust and dust extraction where applicable. Compound and direct operation are related to mill operations (mill on, mill off).

Types of systems and operational data for dust reduction			
Parameter	**Unit**	**ESPs**	**Fabric filters**
Year of construction		1962 – 2004	1999 – 2005
Pressure loss	hPa	1 – 8	(2)$^{1)}$ 10 – 12
Temperature	°C	90 – 190	90 – 160$^{2)}$
Electric energy demand	kWh/t clinker	1 – 4	0.1 – 0.2
Fan power demand	kWh/t clinker	0.15 – 1.2	1.5 – 1.8
Total energy demand	kWh/t clinker	1.15 – 5.2	1.6 – 2.0
Amount of filter dust and dust extraction			
Parameter	**Unit**	**Compound operation**	**Direct operation**
Amount of filter dust	kg/t clinker	54 – 144 (1718)$^{1)}$	(10 – 70)$^{1)}$ 80 – 200
Dust extraction	kg/t clinker	0 – 35	0 – 66 (165)$^{1)}$

$^{1)}$ Reference to extreme values that have been reported in some individual cases.
$^{2)}$ 240 °C was reported by using glass fibres with a PTFE membrane.

Table 1.24: Example of system types used for dust extraction, operational data and energy demand
[76, Germany, 2006], [103, CEMBUREAU, 2006]

In some cases, ESPs will have to be shut down during elevated CO levels in the flue-gases for safety reasons (CO trips). To preclude any operating trouble, elevated CO concentrations in exhaust gas and the resultant formation of explosive mixtures must be reliably ruled out. An automatic CO monitoring device needs to monitor the flue-gas continuously. During different phases of the kiln firing process as well as during shutdowns and start-ups of the kiln system, examples of CO trips were reported in different ranges and time periods. In Ireland in 2006, in some cases during CO trips dust emissions above 60 and up to 130 mg/Nm^3 (half hourly average values) have been reported with frequencies of between one to six times per month. Of these, ESP trip-outs of between 1 – 13 minutes/trip and a total duration of up to 184 minutes have been reported [159, Ireland, 2006]. However, frequencies of CO trips were minimised, e.g. at German cement plants, and examples of total duration ranges of between 1 and 29 minutes per year, respectively <0.001 – 0.009 % of the total kiln operation were reported as shown in Table 1.25.

Year	**Total duration**	
	(minutes)	**(% of total kiln operation time)**
2000	12	0.003
2001	29	0.009
2002	1	<0.001
2003	6	0.001
2004	5	0.001

Table 1.25: Examples of frequencies of CO trips in a German cement plant
[158, Germany, 2007]

1.3.4.1.2 Fine dust emissions PM_{10} and $PM_{2.5}$

Dust emissions of PM_{10} and $PM_{2.5}$ consist of fine particles with a grain size of less than 10 and less than 2.5 microns in diameter respectively which can arise in solid form or as aerosols. These types of fine dust may result from a series of physico-chemical reactions involving different precursor gases, such as nitrogen oxides and sulphur, and ammonia reacting to form sulphate, nitrate and ammonium particulate matter, and can cause human health problems. In the cement industry, PM_{10} and/or $PM_{2.5}$ may arise from the burning and cooling process; however, subsidiary processes (see Section 1.3.4.1.1) can also lead to fine dust formation.

Within the last few years, different measurement methodologies and sampling devices in combination with calculation models have been developed to determine and size segregate these very fine dust fractions and their distribution, e.g. on the basis of the dust total emissions measured from the flue-gas stream. An investigation from Germany shows that the major part of the total dust emissions is emitted as fine dust, independent of the concentration of the total dust in the waste gas. By applying electrostatic precipitators, approximately 90 % of the dust fraction is less than 10 µm (PM_{10}) and approximately 50 % less than 2.5 µm ($PM_{2.5}$), as examples from the cement industry show (see Table 1.26). Total dust emissions were measured with filter sampler measurements (plane filter device). Cascade impactors were used to withdraw dust under isokinetic conditions and to separate it into size segregated particulate fractions from the flue-gas stream. Furthermore, examples of fine dust fractions emitted from Irish cement plants can be found in Section 4.2.2.3. Hence a major part of the fine dust can be reduced by reduction of the total dust load. Plants equipped with high efficiency dedusting systems contribute relatively little to the fine dust burden [113, Ireland, 2007], [117, Germany, 2000].

Emissions source		**Total dust concentration1) (mg/Nm^3)**	**Fine dust fraction (%)**			**Fine dust concentration (mg/Nm^3)**		
			<2.5	**<10**	**>10**	**<2.5**	**<10**	**>10**
			µm					
Kiln (ESP)2)	Kiln flue-gas after ESP	15.4	51	87	13	7.9	13.4	2.9
Clinker cooler ESP)	Clinker cooler flue-gas after ESP	14.0	68	99	1	9.5	13.9	≤0.1
Cyclone preheater (ESP), direct mode3)	Kiln flue-gas after ESP	2.3	84	97	3	1.9	2.2	≤0.1
Cyclone preheater (ESP), combined mode4)	Kiln flue-gas after ESP	4.8	66	97	3	3.2	4.7	≤0.1

1) Total dust measured with filter sampler measurements (plane filter device), size segregation with cascade impactors
2) Lepol kiln, now shut down
3) Mill off
4) Mill on

Table 1.26: Investigation on fine dust distribution in total dust from German cement kilns [117, Germany, 2000]

Investigations from France show that PM_{10} and $PM_{2.5}$ represent 60 % of total particulate matter in the raw gas (before treatment), as shown in Table 1.27. Examples of dust reduction techniques along with reduction efficiencies from French cement plants can be found in Table 1.28.

Parameter	**Raw gas concentration**
Total particulate matter (TPM)	130 g/Nm^3
PM_{10}	42 % of TPM
$PM_{2.5}$	18 % of TPM

Table 1.27: Examples of raw gas concentrations of dust in French cement plants [172, France, 2007]

Technique	Reduction efficiency (%)		
	Total particulate matter	PM_{10}	$PM_{2.5}$
Cyclone	74.4	52.86	30
ESP 1	95.8	94.14	93
ESP 2	98.982	97.71	96
ESP 3	99.767	99.51	99
Fabric filter	99.784	99.51	99
Wet scrubber	98.982	97.71	96

Table 1.28: Examples of dust reduction techniques along with reduction efficiencies from French cement plants
[172, France, 2007]

1.3.4.1.3 Diffuse dust emissions

Diffuse dust emissions can arise during the storage and handling of materials and solid fuels, e.g. from open storage, conveyors of raw materials, and also from road surfaces because of road transport. Dust arising from packaging and dispatch of clinker/cement can also be significant. The impact of diffuse emissions can be a local increase in levels of dust, whereas process dust emissions (generally from high stacks) can have an impact on the air quality over a much larger area.

Conveyors and elevators are constructed as closed systems, if dust emissions are likely to be released from dusty material. Roads used by lorries are paved and cleaned periodically in order to avoid diffuse dust emissions. In addition, spraying with water at the installation site is used to avoid these emissions. Wherever possible, closed storage systems are used [76, Germany, 2006].

1.3.4.2 Nitrogen oxides

The clinker burning process is a high temperature process resulting in the formation of nitrogen oxides (NO_X). These oxides are of major significance with respect to air pollution from cement manufacturing plants. They are formed during the combustion process either by a combination of fuel nitrogen with oxygen within the flame or by a combination of atmospheric nitrogen and oxygen in the combustion air.

There are two main sources for the production of NO_X:

- thermal NO_X:
  - part of the nitrogen in the combustion air reacts with oxygen to form various oxides of nitrogen
  - is the major mechanism of nitrogen oxide formation in the kiln flame
- fuel NO_X:
  - compounds containing nitrogen, chemically bound in the fuel, react with oxygen in the air to form various oxides of nitrogen.

Nevertheless, some slight changes in the NO_X emissions while using wastes may be observed:

- NO_X from primary firing can be lower if waste fuels include water or require more oxygen (impact on the flame temperature, which is lowered). The effect is comparable to flame cooling
- NO_X from secondary/precalciner firing can be lower if coarse fuel creates a reducing zone [97, CEMBUREAU, 2007].

Furthermore, NO_x may also be formed by the oxidisation of NH_3, if this is injected for NO_x reduction into an inadequate temperature zone of the kiln.

Thermal NO_x forms at temperatures above 1050 °C. For reasons of clinker quality, the burning process takes place under oxidising conditions, under which the partial oxidation of the molecular nitrogen in the combustion air results in the formation of nitrogen monoxide. Thermal NO_x is produced mainly in the kiln burning zone where it is hot enough to achieve this reaction. The amount of thermal NO_x produced in the burning zone is related to both burning zone temperature and oxygen content (air excess factor). The rate of reaction for thermal NO_x increases with temperature; therefore, hard-to-burn mixes which require hotter burning zones will tend to generate more thermal NO_x than kilns with easier burning mixes. The rate of reaction also increases with increasing oxygen content (air excess factor). Running the same kiln with a higher back-end oxygen content (air excess factor) will result in a higher thermal NO_x generation in the burning zone (although emissions of SO_2 and/or CO may decrease).

NO and NO_2 are the dominant nitrogen oxides in cement kiln exhaust gases. Fuel NO_x from nitrogen compounds in fuel is of lower importance. In cement rotary kiln systems, formation of fuel NO (nitrogen monoxide) in the area of the main firing is insignificant. NO_x emissions from a cement kiln are normally related to the airborne nitrogen rather than by the fuel fired. Nitrogen monoxide (NO) accounts for about 95 % and nitrogen dioxide (NO_2) for about 5 % of nitrogen oxides present in the exhaust gas of rotary kiln plants [76, Germany, 2006], [92, Austria, 2006], [97, CEMBUREAU, 2007]. Fuel NO_x is generated by the combustion of the nitrogen present in the fuel at the lower temperatures prevailing in a secondary firing unit. Nitrogen in the fuel either combines with other nitrogen atoms to form N_2 gas or reacts with oxygen to form fuel NO_x. In a precalciner, the prevailing temperature is in the range of 850 – 950 °C, which is not high enough to form significant thermal NO_x, but fuel NO_x will occur. Similarly, other types of secondary firing of fuel in the back-end of a kiln system, such as in the kiln riser pipe of a suspension preheater kiln or the calcining chamber of a preheater grate, may give rise to fuel NO_x. Therefore, in precalciner kilns, where up to 60 % of the fuel can be burned in the calciner, fuel NO_x formation significantly contributes to the total NO_x emissions. The thermal NO_x formation in these kilns is much lower when compared to kilns where all the fuel is burned in the sintering zone.

The NO_x emissions vary depending on which kiln process is used. Besides temperature and oxygen content (air excess factor), NO_x formation can be influenced by flame shape and temperature, combustion chamber geometry, the reactivity and nitrogen content of the fuel, the presence of moisture, the available reaction time and burner design.

On a yearly average, the European cement kilns emit about 785 mg NO_x/Nm^3 (expressed as NO_2) with a minimum of 145 mg/Nm^3 and a maximum of 2040 mg/Nm^3. In 2004, example data of NO_x emissions were collected from different plants located in several EU-27 and EU-23+ countries (see Glossary) and categorised by the thermal substitution rate as shown in Figure 1.25 and Figure 1.26. Continuously measured emissions were reported as the annual average of 24 hour averages. Measured values relate to one m^3 of dry gas under standard conditions [94, European Commission, 2004], [97, CEMBUREAU, 2007].

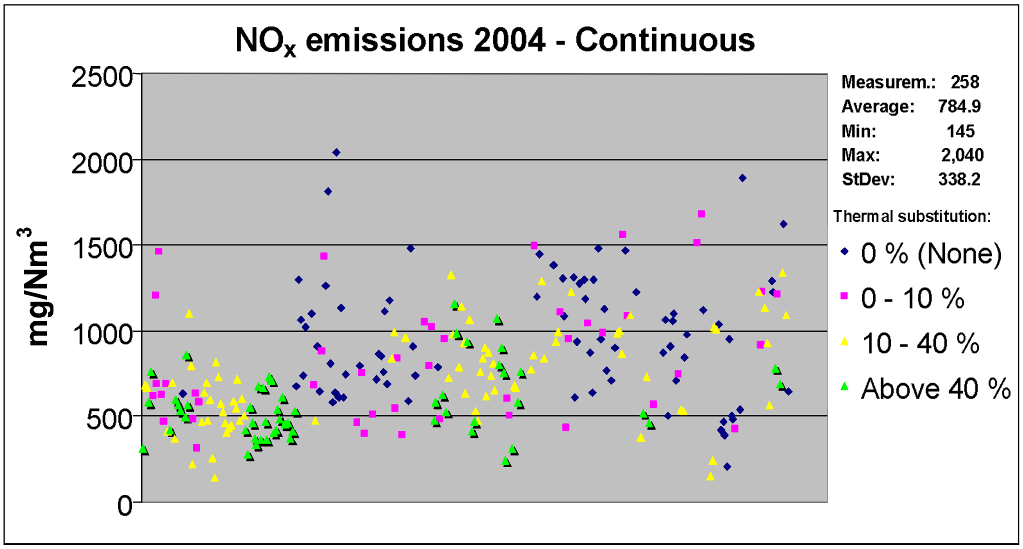


Figure 1.25: NO$_x$ emissions (expressed as NO$_2$) from cement kilns in the EU-27 and EU-23+ countries in 2004 categorised by substitution rate
[97, CEMBUREAU, 2007]

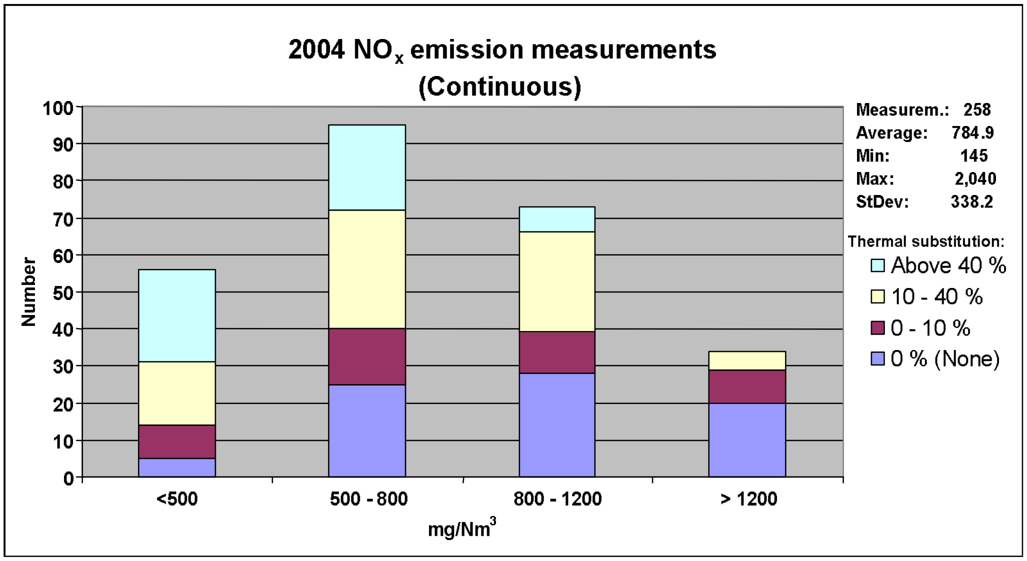


Figure 1.26: Distribution of measurements categorised by the thermal substitution rate of NO$_x$ levels
[97, CEMBUREAU, 2007]

In Austria, the yearly average of NO$_x$ emissions in 2004 was 645 mg/Nm^3 (yearly mean average, based on continuous measurement, standard conditions) and these values varied from 313 – 795 mg NO$_x$/Nm^3, measured as yearly average values. The highest and the lowest ranges were measured at different plants. All Austrian kilns use primary measures/techniques, three kilns have flame cooling, two kilns have staged combustion and five kilns are equipped with the SNCR technique, of which two are in a pilot phase. In 2007, all Austrian cement kilns were equipped with SNCR [92, Austria, 2006].

In Germany in 2006, eight kilns were operated with the staged combustion technique while 34 kilns used the SNCR technique for NO_x reduction. Ranges of NO_x emissions concentrations of 200 – 800 mg/Nm^3 as yearly average values were measured in the clean gas from 43 rotary kilns. Since 2007 due to national legislation, German cement kilns have to keep a NO_x emission limit of at least 500 mg/Nm^3. Most SNCR installations operating in Germany are designed and/or operated for NO_x reduction rates of 10 – 50 % and NO_x emission levels of below 500 mg/Nm^3. In combination with process-integrated measures/techniques, emission values of between 200 – 500 mg/Nm^3 as a daily average value are achieved depending on the individual emission limit value determined in the permit [76, Germany, 2006], [168, TWG CLM, 2007], [173, Germany, 2007].

In Sweden, the high efficiency SNCR technique has been in operation since 1997 in three cement kilns. Since then, the long term NO_x emissions have been around 200 mg/Nm^3. The yearly average value in 2004 was 221 mg/Nm^3, while monthly average values range from 154 to 226 mg/Nm^3. The NO_x load is between 130 and 915 t/yr [114, Sweden, 2006].

NO_x emissions in Finnish cement plants range between 500 and 1200 mg/Nm^3 measured as a yearly average value [63, Finland, 2006]. In the Czech Republic, NO_x emissions in a range of 400 to 800 mg/Nm^3 have been measured [112, Czech Republic, 2006]. In France in 2001, the average measure of NO_x emissions from 33 cement plants was 666 mg/Nm^3 [116, France, 2002]. On a wet long cement kiln in Denmark, SNCR is applied and with a reduction efficiency of 40 – 50 % a NO_x emission level of <800 mg/Nm^3 were reported [182, TWG CLM, 2008]

For white cement production, some raw materials have difficulties in becoming clinker during the firing process and they need higher flame temperatures, depending on their crystallography or mineralogy. One special case is that of white clinker, where the absence of fusing metals leads to clinker temperatures of about 150 °C higher than for grey clinker. Higher flame temperatures also lead to higher thermal NO_x formation [120, Spain, 2007].

Techniques for NO_x reduction in the cement industry are described in Section 1.4.5.1. Furthermore, the in 2008 known numbers of full scale installations with NO_x abatement techniques in the EU-27 and EU-23+ countries are presented in Table 1.33 in Section 1.4.5.1.

Flame cooling is used for NO_x reduction. Reduction rates/efficiencies from 10 – 35 % have been reported. Reported emissions ranges which have been achieved by using flame cooling are shown in Figure 1.27. A level of less than 500 mg/Nm^3 was achieved from two plants, emissions ranges of 500 – 800 mg/Nm^3 were achieved by seven plants, and ranges of 800 - 1000 mg/Nm^3 were achieved by 11 plants (yearly average values). In comparison to these emissions ranges achieved by several plants, Figure 1.28 shows the NO_x emissions ranges which were achieved by several cement plants without applying flame cooling. Just a small numbers of plants achieve the lower NO_x emissions range.

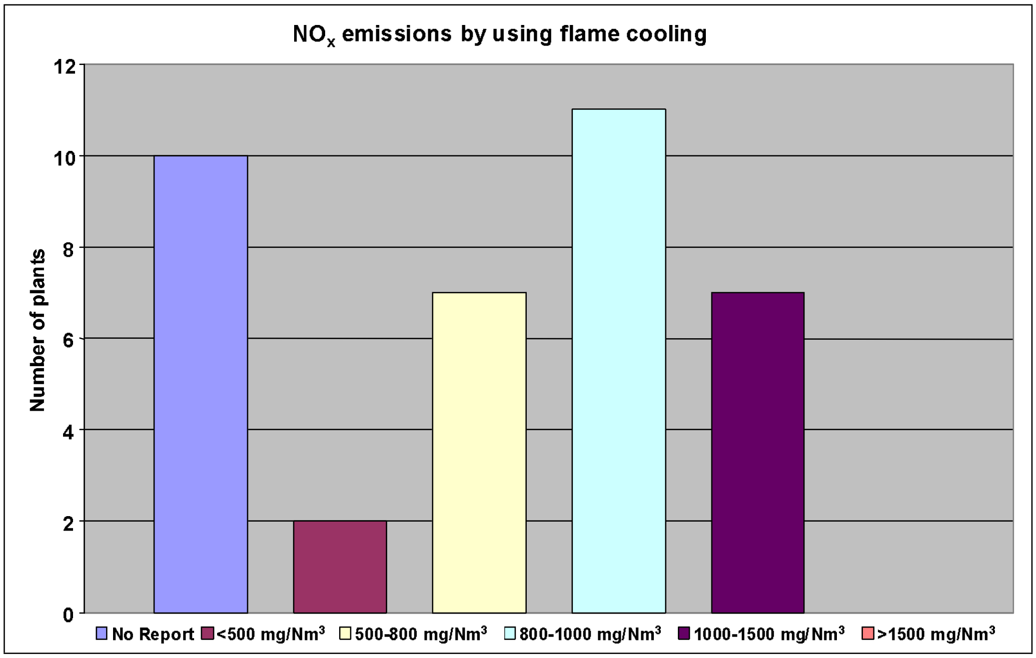


Figure 1.27: **Achieved NO$_x$ emissions ranges by using flame cooling in several cement plants in the EU-23+**
[85, CEMBUREAU, 2006]

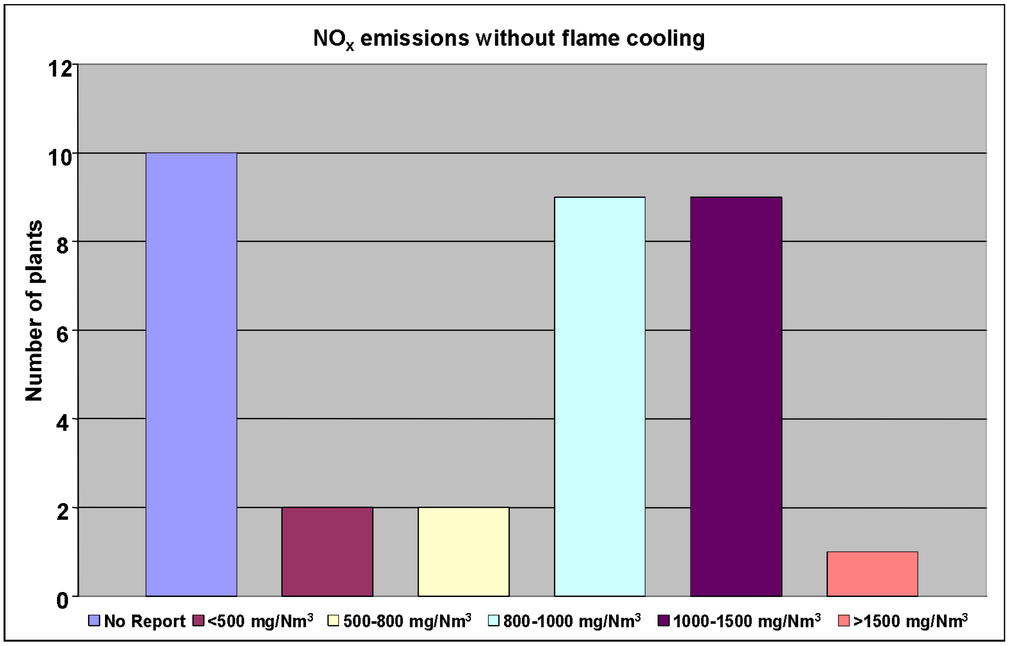


Figure 1.28: **Achieved NO$_x$ emissions ranges from several cement plant in the EU-23+ not using flame cooling**
[85, CEMBUREAU, 2006]

As shown in Figure 1.29 and Figure 1.30, the use of SNCR for NO$_x$ reduction in cement plants reduces the achieved NO$_x$ emissions range in comparison to cement plants not using SNCR technique (yearly average values).

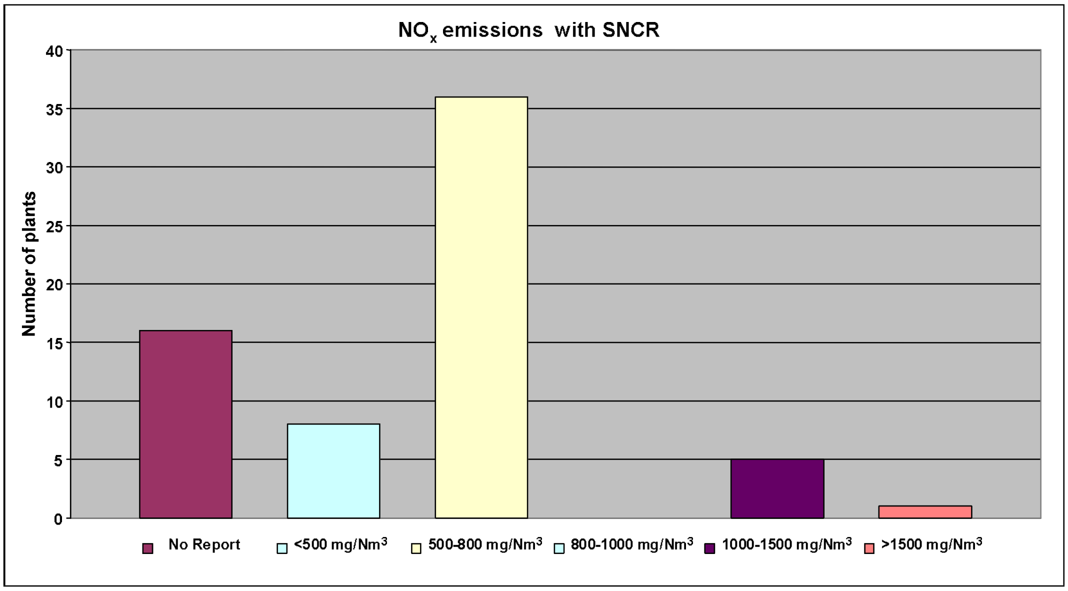


Figure 1.29: NO$_x$ emissions achieved by several cement plants using SNCR for NO$_x$ reduction [85, CEMBUREAU, 2006]

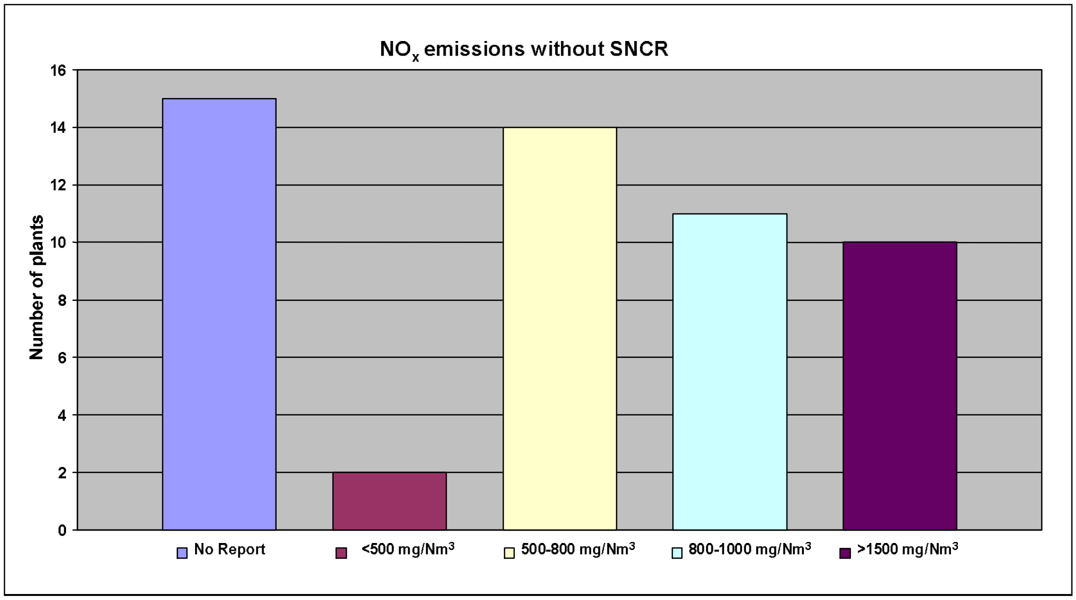


Figure 1.30: NO$_x$ emissions ranges achieved by several cement plants without using SNCR [85, CEMBUREAU, 2006]

1.3.4.3 Sulphur dioxide

SO_2 emissions from cement plants depend on the total input of sulphur compounds and the type of process used, and are primarily determined by the content of the volatile sulphur in the raw materials and possibly by the fuels. The production and potential emissions of SO_x also depend on the sulphur circulation which occurs in the kiln system. The sulphur is emitted from different outputs of the kiln system, such as SO_2 in the exhaust gases, $CaSO_4$ and other combined compounds in the clinker and the dust. However, the greater part of the sulphur is incorporated in the clinker or discharged from the system by the process.

Depending on their respective deposits, the raw materials may contain sulphur bound as sulphate or sulphide. Sulphates are stable compounds which are only partly thermally decomposed at the high temperatures prevailing in the sintering zone of rotary kiln systems, which may be increased by localised reducing conditions, and the combustion of fuels and wastes. Consequently, sulphur present in sulphate form is more or less completely discharged from the kiln system with the clinker when the clinker quality enables this to happen. Sulphides, by contrast, are oxidised in the preheater and partly emitted in the form of sulphur dioxides.

Sulphur introduced into the kiln system with the fuels is oxidised to SO_2 and will not lead to significant SO_2 emissions, due to the strong alkaline nature in the sintering zone, the calcination zone and in the lower stage of the preheater. This sulphur enters the calcining zone of the kiln system together with the minor concentrations of SO_2 resulting from partial sulphate decomposition in the sintering zone. In the calcining zone, SO_2 reacts among other things (inter alia) with alkalis and alkali sulphates originating from the raw materials. On contact with the partly decarbonated raw meal, the excess SO_2 is first reacted to $CaSO_3$ and then to $CaSO_4$. These sulphates once again enter the rotary kiln. In this way, sulphur cycles are created, which are at equilibrium with the sulphur discharged via the clinker (Figure 1.31).

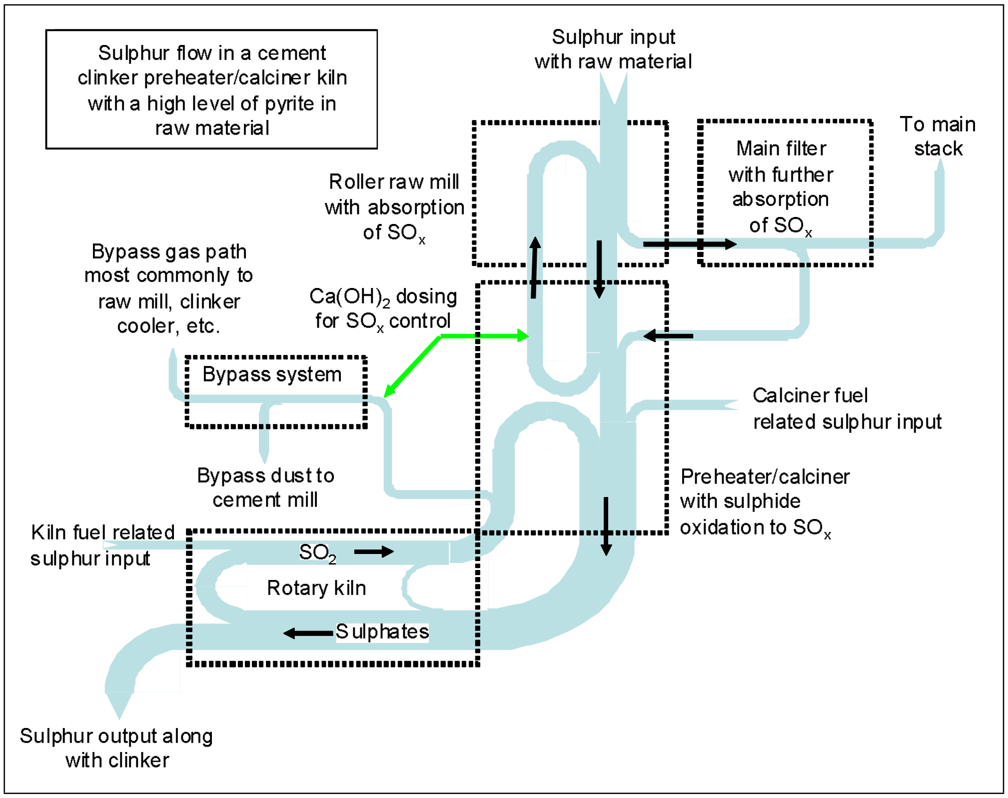


Figure 1.31: Sulphur flow diagram in a cement preheater/precalciner kiln [97, CEMBUREAU, 2007]

The calcining area of a rotary kiln offers ideal conditions for SO_2 capture from the kiln exhaust gases. SO_2 emissions may, however, occur when the operating conditions of the kiln system, e.g. the oxygen concentration in the rotary kiln, have not been optimised for SO_2 capture. Furthermore, various factors may influence the efficiency of the reaction, such as temperature, moisture content, the retention time of the gas, the concentration of oxides in the gaseous phase, the availability of solid surface area, etc. [60, VDI 2094 Germany, 2003], [76, Germany, 2006], [86, EURITS, 2006], [97, CEMBUREAU, 2007].

Elevated SO_2 emissions are to be expected when raw materials containing organic sulphur, and in particular when raw material-borne sulphur is present in a readily oxidisable form, e.g. as pyrite or marcasite. In contrast with the sulphatic raw material components, these readily oxidisable compounds may be converted to SO_2 as early as in the upper cyclone stages.
Under these conditions, raw material-related SO_2 emissions concentrations may be as high as 1.2 g/Nm^3 and in individual cases, even higher, if no secondary emissions control measures/techniques are provided.

However, kilns that use raw materials with little or no volatile sulphur have few problems with SO_2 emissions and emissions concentrations in the flue-gas are below 10 mg/Nm^3 without abatement at some kilns, the SO_2 emissions concentration increases with increased levels of volatile sulphur in the used raw material.

By using secondary control measures/techniques, e.g. utilisation of lime hydrate, the SO_2 emissions can significantly be reduced. Figure 1.32 shows values of SO_2 measurements in the clean gas from cement plants in the EU-25 [97, CEMBUREAU, 2007].

SO_2 is the main (99 %) sulphur compound to be emitted, although some SO_3 is produced and, under reducing conditions, H_2S could be evolved. Sulphur in the raw material occurring as sulphides and organically combined sulphur will evaporate, and 30 % or more may be emitted from the first stage of a preheater.

In contrast to the calcining area, 40 to 85 % of the SO_2 formed is recaptured in the preheater. Apart from the water vapour content of the kiln exhaust gases, the key influencing parameters for SO_2 capture by the $CaCO_3$ in the cyclone preheater are the raw gas dust content and in particular, the raw gas oxygen concentration in the uppermost cyclone stage. The excess oxygen (1 to 3 % O_2 maintained in the kiln for satisfactory cement product quality) will normally immediately oxidise any released sulphide compounds to SO_2. In long kilns the contact between SO_2 and alkaline material is not so good, and sulphur in the fuels, such as waste fuels, can lead to significant SO_2 emissions.

At approximately 10 %, SO_2 capture in the gas conditioning tower/evaporation cooler is relatively low. In the grinding-drying unit, by contrast, material comminution continuously exposes new, highly active particle surfaces which are available for SO_2 capture. The drying process ensures that the gas atmosphere is always enriched with water vapour improving absorption. Experience with plants operating in the compound mode has shown that between 20 and 70 % SO_2 can be captured in the raw mill. Factors influencing SO_2 capture include the raw material moisture, the mill temperature, the retention time in the mill as well as the fineness of the ground material. Thus, it is important that raw milling is optimised so that the raw mill can be operated to act as SO_2 abatement for the kiln [60, VDI 2094 Germany, 2003], [76, Germany, 2006], [86, EURITS, 2006], [97, CEMBUREAU, 2007].

Despite the fact that most sulphur remains in the clinker as sulphate, SO_2 emissions can be significant from raw materials with a high volatile sulphur content and can be regarded as a major pollutant.

Deviation from regular operating conditions

Events deviating from regular operating conditions lead to an increase of SO_2 emissions, such as combustion carried out under reducing conditions that curtails sulphur incorporation efficiency:

- incomplete combustion in the precalciner or coarse waste fuels are not properly burned in the back-end of the kiln
- an excessively hot burning zone which may occur in kilns burning fuel mix which have a very hard burnability
- excess of sulphur via alkalis in the kiln charge
- extreme levels of sulphur recirculation between the kiln and the preheater stages.

In 2004, example data of SO_2 emissions were collected from different plants located in several EU-27 and EU-23 countries (see Glossary). Continuously measured emissions were reported as the yearly average of 24 hour averages. Measured values relate to 1 m^3 of dry gas under standard conditions. Values of SO_2 measurements in the clean gas were collected from 253 rotary kilns. 11 measurements were above the scale. Of these, seven were of zero substitution rate, three were between 0 and 10 and one of them was above 40, as shown in Figure 1.32 [97, CEMBUREAU, 2007]. However, raw gas concentration ranges of 1400 – 1700 mg/Nm^3 with peaks of up to 3000 mg/Nm^3 have been found in a Swiss cement plant [86, EURITS, 2006].

A large proportion of SO_2 is absorbed and locked into the cement clinker and the cement kiln dust (CKD) as also shown in Figure 1.32. The use of waste fuels does not have an influence on the total SO_2 emissions. In long rotary kilns, the contact between SO_x and alkaline materials is less efficient and sulphur in the fuels might lead to SO_x emissions.

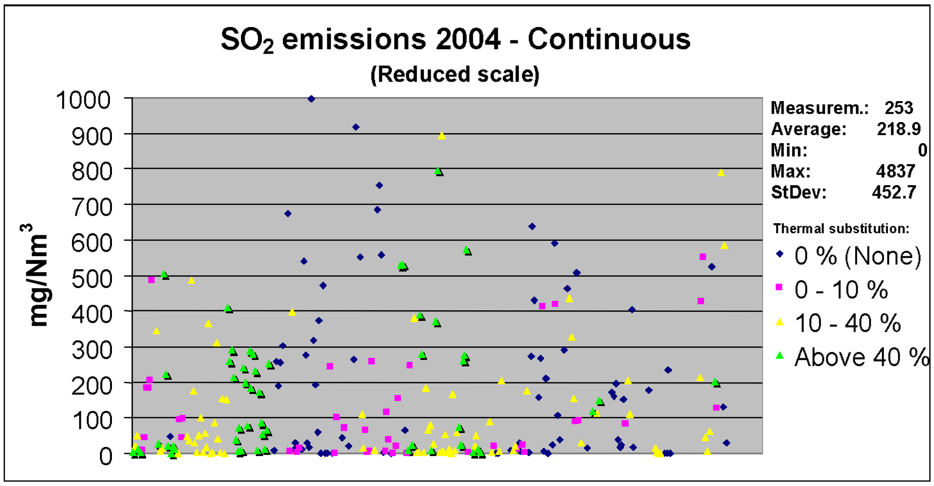


Figure 1.32: Values of SO_2 measurements in the clean gas from cement plants in the EU-27 and EU-23+ countries
[97, CEMBUREAU, 2007]

The categorisation and distribution of these SO_2 emissions is shown in Figure 1.33 [97, CEMBUREAU, 2007].

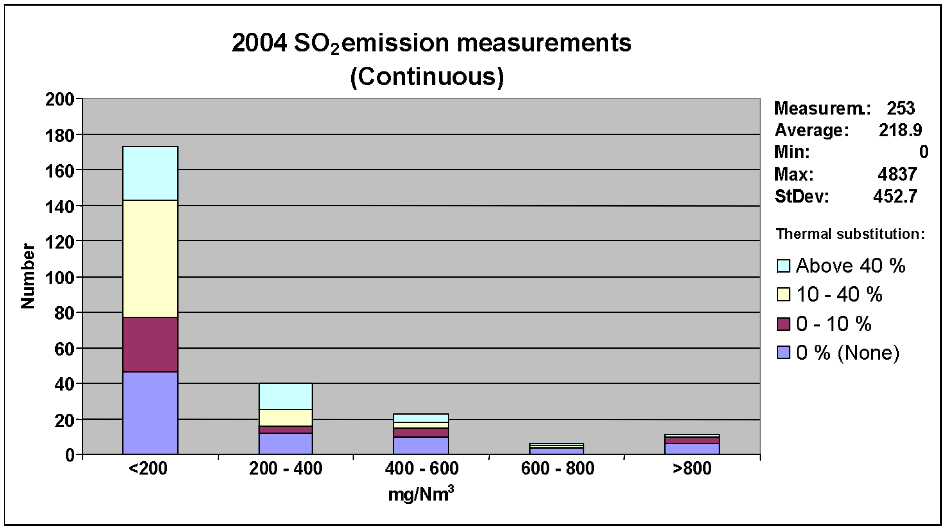


Figure 1.33: Distribution of measurements categorised by the thermal substitution rate of SO_2 levels
[97, CEMBUREAU, 2007]

In the case of white cement manufacture, different conditions and their combination might lead, in specific cases, to significantly lower ability for fuel sulphur retention in the clinker, and thus, to higher SO_2 emissions. These conditions are the following:

- hard burnability of raw meal
- low alkali content of the kiln feed because of the high purity of raw materials
- kiln conditions, such as a generally reducing atmosphere
- kiln configuration: Lepol kilns are common and in modern preheater kilns, the number of cyclones can be limited by the chemical composition of the raw material (alkalis-sulphur balance [120, Spain, 2007].

1.3.4.4 Carbon oxides (CO_2, CO)

1.3.4.4.1 Carbon dioxide (CO_2)

The emissions of CO_2 are estimated to be 900 to 1000 kg/tonne grey clinker, related to a specific heat demand of approximately 3500 to 5000 MJ/tonne clinker, but this also depends on fuel type. Due to cement grinding with mineral additions, the emissions of CO_2 are reduced when related to tonnes of cement (compare with Figure 1.19). Approximately 62 % originates in the calcining process and the remaining 38 % is related to fuel combustion. The CO_2 emissions resulting from the combustion of the carbon content of the fuel is directly proportional to the specific heat demand as well as the ratio of the carbon content to the calorific value of the fuel. Emissions of combustion CO_2 have progressively reduced, with a reduction of about 30 % in the last 25 years being accomplished mainly by the adoption of more fuel efficient kiln processes.

Regarding CO_2 emissions and the emissions trading scheme, information can be found in Directive 2003/87/EC of the European Parliament and the Council of 13 October 2003 establishing a scheme for greenhouse gas emissions allowance trading within the Community and amending Council Directive 96/61/EC as well as from the European Commission's Decision of 29 January 2004 (2004/156/EC), establishing guidelines for the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council [99, European Commission, 2003]. Furthermore, information regarding monitoring and reporting of greenhouse gas emissions under the Emissions Trading scheme Directive can be found in Europeans Commission Decision of 29 January 2004 (2004/156/EC) [122, European Commission, 2004].

1.3.4.4.2 Carbon monoxide (CO)

The emissions of CO and organically bound carbon during the clinker burning process are caused normally by the small quantities of organic constituents input via the natural raw materials (remnants of organisms and plants incorporated in the rock in the course of geological history). These are converted during kiln feed preheating and become oxidised to form CO and CO_2. In this process, small portions of organic trace gases, such as total organic carbon, are formed as well. In the case of the clinker burning process, the content of CO and organic trace gases in the clean gas therefore do not allow any conclusions on combustion conditions.

However, additional CO emissions may also result from poor combustion and improper burning conditions in the secondary firing. On the other hand, it has to be pointed out that such an increase in the CO emissions rate coincides with a decrease in the NO_x emissions. However, the reducing conditions may have a positive effect on SO_x emissions.

In energy conversion plants, such as power stations, the exhaust gas concentrations of CO and organically bound carbon are a yardstick for the burnout rate of the fuels. By contrast, the clinker burning process is a material conversion process that must always be operated with excess air for reasons of clinker quality. Together with long residence times in the high temperature range, this leads to complete fuel burn up [76, Germany, 2006].

Depending on the raw material deposit, between 1.5 and 6 g of organic carbon per kg clinker are brought into the process with the natural raw material. Tests using raw meals of various origins showed that between 85 – 95 % of the organic compounds in the raw material are converted to CO_2 in the presence of 3 % oxygen, but at the same time 5 – 15 % are converted to CO. The proportion emitted as volatile organic carbon compounds (VOC) under these conditions is well below 1 %. The CO concentration can be as high as 1000 mg/Nm^3, exceeding 2000 mg/Nm^3 or can even be higher than 5000 mg/Nm^3 in some cases as shown in Figure 1.34. However, most examples of these CO emissions concentration values continuously measured from 29 German rotary kilns are in the range of between 200 and 2200 mg/Nm^3 as the yearly average value (CO detection limit 1.8 – 2.5 mg/Nm^3) [9, CEMBUREAU, 1997 November], [76, Germany, 2006], [168, TWG CLM, 2007]. Good hopper, transport conveyor and feeder design are essential to ensure that the feed rate of solid fuel is steady with minimal peaks. Otherwise, substoichiometric combustion may occur which can lead to short term peaks of greater than 0.5 % CO. These cause the additional problem that any ESP abatement will have to be switched off automatically to avoid explosion.

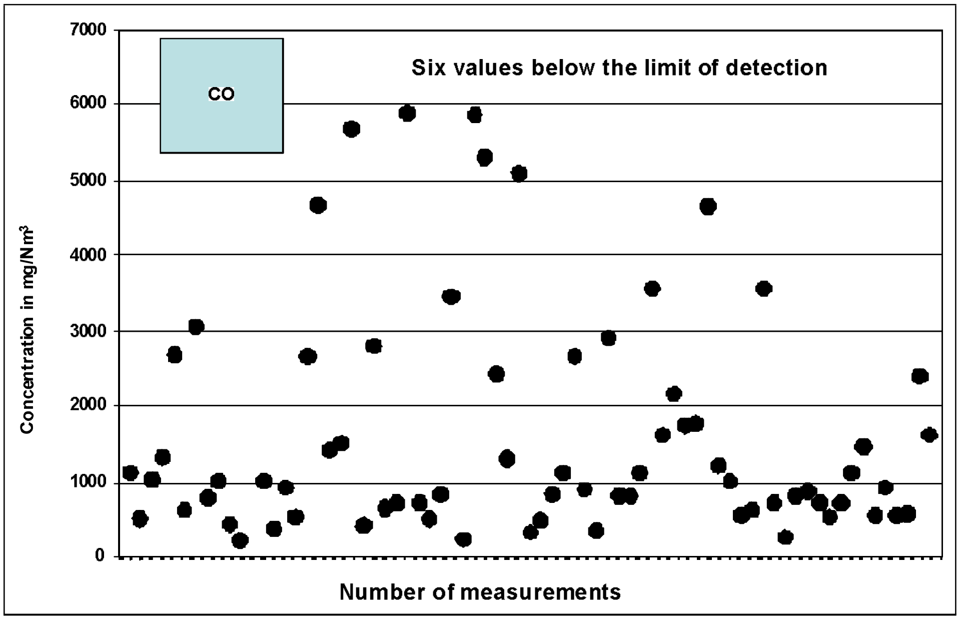


Figure 1.34: CO emissions concentration values measured in the clean gas from 29 German rotary kilns in 2004
[76, Germany, 2006]

1.3.4.5 Total organic compounds (TOC)

In heat (combustion) processes in general, the occurrence of volatile organic compounds (and carbon monoxide) is often associated with incomplete combustion. In cement kilns, the emissions will be low under normal steady-state conditions, due to the type of kiln used, the large residence time of the gases in the kiln, the high temperature, the nature of the flame (2000 °C) and the excess oxygen conditions. These are process conditions where the organic compounds are decomposed and destroyed with a high efficiency rate (>99.9999 %) [86, EURITS, 2006], [97, CEMBUREAU, 2007]. Concentrations may increase during start-up or abnormal operating (upset) conditions. These events can occur with varying frequency, for example between once or twice per week to once per two or three months.

Emissions of volatile organic compounds (VOCs) can occur in the primary steps of the process (preheater, precalciner), when organic matter that is present in the raw meal, is volatilised as the feed is heated. The organic matter is released between temperatures of 400 and 600 °C. The VOC content of the exhaust gas from cement kilns typically lies between 1 and 80 mg/Nm^3, measured as TOC, as shown in Figure 1.35. However, in rare cases emissions can reach 120 mg/Nm^3 because of the raw material characteristics. In 2004, example data of TOC emissions were collected from different plants located in several EU-27 and EU-23+ countries (see Glossary). Values from continuous TOC measurements in the clean gas were collected from 120 rotary kilns and the distribution of these measurements were also categorised in thermal substitution as TOC levels, as shown in Figure 1.35 and Figure 1.36. Continuously measured emissions were reported as the annual average of 24 hour averages. Measured values relate to 1 Nm^3 of dry gas under standard conditions [9, CEMBUREAU, 1997 November], [97, CEMBUREAU, 2007]. Continuous measurements from 27 German rotary kilns show examples of carbon emissions concentration values of up to 75 mg/Nm^3, (yearly average value), as shown in Figure 1.37. The majority of the measurements range below 30 mg/Nm^3 (yearly average value) (detection limit 1.5 – 2.1 mg/Nm^3) [76, Germany, 2006].

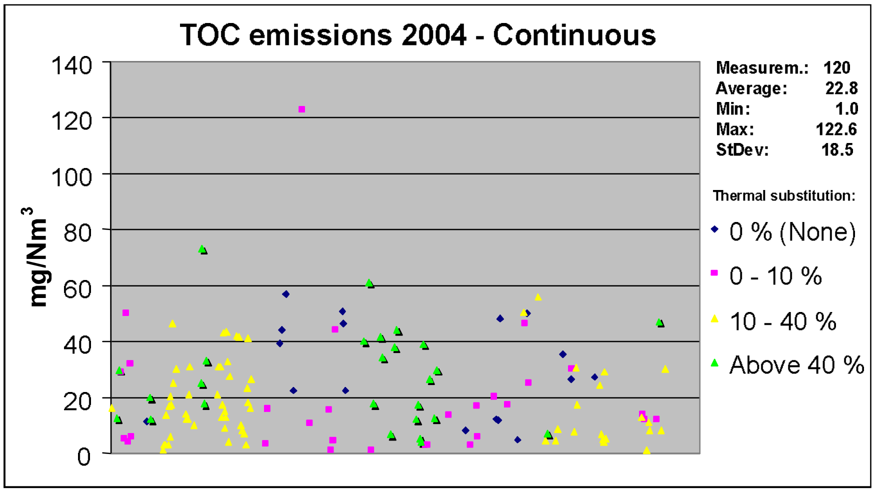


Figure 1.35: TOC emission values from continuous measurements in the clean gas of cement kilns in the EU-27 and EU-23+ countries
[97, CEMBUREAU, 2007]

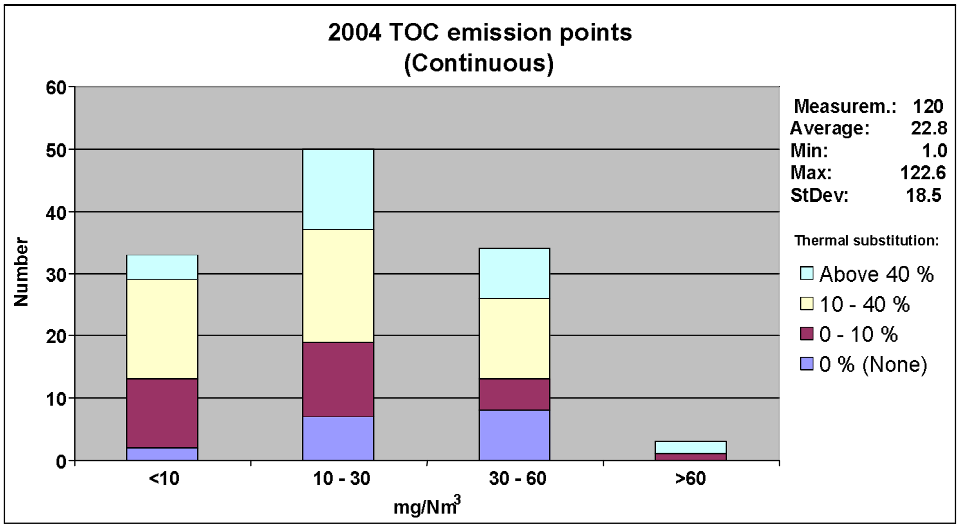


Figure 1.36: Distribution of continuous measurements categorised by the thermal substitution rate of TOC levels
[97, CEMBUREAU, 2007]

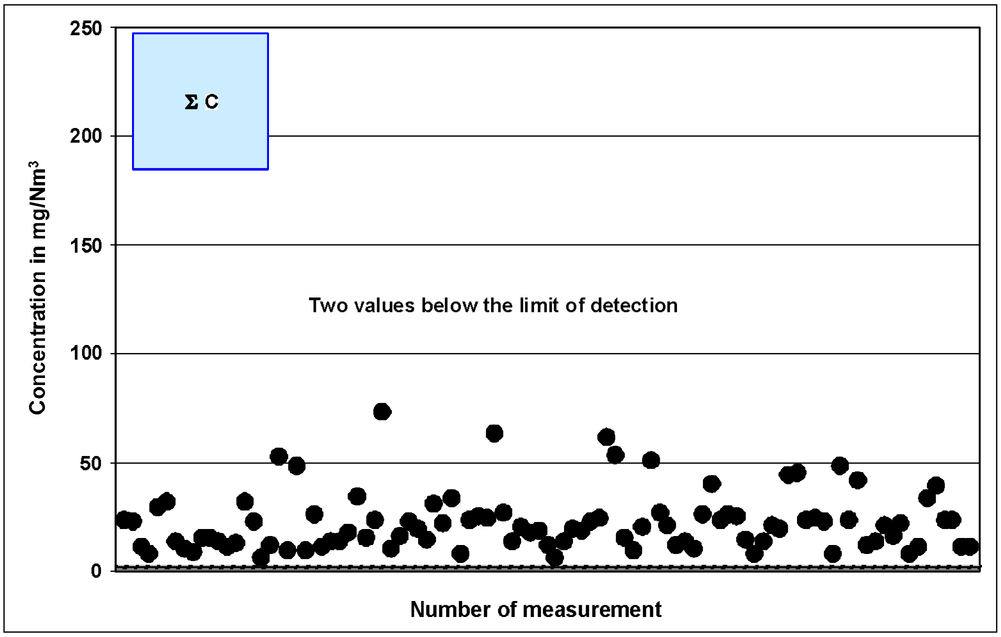


Figure 1.37: **Total organic carbon emissions concentration values measured in the clean gas from 27 German rotary kilns in 2004**
[76, Germany, 2006]

1.3.4.6 Polychlorinated dibenzo-p-dioxins (PCDD) and dibenzofurans (PCDF)

PCDD/F can result from a combination of formation mechanisms, depending on kiln and process design, combustion conditions, feed characteristics and the type and operation of emissions control equipment. Furthermore, any chlorine input in the presence of organic material may potentially cause the formation of PCDD and PCDF in heat (combustion) processes. PCDD/F can be formed in/after the preheater and in the air pollution control device if chlorine and hydrocarbon precursors from the raw materials are available in sufficient quantities (see also Section 1.2.4). However, formation of PCDD/F and their subsequent emissions require the simultaneous presence of five factors:

- hydrocarbons
- chlorides
- a catalyst:
  - some reports suggest that Cu^{2+} (and Fe^{2+}) have a catalytic effect
- an appropriate temperature window:
  - between 200 and 450 °C with a maximum at 300 – 325 °C
- a long retention time in the appropriate temperature window.

In addition, molecular oxygen has to be present in the gas stream. The formation rate increases with oxygen concentration by a reaction order of 0.5.

As mentioned above, the reformation of PCDD/F is known to occur by de novo synthesis within the temperature window of cooling from 450 to 200 °C. Thus, it is important that, as the gases are leaving the kiln system, they should be cooled rapidly through this range. In practice, this is what occurs in preheater systems as the incoming raw materials are preheated by the kiln gases. Elevated concentrations of PCDD/F in the preheater are not expected because of the increased temperature where PCDD/F are destroyed. At temperatures of about 925 °C PCDD/F are rapidly decomposed. Moreover, destruction is supported by the dynamic process of material transport to hotter zones while gas is transported to cooler zones. PCDD and PCDF adsorbed to the kiln feed are transported to zones with higher temperatures (400 – 600 °C) where they are thermally destroyed or degraded to lighter homologues. They are released to the gas phase and, in colder zones (200 – 300 °C), they resublime to the kiln feed. Furthermore, due to the long residence time in the kiln and the high temperatures, emissions of PCDD/F are generally low during steady kiln conditions. Detailed investigations and measurements have shown that PCDD/F emissions from the cement industry can be classified as low today, even when wastes and hazardous wastes are used as fuel. The measured data were collected from both wet and dry kilns, performing under different operating conditions, and with using a wide range of wastes and hazardous wastes fed to both the main burner and to the kiln inlet (preheater/precalciner). These investigations have concluded that, in Europe, cement production is rarely a significant source of PCDD/F emissions, because:

- most cement kilns can meet an emission level of 0.1 ng I-TEQ/Nm^3 if primary measures/techniques are applied (see Section 1.4.6)
- the use of wastes as fuels and as raw materials fed to the main burner, kiln inlet or the precalciner do not seem to influence or change the emissions of POPs [88, SINTEF, 2006].

In 2004, example data of PCDD/F emissions were collected from different plants located in EU-27 and EU-23+ countries (see Glossary). Values from PCDD/F measurements in the clean gas were collected as spot measurements, as shown in Figure 1.38 and Figure 1.39. Measured values relate to 1 m^3 of dry gas under standard conditions [97, CEMBUREAU, 2007]. As shown in Figure 1.38, reported data indicate that cement kilns in Europe can mostly comply with an emissions concentration of 0.1 ng I-TEQ/Nm^3, which is the limit value in the European legislation for hazardous waste incineration plants (Council Directive 2000/76/EC). German measurements of PCDD/F concentration values measured in the clean gas of 39 rotary kilns (suspension preheater kilns and Lepol kilns) indicate that emissions concentrations are generally well below 0.1 ng I-TEQ/Nm^3 while the average concentration amounts to less than 0.02 ng I-TEQ/Nm^3, as shown in Figure 1.40. In 26 cases, no PCDD/F emissions were detected. In Spain, PCDD/F measurements were carried out in the period from 2000 to 2003 including 89 measurements from 41 kilns which represent 69.5 % of coverage. These investigations were carried out for different fuels used for the kiln firing process. For those kilns using waste fuels, e.g. refuse derived fuels (RDF), PCDD/F emissions factors range between 0.83 – 133 ng I-TEQ/t$_{clinker}$ and are quite comparable with the results obtained for conventional fuel feedings with emissions factor ranges of between 0.67 – 246 ng I-TEQ/t$_{clinker}$ [60, VDI 2094 Germany, 2003], [76, Germany, 2006], [86, EURITS, 2006],[88, SINTEF, 2006],[91, CEMBUREAU, 2006], [150, Fabrellas/Larrazabal/Martinez/Sanz/Ruiz/Abad/Rivera, 2004].

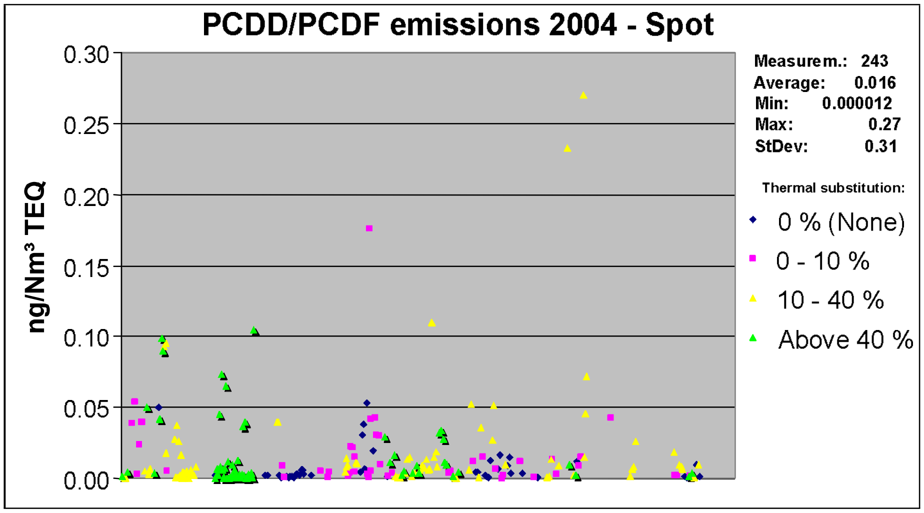


Figure 1.38: Emissions of PCDD/F in the EU-27 and EU-23+ countries in 2004 categorised by thermal substitution rate
[97, CEMBUREAU, 2007]

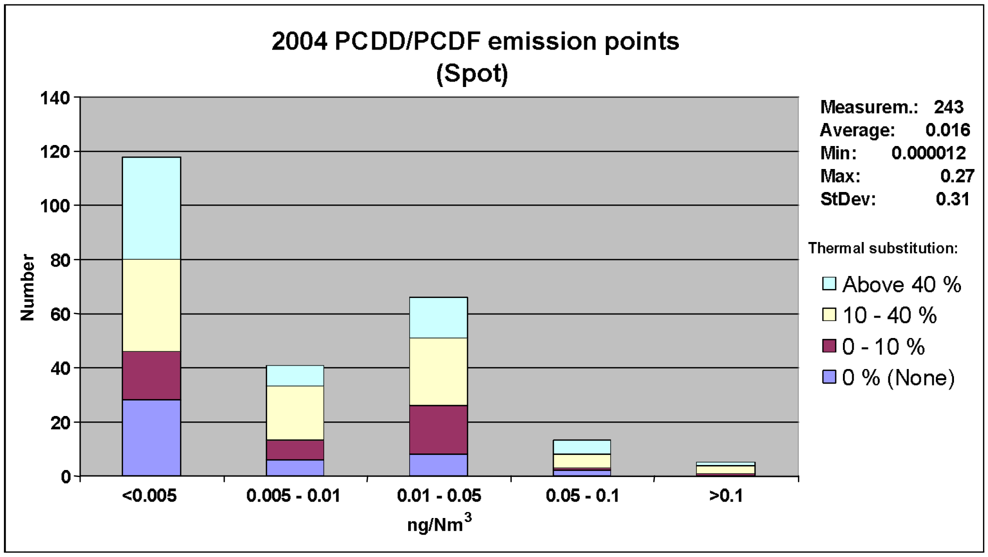


Figure 1.39: Distribution of spot measurements categorised by the thermal substitution rate of PCDD/F levels from cement kilns in the EU-27 and EU-23+ countries
[97, CEMBUREAU, 2007]

Examples of PCDD/F emissions measured from 39 German rotary kilns are shown in Figure 1.40. This information results from individual measurements carried out three times a year on one particular day. In 26 cases, no PCDD/F emissions were detected. It has to be noted that no detection limit was deducted/subtracted from the standard. PCDD/F measurements/samplings are usually based on a detection limit of 0.0024 ng I-TEQ/Nm^3. To evaluate the measurement results, an inter laboratory variation of the method (comparison between different laboratories) can be referred to. I-TEQ is the abbreviation for international toxicity equivalent [76, Germany, 2006].

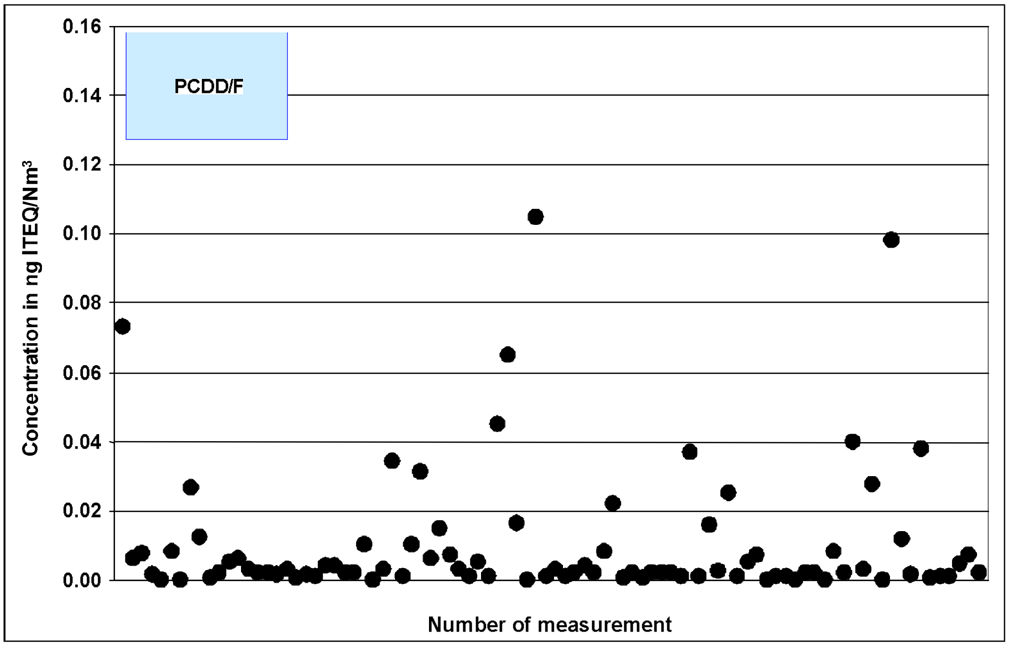


Figure 1.40: Emissions of PCDD/F measured in the clean gas of 39 German rotary kilns in 2004
[76, Germany, 2006]

1.3.4.7 Metals and their compounds

Raw materials and fuels will always contain metals. Their concentrations vary widely from one location to another and the potential for emissions to the atmosphere is affected by very complex mechanisms. Furthermore, metal concentrations from wastes used as fuel varies with the waste origin. Metal compounds can be categorised into four classes, based on the volatilities of the metals and their salts:

1. Metals which are or have compounds that are refractory or non-volatile, such as Ba, Be, Cr, As, Ni, V, Al, Ti, Ca, Fe, Mn, Cu and Ag:
   - these metals are completely absorbed by the clinker and discharged with it, and therefore do not circulate in the kiln system. In the exhaust gas, the only emissions are with the dust; they depend only on the input and the efficiency of dust segregation. Consequently, emissions are generally very low.
2. Metals that are or have compounds that are semi-volatile: Sb, Cd, Pb, Se, Zn, K and Na:
   - these metals condense as sulphates or chlorides at temperatures of between 700 and 900 °C; and inner circulation occurs. In this way, the semi-volatile elements which are accumulated in the kiln's preheated system are precipitated again in the cyclone preheater remaining to a high extent but almost completely in the clinker.
3. Thallium: metal that is or has a compound that is volatile:
   - thallium compounds (e.g. TlCl) condense at between 450 and 550 °C, in the case of heat exchanger kilns, in the upper area of the preheater, where they can accumulate (inner circulation).
4. Mercury: metal that is or has a compound that is volatile (see Section 1.3.4.7.1):
   - mercury and mercury compounds pass for the most part through the kiln and preheater; they are only partly adsorbed by the raw gas dust, depending on the temperature of the waste gas [12, Netherlands, 1997], [76, Germany, 2006], [91, CEMBUREAU, 2006], [92, Austria, 2006].

The pathway of metals in cement kilns with preheaters in a dry process is shown in Figure 1.41.

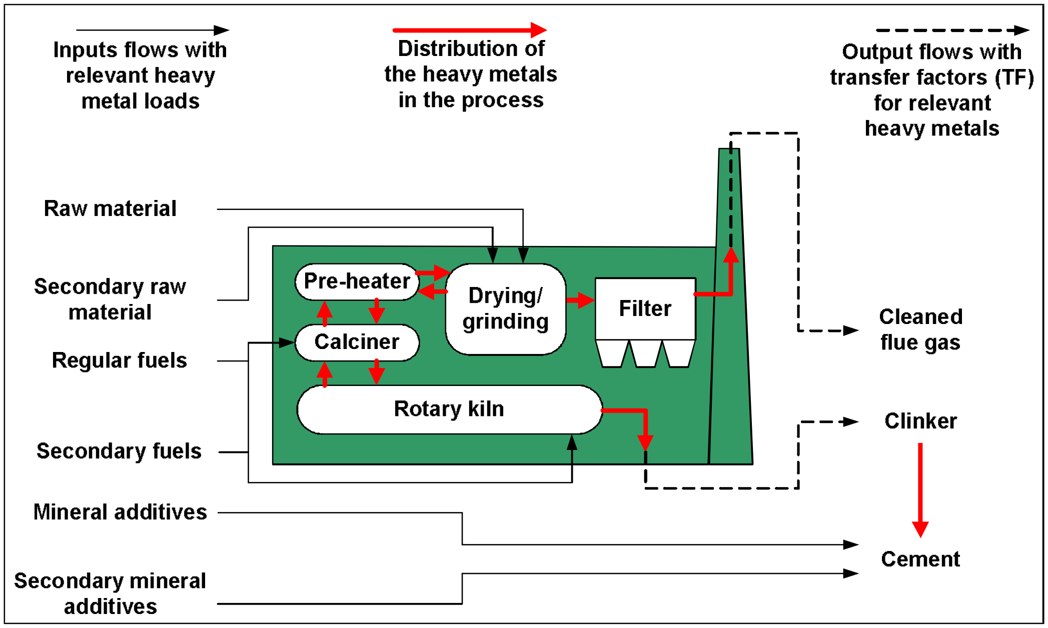


Figure 1.41: Pathway of metals in cement kilns with preheaters in a dry process
[89, ERFO, 2005]

The behaviour and the emission level of the individual metals in the clinker burning process are dependent on the volatility, the input scenario into the kiln, the concentration of the metallic elements in raw materials and fuels, especially when wastes or hazardous wastes are used, the type of process and, most important, the precipitation efficiency of the dust collection systems on the main stack.

Metals introduced into the burning process via the raw materials and fuels may evaporate completely or partially in the hot zones of the preheater and/or rotary kiln depending on their volatility, react with the constituents present in the gas phase, and condense on the kiln feed in the cooler sections of the kiln system. Metals from the fuels initially enter the combustion gases, but are emitted to an extremely small extent only owing to the retention capacity of the kiln and the preheater. As the raw material:fuel mass ratio for clinker production is approximately 10:1, the raw material-related inputs are decisive for the emissions [76, Germany, 2006], [86, EURITS, 2006] [92, Austria, 2006]

Non-volatile metal compounds remain within the process and exit the kiln as part of the cement clinker composition (>99.9 %). Semi-volatile metal compounds are partly taken into the gas phase at sintering temperatures to condense on the raw material in cooler parts of the kiln system. This leads to a cyclic effect within the kiln system (internal cycles), that is either restricted to the kiln and the preheater or is included in the drying grinding unit as well. If the metals are largely condensed in the preheater area, they will be returned to the kiln with the kiln charge. This results in an inner metal cycle (kiln/preheater cycle). This cyclic effect builds up to the point where an equilibrium is established and maintained between input and output via the cement clinker [9, CEMBUREAU, 1997 November], [60, VDI 2094 Germany, 2003], [76, Germany, 2006].

Volatile metal compounds condense on raw material particles at lower temperatures and potentially form internal or external cycles, if not emitted with the flue-gas of the kiln. Thallium and mercury and their compounds are particularly easily volatilised. They are not fully captured in the clinker matrix. Thallium and its compounds condense in the upper zone of the cyclone preheater at temperatures of between 450 and 500 °C. A large part of the thallium brought into the kiln system is therefore retained in the preheater. As a consequence, a cycle can be formed between the preheater, the raw material drying and the exhaust gas purification (internal and external). The emission level of thallium is determined by the concentration level of the external cycle and the collection efficiency of the dust collector. The thallium concentration of, e.g. the ESP dust is a measure for the concentration level of the thallium cycle [60, VDI 2094 Germany, 2003].

Furthermore, but to a lesser extent, cadmium, lead, selenium and their compounds are particularly easily volatilised. An internal cycle of easily volatile metal compounds is formed, when they react with the calcination feedstock or when they precipitate on the feedstock in cool areas of the calcination chamber, in the preheater, or in subsequent drying plants.

Metals form an external cycle when the dust, together with the condensed volatile compounds, is separated in dust separators and returned to the raw meal [27, University of Karlsruhe, 1996].

The dusts from the production of cement contain small amounts of metal compounds such as arsenic (As), cadmium (Cd), mercury (Hg), lead (Pb), thallium (Tl) and zinc (Zn). The main source of metal-laden dusts is the kiln system, including preheaters, precalciners, rotary kilns and clinker coolers. The metal concentration depends on the feedstock and recirculation in the kiln system. In particular, the use of coal and waste fuels may increase the input of metals into the process. As the metals entering the kiln system are of varying volatility and because of the high temperature, the hot gases in the cement kiln system also contain gaseous metal compounds. Balance investigations show that there is low retention of elements with high volatility in the clinker, resulting in an accumulation of these substances in the kiln system [27, University of Karlsruhe, 1996].

Cadmium and thallium emissions were collected from 262 spot ∑ (Cd, Tl) measurements in the clean gas of rotary kilns, as shown in Figure 1.42 and Figure 1.43. In 2004, these measurements were all taken from different plants located in several EU-27 and EU-23+ countries (see Glossary). The thermal substitution is marked in Figure 1.43 by using different colours. Five measurements are above the scale. Of these, four are of '0' substitution rate and one is '0 – 10'. Emissions vary irrespective of the fuel used. This is due to the fact that cadmium and thallium are not sufficiently volatile to escape with the gas and that they concentrate mainly in the dust and the clinker. Emissions therefore depend on the dedusting device efficiency more than on the fuels [97, CEMBUREAU, 2007].

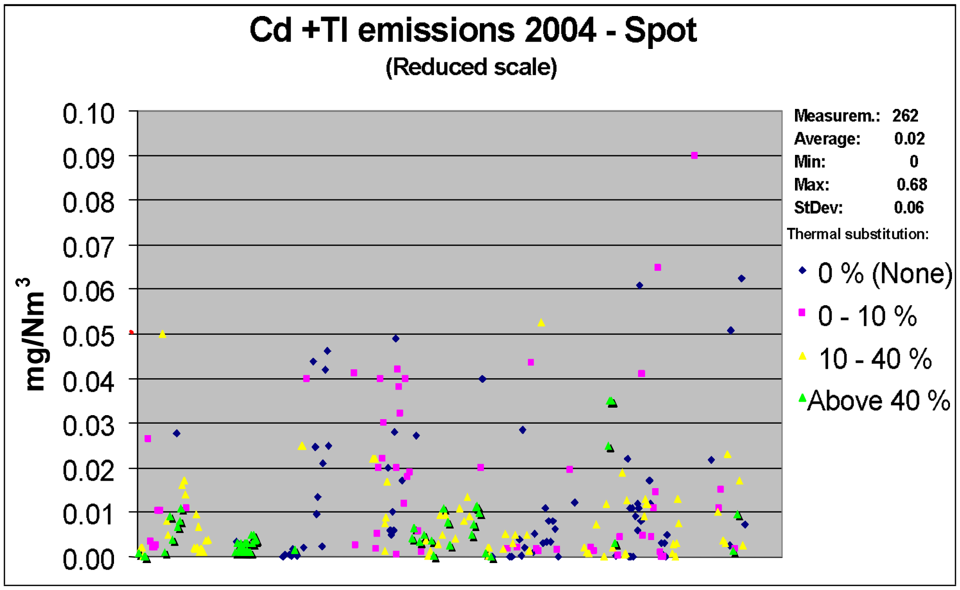


Figure 1.42: Cadmium and thallium emission values from 262 spot ∑ (Cd, Tl) measurements in the EU-27 and EU-23+ countries
[91, CEMBUREAU, 2006]

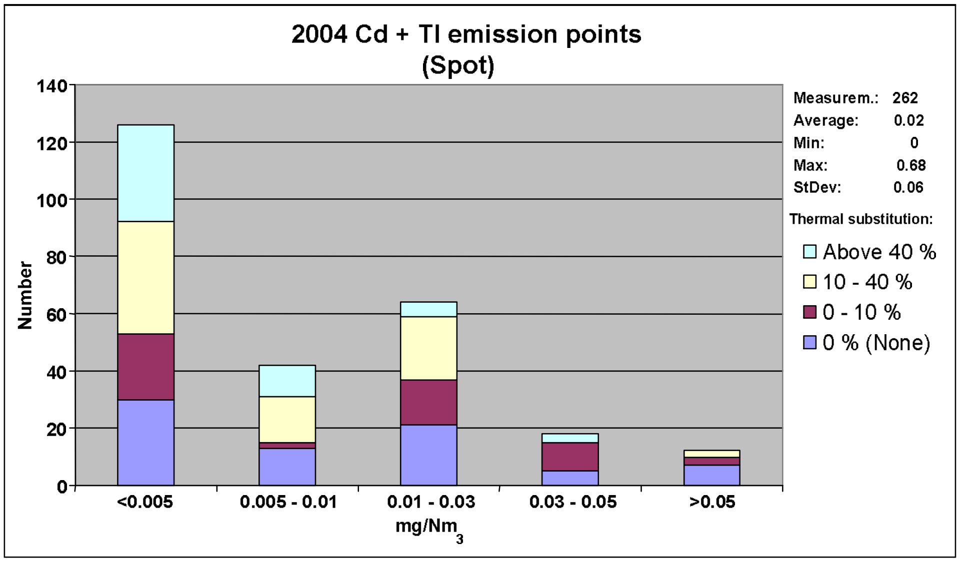


Figure 1.43: Distribution of measurements categorised by the thermal substitution rate of ∑ (Cd, Tl) levels
[91, CEMBUREAU, 2006]

As shown in Figure 1.44 and Figure 1.45, emissions of ∑ (Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V) were collected from 287 spot measurements in the clean gas of rotary kilns. In 2004, these measurements were all taken from different plants located in several EU-27 and EU-23+ countries (see Glossary). The thermal substitution is marked in Figure 1.45 by using different colours. Three measurements are above the scale. Of these, one is of '0' substitution rate, one is '0 – 10' and one is '10 – 40'.

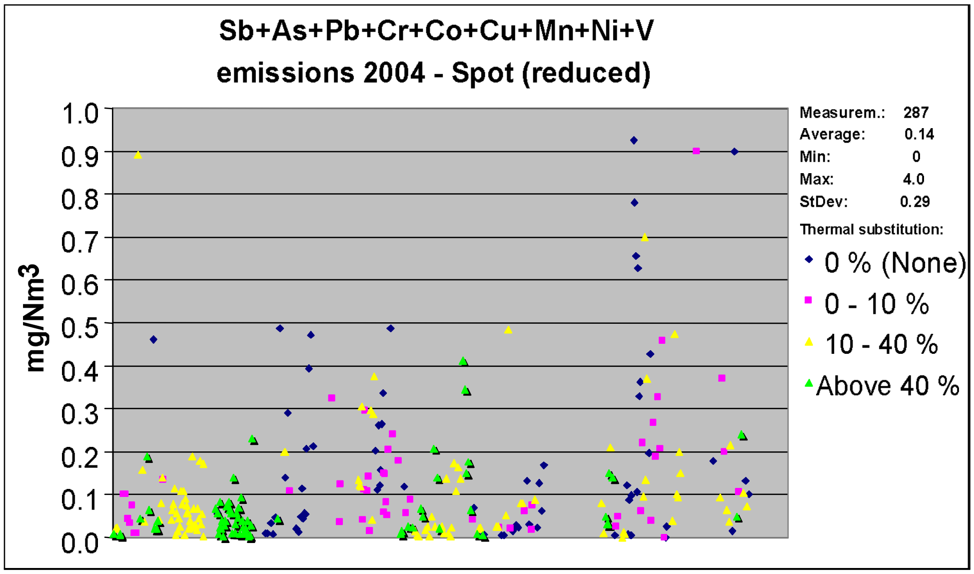


Figure 1.44: **Emission values from spot ∑ (Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V) measurements in the EU-27 and EU-23+ countries**
[91, CEMBUREAU, 2006]

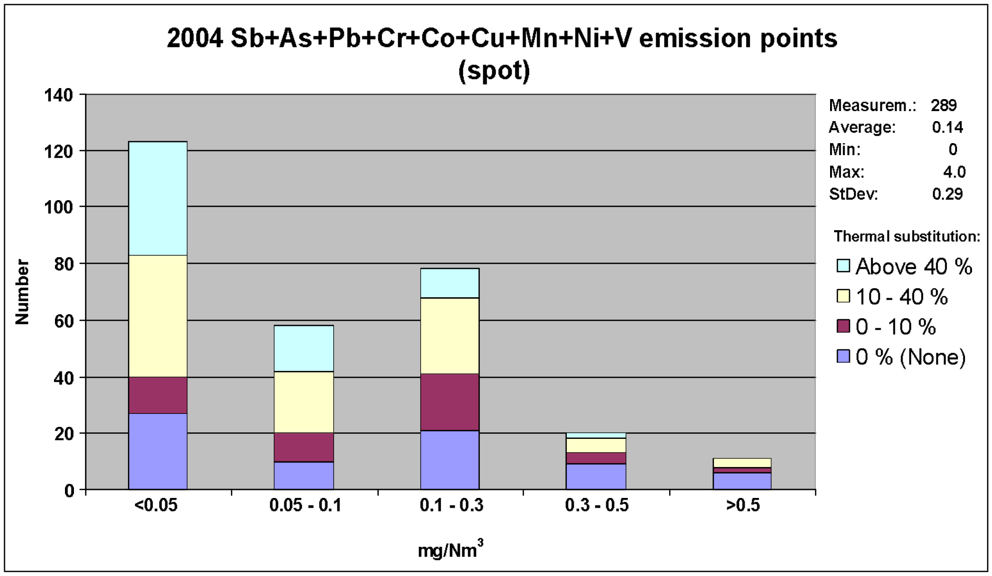


Figure 1.45: **Distribution of measurements categorised by the thermal substitution rate of ∑ (Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V) levels**
[91, CEMBUREAU, 2006]

Example concentration ranges of different metal components in the clean gas of cement kiln systems' measurements from 1996 to 1998 are shown in Table 1.29.

Component	Concentration[1] (mg/Nm^3)
Antimony	<0.007 – 0.05
Arsenic	<0.007 – 0.025
Beryllium	<0.004
Lead	<0.012 – 0.2
Cadmium	<0.002 – 0.008
Chromium	<0.014 – 0.03
Cobalt	<0.012 – 0.15
Copper	<0.011 – 0.095
Manganese	<0.007 – 2
Nickel	<0.008 – 0.075
Mercury	<0.005 – 0.12
Selenium	<0.008 – 0.02
Tellurium	<0.0017 – 0.015
Thallium	<0.005 – 0.03
Vanadium	<0.007 – 0.075
Zinc	<0.1 – 0.45
Tin	<0.01 – 0.025
[1] Concentration is related to standard temperature and pressure conditions after reduction of water vapour content; total of particle-borne and filter passing fractions; results from single measurements averaged over the sampling period	

Table 1.29: Ranges of heavy metal concentrations in the clean gas of cement kiln systems' measurements from 1996 to 1998
[60, VDI 2094 Germany, 2003]

1.3.4.7.1 Mercury

Mercury and its compounds are particularly easily volatilised (highly volatile metal). It is a toxic metallic element and pollution of mercury is understood to be global, diffuse and chronic, so atmospheric emissions from plants have to be reduced. Therefore, to control mercury emissions, it can be necessary to limit mercury input into the kiln system (see Sections 1.2.4.3.2, 1.2.4.3.2.1 and 1.3.4.13). Mercury and its compounds are not completely precipitated and retained in the kiln system and/or the preheater and therefore, they are not captured in the clinker. They are precipitated on the exhaust gas route due to the cooling of the gas and are partially adsorbed by the raw material particles, depending on the temperature of the waste gas. This portion is precipitated in the kiln exhaust gas filter. Therefore, mercury may only become enriched in the external cycle, where the concentration level and the emissions are mainly determined by the exhaust gas conditions. To prevent a long-cycle increase in mercury emissions, it may become necessary to limit the concentration of the external cycle, e.g. by continuously or intermittently extracting part of the dust collected in the filter system. Furthermore, precipitation and hence, mercury removal increases with decreasing exhaust gas temperature. Indications from measurements performed on cyclone preheater kiln systems show that more than 90 % of mercury exists on particles which are formed at exhaust gas temperatures of below 130 °C. Mercury compounds are then completely removed from the dust collector of the kiln system. Due to the high collection efficiency of the dust collector, mercury concentrations in the clean gas of rotary kiln systems are often below the detection limit (see Figure 1.46 and Figure 1.47).

The dust from the dust collector can be recirculated back to the cement mill. In the case of the use of waste fuels, the mercury input to the kiln can be limited regularly (see Sections 1.2.4.3.2.1 and 4.2.2.1.1). Another possibility to reduce mercury emissions is to reduce the off-gas temperature after the conditioning tower to improve the precipitation of mercury and its compounds during dust filtration. Furthermore, in one German plant, activated carbon is injected as an adsorbent to the flue-gas [12, Netherlands, 1997], [76, Germany, 2006], [86, EURITS, 2006], [91, CEMBUREAU, 2006], [92, Austria, 2006], [168, TWG CLM, 2007].

As shown in Figure 1.46 and Figure 1.47, mercury emissions were collected from 306 spot Hg measurements in the clean gas of rotary kilns. In 2004, these measurements were all taken from different plants located in several EU-27 and EU-23+ countries (see Glossary). The thermal substitution is marked in Figure 1.47 by using different colours. Six measurements are above the scale. Of these, one is of '0' substitution rate, one is '0 – 10', two are '10 – 20' and two measurements are 'above 40'. As explained, mercury is the most volatile heavy metal and has a poor trapping coefficient. Waste fuels undergo a rigorous acceptance and inspection procedure before being used [97, CEMBUREAU, 2007].

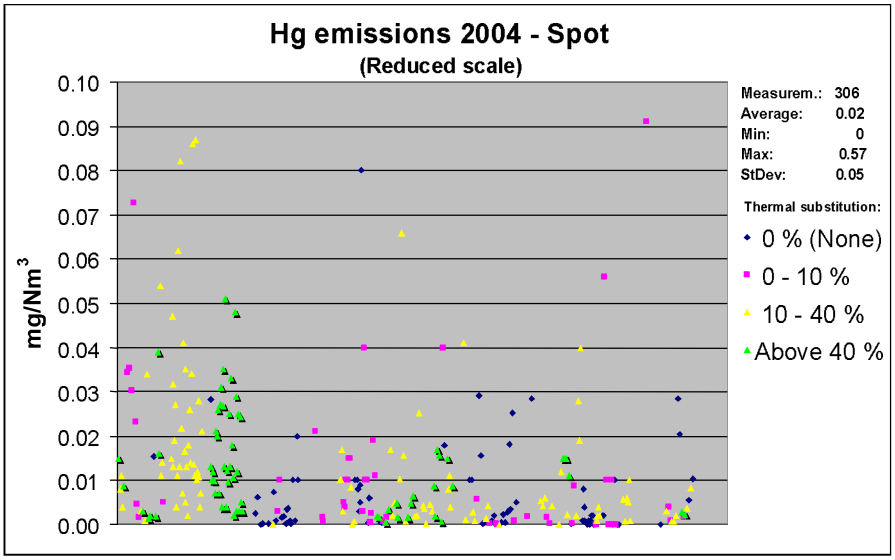


Figure 1.46: Mercury emission values from 306 spot Hg measurements in the EU-27 and EU-23+ countries
[91, CEMBUREAU, 2006]

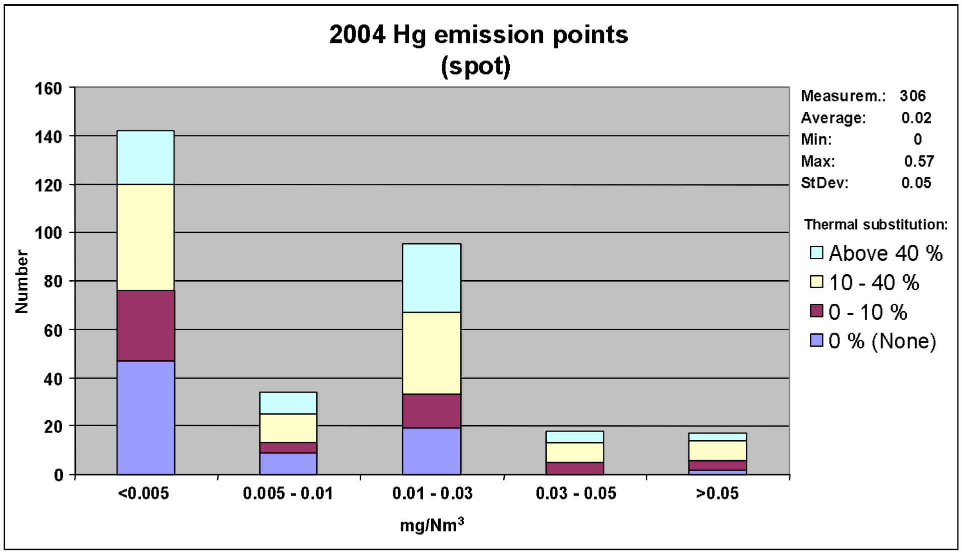


Figure 1.47: Mercury emission values from 306 spot Hg measurements in the EU-27 and EU-23+ countries
[91, CEMBUREAU, 2006]

1.3.4.8 Hydrogen chloride and hydrogen fluoride (HCl and HF)

Chlorides and fluorides are minor additional constituents. They may enter into the kiln system with the different inputs as raw materials and/or fuels. Carrying out regular periodic monitoring is appropriate for these substances.

1.3.4.8.1 Gaseous inorganic chlorine compounds

Chlorine compounds are minor additional constituents contained in the raw materials and fuels of the clinker burning process. They may enter into the kiln system with the different inputs and during the firing process in the kiln system; they react with the alkalis of the kiln charge to form alkali chlorides. These compounds, which are initially vaporous, condense on the kiln feed or the kiln dust, at temperatures of between 700 and 900 °C, subsequently re-enter the rotary kiln system and evaporate again. They show a cycling behaviour and may become enriched in the area between the rotary kiln and the preheater. A bypass at the kiln inlet allows the effective reduction of alkali chloride cycles and thus diminishes operational malfunctions. From a chloride input of 0.2 g Cl/kg clinker, depending on the specific plant, a branch stream of the kiln exhaust gases is diverted through a bypass and cooled to forestall accretions in the preheater bottom section. As the gas stream is being cooled, the gaseous alkali chloride compounds condense on the kiln dust particles and can then be removed from the system via a dust collector. The collected bypass dust is returned under controlled conditions to the cement mill feed stream.

As shown in Figure 1.48, during the clinker process, gaseous inorganic chlorine compounds are either not emitted at all or only available in very small quantities from European cement plants. Gaseous inorganic chlorides detected in the exhaust gas of rotary kiln systems are generally attributable to the ultrafine grain size fractions of alkali chlorides in the clean gas dust [60, VDI 2094 Germany, 2003], [76, Germany, 2006], [86, EURITS, 2006], [97, CEMBUREAU, 2007].

In 2004, example data of continuous HCl emissions measurements and spot measurements were collected from plants located in several EU-27 and EU-23+ countries (see Glossary). Values from continuous HCl measurements in the clean gas were collected from 98 rotary kilns as well as values from 233 spot measurements, as shown in Figure 1.48 and Figure 1.50. Figure 1.49 and Figure 1.51 show the emissions distribution of the continuous HCl measurements and the spot measurements. Continuously measured emissions were reported as the annual average of 24 hour averages. Measured values relate to 1 Nm^3 of dry gas under standard conditions [97, CEMBUREAU, 2007]. Furthermore, Figure 1.52 shows emissions examples in a range of between 0 – 8 mg/Nm^3 (yearly average value), while 91 values are below the detection limit and one is above 15 mg/Nm^3, measured from 39 German rotary kilns [76, Germany, 2006].

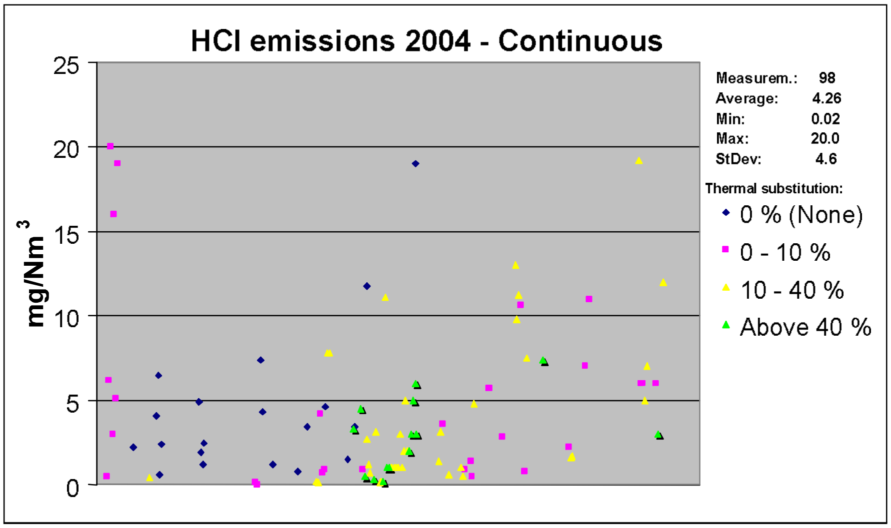


Figure 1.48: HCl emission values from continuous HCl measurement in the clean gas from 98 cement kilns in the EU-27 and EU-23+ countries
[97, CEMBUREAU, 2007]

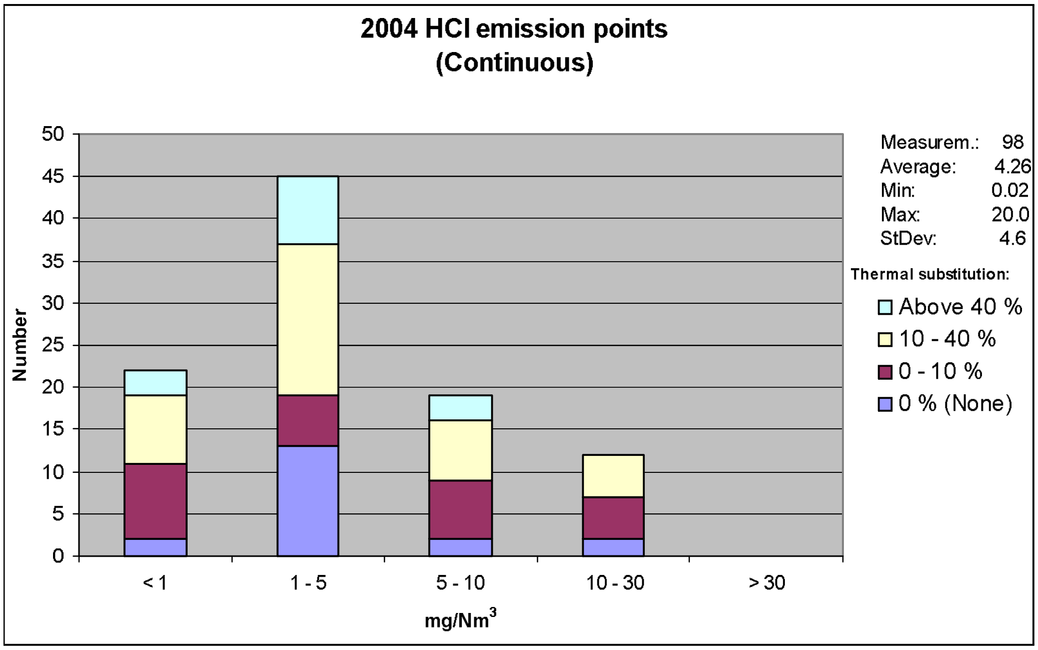


Figure 1.49: Distribution of continuous HCl measurements categorised by the thermal substitution rate
[97, CEMBUREAU, 2007]

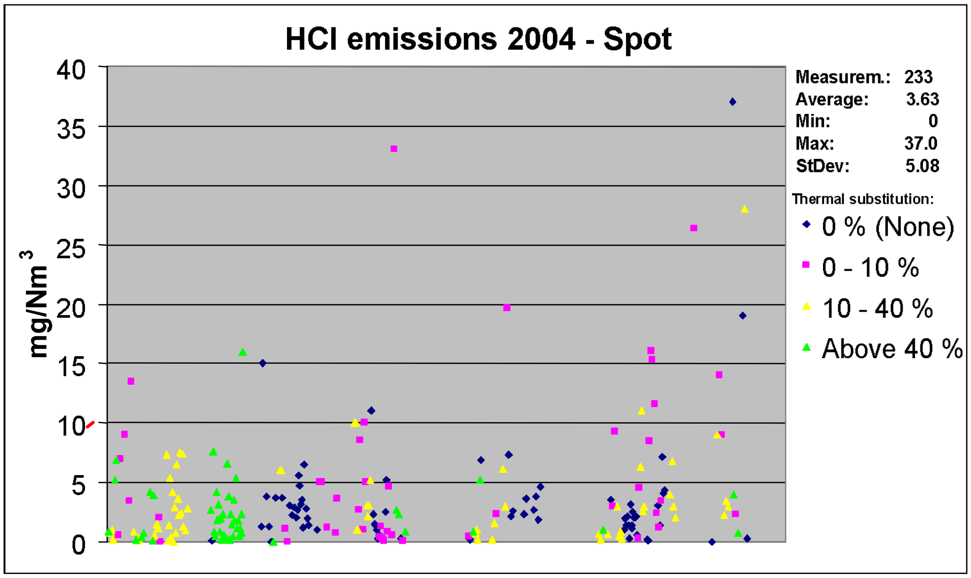


Figure 1.50: Emission values from 233 spot measurements in the clean gas of rotary kilns in the EU-27 and EU-23+ countries
[97, CEMBUREAU, 2007]

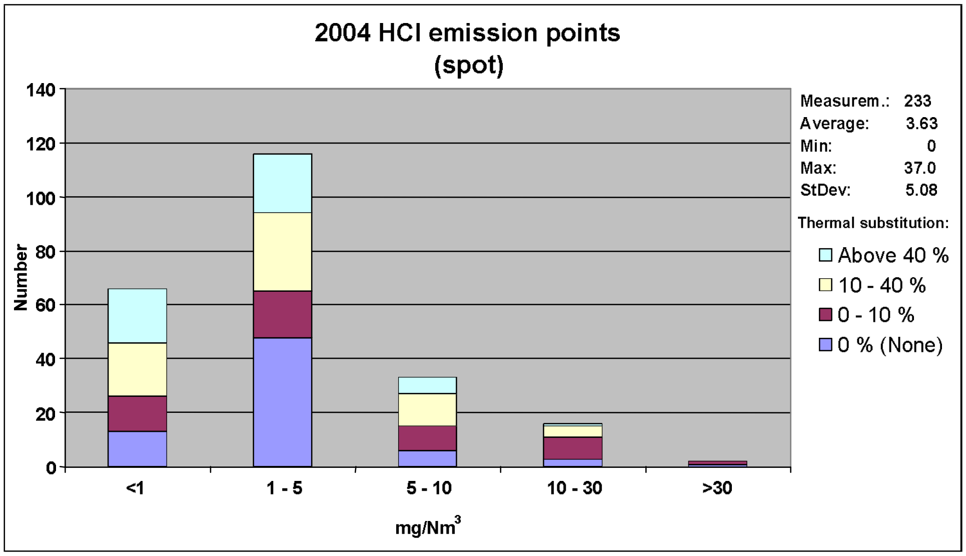


Figure 1.51: Distribution of HCl spot measurements categorised by the thermal substitution rate of HCl levels
[97, CEMBUREAU, 2007]

Examples of HCl emissions measured from 38 German rotary kilns are shown in Figure 1.52. This information results from individual measurements carried out three times a year on one particular day. In 91 cases, the emission value was below the detection limit of between 1.5 – 2.1 mg/Nm^3.

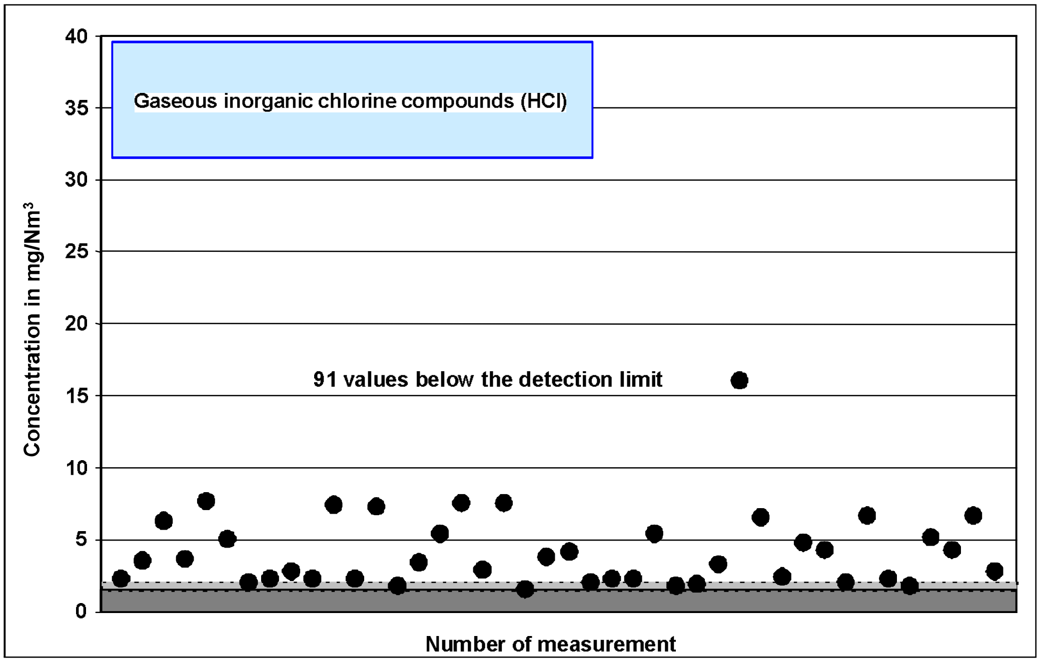


Figure 1.52: **Emissions of gaseous inorganic chlorine compounds, stated as HCl, measured in the clean gas from 38 German rotary kilns in 2004**
[76, Germany, 2006]

1.3.4.8.2 Gaseous inorganic fluorine compounds

Of the fluorine present in rotary kilns, 90 to 95 % is captured in the clinker, and the remainder is bound with dust in the form of calcium fluoride (CaF_2) which is stable under the conditions of the burning process. Owing to the great excess of calcium, the emissions of gaseous fluorine compounds and of hydrogen fluoride in particular, are virtually excluded. Ultrafine dust fractions that pass through the measuring gas filter may simulate low contents of gaseous fluorine compounds in rotary kiln systems. Minor amounts of fluorides are discharged with the kiln dust, such as in the form of CaF_2.

In 2004, example data of continuous HF emissions measurements and spot measurements were collected from different plants located in the EU-27 and the EU-23+ countries (see Glossary). Values from continuous HF measurements in the clean gas were collected from 28 rotary kilns as well as values from 210 spot measurements, as shown in Figure 1.53 and Figure 1.55. Five measurements are above the scale. Out of these, four are of zero substitution rate and one is above 40. Figure 1.54 and Figure 1.56 show the emissions distribution of the continuous HF measurements and the HF spot measurements. Continuously measured emissions were reported as the annual average of 24 hour averages. Measured values relate to 1 Nm^3 of dry gas under standard conditions. Fluorides from cement kiln systems are below 1 mg/Nm^3, expressed as HF [76, Germany, 2006], [86, EURITS, 2006], [97, CEMBUREAU, 2007].

Furthermore, Figure 1.57 shows examples of HF emissions in a range of between 0.005 – 0.35 mg/Nm^3, and 106 values are below the detection limit, measured from 38 German rotary kilns. This information results from individual measurements carried out three times a year on one particular day. The detection limit is between 0.04 and 0.06 mg/Nm^3 [76, Germany, 2006], [103, CEMBUREAU, 2006].

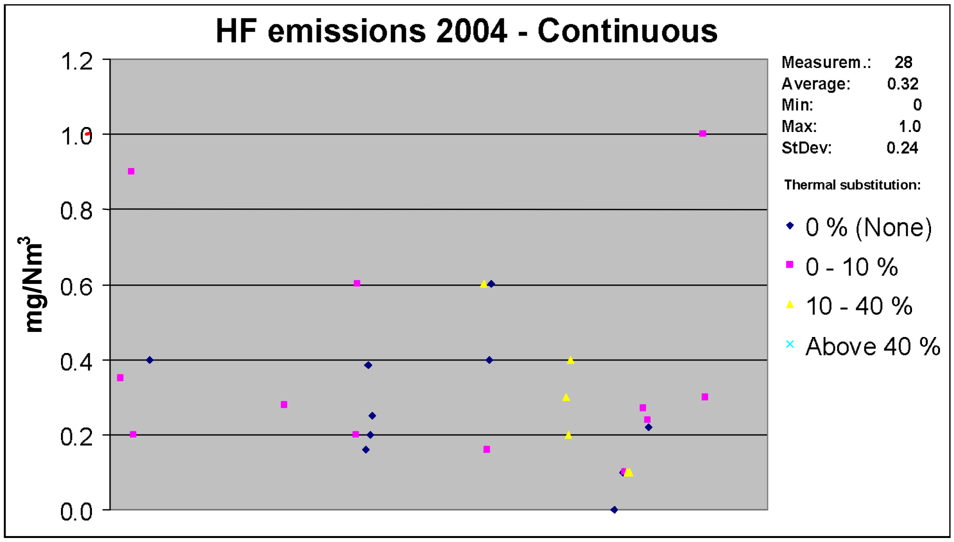


Figure 1.53: Emission values from continuous HF emissions measurement in the clean gas from rotary kilns in the EU-27 and EU-23+countries
[97, CEMBUREAU, 2007]

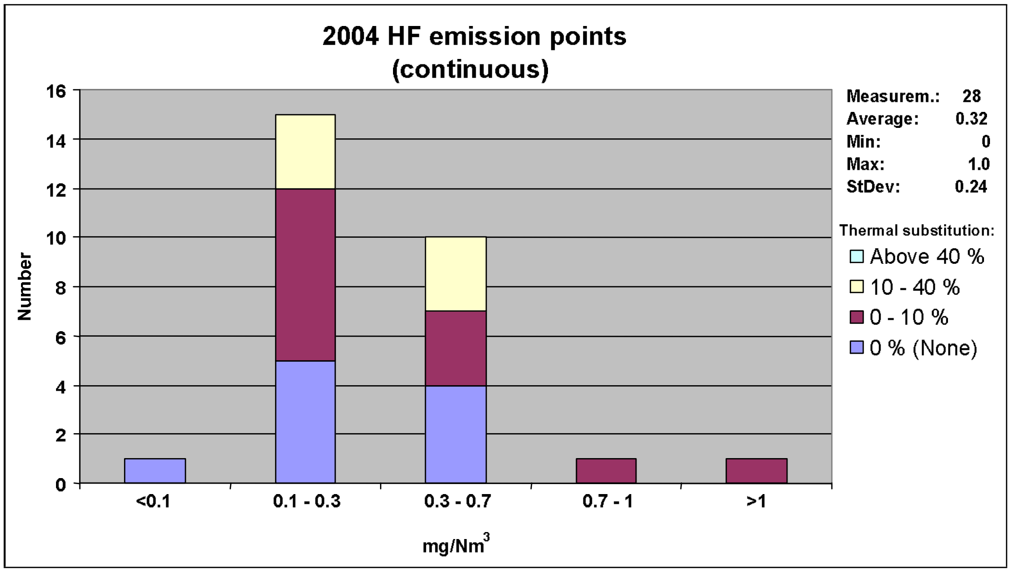


Figure 1.54: Distribution of continuous HF emissions measurements categorised by the thermal substitution rate of HF levels
[97, CEMBUREAU, 2007]

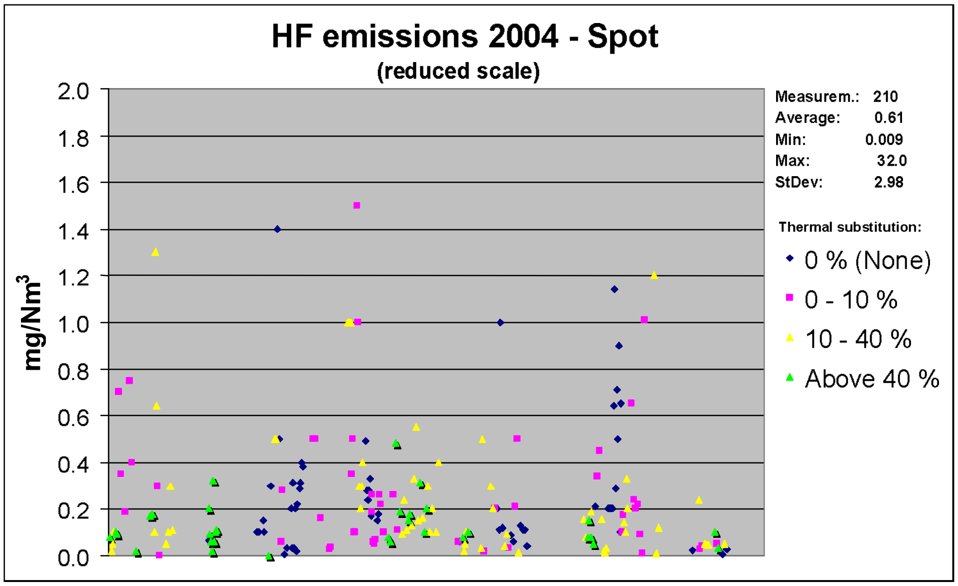


Figure 1.55: Emission values from spot HF measurements in the clean gas of rotary kilns in the EU-27 and EU-23+ countries
[97, CEMBUREAU, 2007]

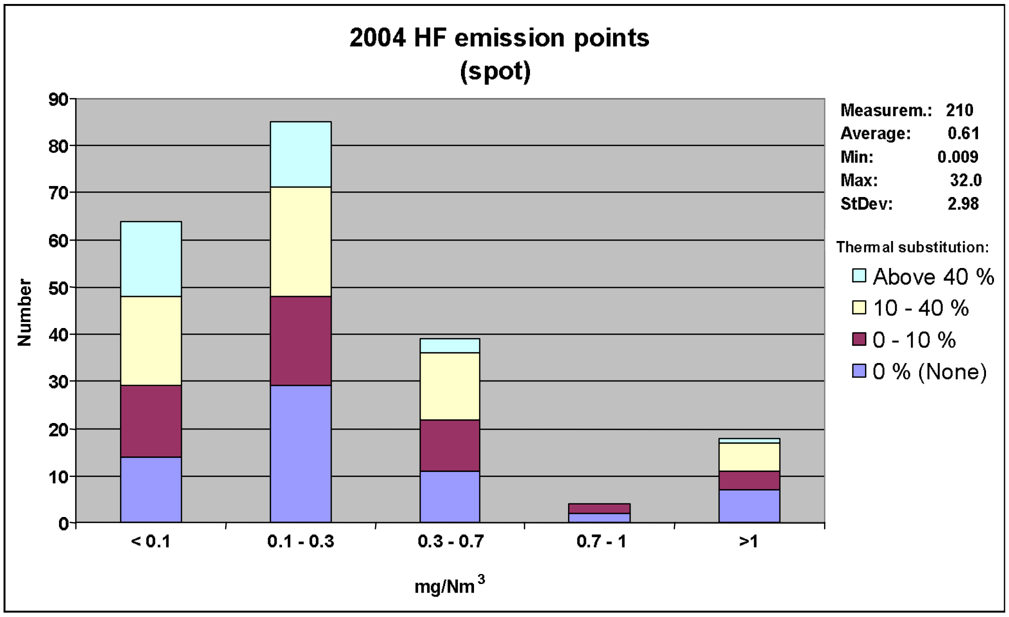


Figure 1.56: Distribution of HF spot measurements categorised by the thermal substitution rate of HF levels
[97, CEMBUREAU, 2007]

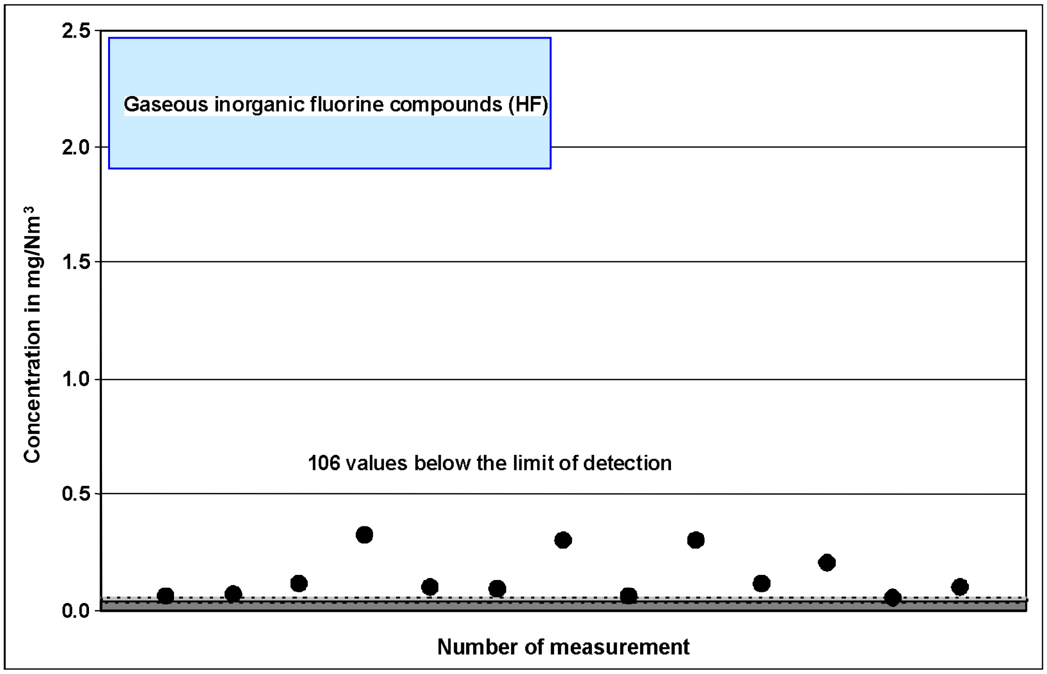


Figure 1.57: Emissions of gaseous inorganic fluorine compounds, stated as HF, measured in the clean gas from 38 German rotary kilns in 2004
[76, Germany, 2006]

1.3.4.9 Ammonia (NH_3)

Emissions of NH_3 occur in the primary steps of the process from the raw materials. The NH_3 content of the exhaust gas from cement kilns can reach as much as 200 mg/Nm^3. Additional NH_3 can occur from abatement techniques, such as the selective non-catalytic reduction (SNCR) technique, where also variable emissions of unreacted ammonia may occur (ammonia slip). A regular monitoring of NH_3 emissions is essential.

Investigations from two plants in Sweden from 1994 to 2006 (initial trials for testing ammonia emissions) show that NH_3 emissions arising from the raw material are in a range of between 10 – 35 mg/Nm^3. Furthermore since 1998, one of these plants has been equipped with a SO_x scrubber which buffers the ammonia in the scrubber liquor and equalises peaks and lows. From the stack of this scrubber, the ammonia emissions have been measured continuously since 1998 as shown in Figure 1.58. Since the scrubber has been in operation, the short term peaks are higher up to 125 mg/Nm^3. This is happening due to the increased scrubber liquor from 53 to 59 °C and the shifted equilibrium so that some accumulated ammonia is released again. However, these plants are equipped with milling systems (raw and coal mill) from where ammonia also is adsorbed and only a small amount of ammonia is transported to the cement mill facilities together with the gypsum (3 kg/h). The cement mill operates at low temperatures in a closed circuit and only very occasionally was the ammonia smell detected from the cement silo.

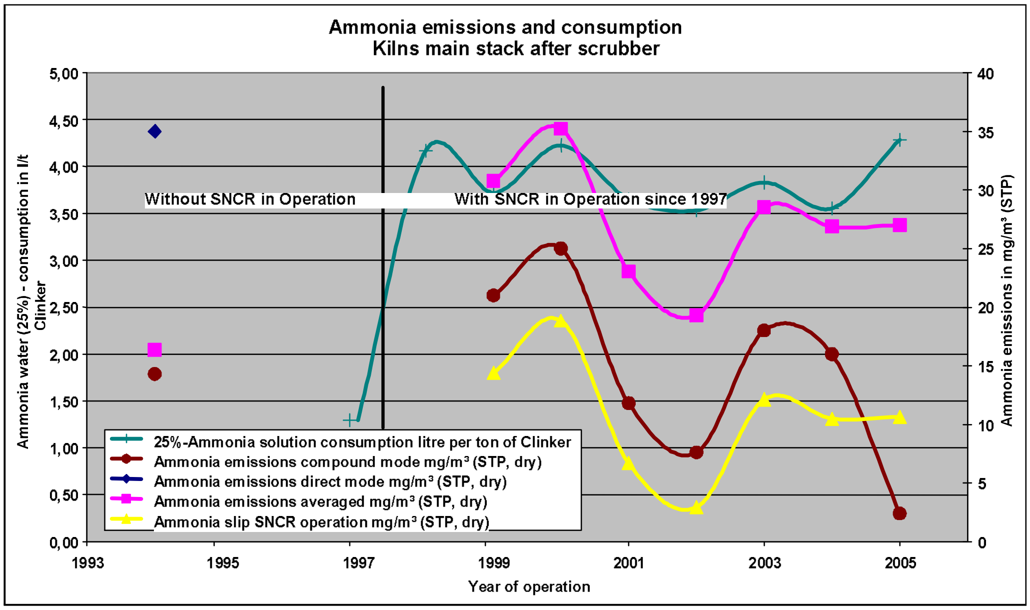


Figure 1.58: Ammonia emissions from a Swedish cement plant equipped with a SO_x scrubber [114, Sweden, 2006]

In 2007, at one German cement plant which is equipped with the high efficiency SNCR technique, investigations and trials were carried out within a period of six months. NO_x emission levels of 350 and 200 mg/Nm³ (daily average value) were achieved by applying corresponding NH_3:NO molar ratios of 0.7 – 0.8 and 1.4 – 1.5. However, for achieving the lower NO_x emission level, the NH_3 measurements resulted in significant ammonia slip of between 50 – 200 mg/Nm^3 particularly during mill-off operation. The ammonia slip was twice as high to achieve the emission level of 200 mg/Nm^3 (NH_3: three months average value of 11 mg/Nm^3) compared to a level of 350 mg/Nm^3 (NH_3: three months average value of 21 mg/Nm^3) (see also Section 4.2.4.2) [160, Germany, 2007], [173, Germany, 2007], [182, TWG CLM, 2008].

Furthermore, investigations at an Irish cement plant in 2004 by carrying out short term SNCR trials showed NH_3 concentrations in a range of between 4 and 26 mg/Nm^3 in the raw gas after the preheater of the kiln. These concentrations have been measured by testing two injection configurations (standard conditions; NH_3:NO molar ratio of one (1) with a NO_x reduction rate of 50 %). The NH_3 slip sets limits to the overstoichiometric addition of a reducing agent. Carrying out regular periodic monitoring is appropriate for this substance [76, Germany, 2006], [103, CEMBUREAU, 2006], [114, Sweden, 2006] [123, Ireland, 2005] [168, TWG CLM, 2007], [173, Germany, 2007].

An example from a German plant equipped with the SCR technique led to NH_3 slip to below 1 mg/Nm^3 [173, Germany, 2007].

It has to be noted that NH_3 in the raw material also serves as the reducing agent (see Section 4.2.5) [76, Germany, 2006], [168, TWG CLM, 2007].

1.3.4.10 Benzene, toluene, ethylbenzene and xylene (BTEX)

Measurements of these substances may be required occasionally under special operating conditions.

In some German plants, additional individual measurements of benzene have been carried out since 2004 which range between 0.02 and 3.6 mg/Nm^3. Benzene emissions in low concentrations are caused by the small quantities of organic constituents input via the natural raw materials (remnants of organisms and plants incorporated in rock in the course of geological history) during kiln feed preheating. Examples of measured emissions concentrations of benzene in German kilns are shown in Figure 1.59 (based on a detection limit of 0.013 mg/Nm^3). The benzene emissions were not dependent on the fuels used.

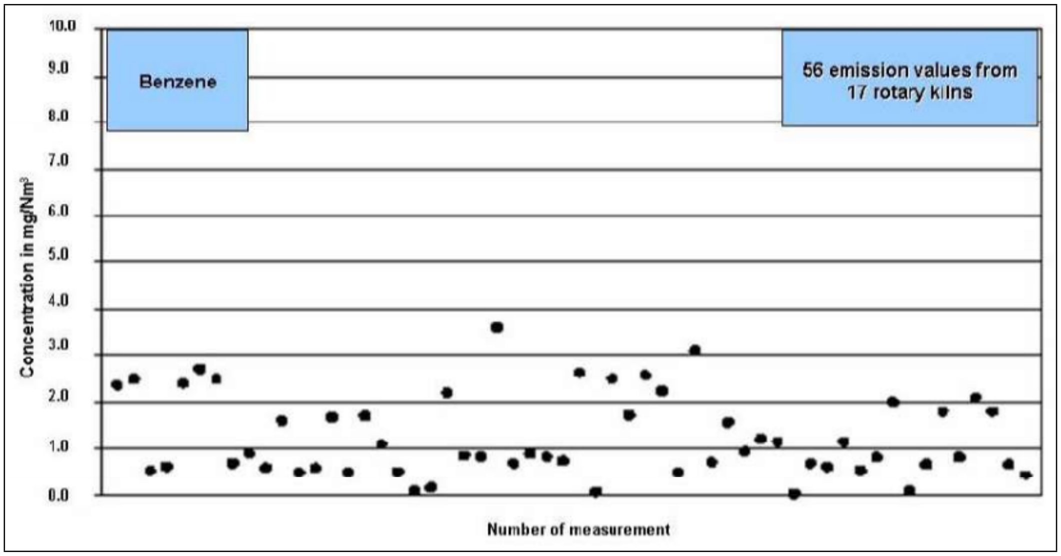


Figure 1.59: Benzene emissions concentrations measured from 17 German rotary kilns [76, Germany, 2006]

1.3.4.11 Polyaromatic hydrocarbons (PAH)

Measurements of these substances may be required occasionally under special operating conditions.

1.3.4.12 Other organic pollutants

Other organic pollutants occurring from the cement manufacturing process are, for example, chlorobenzenes, PCB (polychlorinated biphenyls) including coplanar congeners, and chloronaphthalenes.

Measurements of these substances may be required occasionally under special operating conditions.

1.3.4.13 Impacts on emissions behaviour and energy efficiency by using waste materials

Emissions behaviour

Dust emissions from the clinker burning process remain unaffected by using wastes.

According to current knowledge, the use of suitable waste only has a minor influence on metal emissions from the clinker burning process because of the high retention capacity for particle-bound metals in the preheater and dust collector. It has to be noted that the way the fuels are fed into the kiln (feeding point) is very important because this can have an effect on the emissions (see Section 1.2.4.1). Factors determining metal emissions from the clinker production process are the behaviour of the individual metals in the rotary kiln system, the input situation as well as the collection efficiency of the dust collector. The input situation itself is determined by the metal concentration in the raw materials and fuels used. As the raw material:fuel mass ratio for clinker production is approximately 10:1, this means that the raw material-related inputs are decisive for the emissions. In operating practice, the use of wastes may result in a decreased or increased total input of individual elements into the kiln system. Non-volatile metals are, to a great extent, locked in the clinker matrix and leave the kiln system with the clinker stream. Semi-volatile metals like Pb and Cd form stable cycles in the kiln system. These elements are discharged from the cycle and a large amount is captured either in the clinker stream or in dust. Special cases due to their volatility are Hg and Tl. The prevailing process temperatures combined with a high volatility result in an insufficient removal capacity and establish a plant specific link between the input load and the emissions concentration in the stack. Depending on the exhaust gas temperature, mercury is present in particle-borne and/or vapour form in the dust collector. Therefore, to control mercury and volatile metal emissions it can be necessary to limit mercury and metal inputs into the kiln system. When firing waste fuels recovered from mixed waste fractions, a routine receiving analysis may be required for monitoring the volatile metals input (see Section 1.2.4.3.2).

The inorganic exhaust gas constituents NO_x, HCl and HF remain unaffected by the choice of the feedstock. According to current knowledge, by using the appropriate feeding point to the kiln, the processing of wastes in the cement production process has no significant effects on these emissions. The same applies to the emissions components SO_2, CO and TOC, provided that the input of volatile sulphur compounds or volatile organic compounds via the raw meal path is not increased through the processing of waste. Formed SO_2 is bound to the clinker in the rotary kiln or the precalciner without additional measures/techniques.

The combustion conditions in rotary kiln systems ensure low emissions concentrations of PCDD/F. Waste materials likely to contain relevant concentrations of persistent organic substances, e.g. PCB-laden spent oil, are fed via the main firing system to ensure their reliable destruction. If there are doubts about the feed point selection in the individual case, reference measurements with and without using wastes should be performed. Indications from comprehensive measurement programmes are that in operating practice, PCDD/F emissions are well below the prescribed limit of 0.1 ng I-TEQ/m^3, regardless of the waste used.

Wastes inserted to the secondary firing (see Sections 1.2.4.1 and 1.2.5.1) do not pass the high temperature zone of the rotary kiln which requires qualitative limitations for input and process parameters. However, in many modern precalciners, the temperature is above 850 °C and they have a residence time of longer than 2 seconds, therefore making them suitable for the use of wastes.

Examples of conditions and the result of the yearly emissions monitoring from German cement kiln using waste fuels are shown in Section 4.2.2.1, Table 4.5 and Table 4.6.

Impacts on energy efficiency

Thermal energy demands can increase when using waste fuels with a higher moisture content, coarseness or a lower reactivity compared to, e.g. fine ground, dry and/or high calorific fuels. Lower energy efficiency might also result in higher emissions loads of air pollutants by increasing the flue-gas volume.

[3, Austria, 1997], [76, Germany, 2006], [86, EURITS, 2006], [137, Klein/Hoenig, 2006], [168, TWG CLM, 2007].

1.3.4.14 Impacts on product quality by using wastes

The use of wastes in the clinker burning process may change the metal concentrations in cement products. Depending on the total input via the raw materials and fuels, the concentration of individual elements in the product may increase or decrease as a result of waste processing.

As cement is blended with aggregates, e.g. gravel and sand, for the production of concrete or mortar, it is the behaviour of the metals in the building material (concrete or mortar) which is ultimately decisive for evaluating the environmentally relevant impacts of waste used in the clinker burning process.

Metal emissions from concrete and mortar are low. Results from comprehensive tests confirm that metals are firmly incorporated in the cement brick matrix. In addition, dry-packed concrete offers high diffusion resistance which further counteracts the release of metals.

Tests on concrete and mortar have shown that the metal concentrations in the eluates are noticeably below those prescribed, for instance, by national legislation. Storage under different and partly extreme conditions has not led to any environmentally relevant releases. This also holds true when the sample material is crushed or comminuted prior to the leaching tests.

Careful selection and monitoring of the waste materials ensure that the use of wastes does not result in metal emissions of any environmentally harmful magnitude. The metal emissions are partly orders of magnitude below the applicable air pollution control standards. The use of waste has no negative impact on the environmental quality of the product. Under these conditions, cement can continue to be used without restrictions for concrete and mortar production. The recyclability of these materials remains completely unaffected.

The content of metals in German cements are analysed on a regular basis. The last values were published in 2001. A comparison with results from earlier investigations showed that there was no increase in the metal content of the cements although there has been a remarkable increase in the use of waste materials over the respective period [76, Germany, 2006], [168, TWG CLM, 2007].

1.3.5 Process losses/waste

Process losses/waste originating from cement manufacture, mainly consists of the following materials:

- unwanted rocks which are removed from the raw materials during the preparation of the raw meal
- kiln dust removed from the bypass flow and the stack
- filtrate from the filter presses used in the semi-wet process is fairly alkaline and contains suspended solids
- dust arising from off-gas cleaning units, e.g. dust precipitator
- used sorption agents (granular limestone, limestone dust) arising from the flue-gas cleaning system
- packaging waste (plastic, wood, metal, paper, etc.) arising from the packaging step.

Parts of the accumulated process losses mentioned above, can be recycled and re-used within the plant due to process requirements and product specifications. Materials which cannot be recycled internally leave the plant to be used in other industries or to be supplied to external waste recycling or waste disposal facilities. Kiln dust can directly be re-used within the process of cement manufacturing or can be used for other purposes.

PCDD/Fs are also present in wastes and solid materials from the cement industry and in 2006 the following was reported by a study:

- cement kiln dust (CKD) and filter dust
    - average concentration of 6.7 ng I-TEQ/kg
    - maximum concentration of 96 ng I-TEQ/kg
- clinker
    - average concentration of 1.24 ng I-TEQ/kg
    - maximum concentration of 13 ng I-TEQ/kg.

This study also shows that, compared with other materials, dioxin levels in process losses/waste originating from cement manufacture are of the same magnitude as foods like fish, butter, breast milk, and less than the maximum permissible concentration of 100 ng TEQ per kg for sewage sludge applied to agricultural land [88, SINTEF, 2006].

1.3.6 Emissions to water

In general, cement production does not generate effluent. In cement production by using the dry or the semi-dry process, water is only used in small quantities, e.g. for cleaning processes. In principle, no emissions to water occur because water is recycled back into the process.

In the semi-wet process, slurry is used and dewatered in filter presses. In the wet process, water is used for grinding the raw materials and to form slurry. The raw materials used are often available with a high moisture content. The slurry is either fed directly into the kiln where the water is vaporised or first sent to a slurry dryer.

Water which is sometimes used in the cooling process for cooling down the clinker, is directly vaporised because of the high temperatures of clinker material.

A water balance from a specific example plant can be found in Table 4.24 in Section 4.2.2.3.

1.3.7 Noise

Noise emissions occur throughout the whole cement manufacturing process from preparing and processing raw materials, from the clinker burning and cement production process, from material storage as well as from the dispatch and shipping of the final products. The heavy machinery and large fans used in various parts of the cement manufacturing process can give rise to noise and/or vibration emissions, particularly from:

- chutes and hoppers
- any operations involving fracture, crushing, milling and screening of raw material, fuels, clinker and cement
- exhaust fans
- blowers
- duct vibration.

Plants are required to comply with reduction standards in compliance with national legislation, and noise surveys are being conducted and evaluated. Natural noise barriers, such as office buildings, walls, trees or bushes are used in the cement industry to reduce noise emissions. Where residential areas are located close to a plant, the planning of new buildings at the cement site is connected with a necessity to reduce noise emissions [45, Schorcht, 2006], [81, Castle Cement UK, 2006]

1.3.8 Odour

Odour emissions are very rarely a problem with a well operated plant. If the raw materials contain combustible components (kerogens) which do not burn when they are heated in the preheater, but instead only pyrolise, emissions of hydrocarbons can occur. These hydrocarbon emissions can be seen above the stack as a ‘blue haze’ or plume and can cause an unpleasant smell around the cement plant under unfavourable weather conditions.

Burning of fuels containing sulphur and/or use of raw materials containing sulphur can lead to odour emissions (a problem especially encountered in shaft kilns).

Furthermore, waste materials used as raw materials or fuels may lead to odour emissions, especially during different process steps such as preparation and storage. In cases when ammonia is used for NO_x reduction, this may also lead to odour emissions during certain process steps, if not handled properly.

1.3.9 Monitoring

1.3.9.1 Monitoring of parameters and emissions

To control kiln processes, continuous measurements are recommended for the following parameters:

- pressure
- temperature
- O_2 content
- NO_x
- CO, and possibly when the SO_x concentration is high
- SO_2 (it is a developing technique to optimise CO with NO_x and SO_2).

To accurately quantify the emissions, continuous measurements are recommended for the following parameters (these may need to be measured again if their levels can change after the point where they are measured to be used for control):

- exhaust volume (can be calculated but is regarded by some to be complicated)
- humidity (can be calculated but is regarded by some to be complicated)
- temperature
- dust
- O_2
- NO_x
- SO_2, and
- CO.

Regular periodic monitoring is appropriately carried out for the following substances:

- metals and their compounds
- TOC
- HCl
- HF
- NH_3, and
- PCDD/F.

However, it is also possible to measure and monitor TOC, NH_3, HCl, and HF continuously and to sample PCDD/F and PCB continuously for analysis from 1 to 30 days. Furthermore, Hg is measured continuously in two Member States of the EU-27.

Measurements of the following substances may be required occasionally under special operating conditions:

- BTX (benzene, toluene, xylene)
- PAH (polyaromatic hydrocarbons), and
- other organic pollutants (for example chlorobenzenes, PCB (polychlorinated biphenyls) including coplanar congeners, chloronaphthalenes, etc.).

It is especially important to measure metals when wastes with enhanced volatile metal contents are used as raw materials or fuels. Furthermore, depending on the fuels used, the process conditions and the relevance of the emissions, it may be necessary to carry out additional measurements. The requirements of existing European and national regulations have to be considered, e.g. it has to be noted, when co-incinerating waste, the requirements of the Waste Incineration Directive (WID, 2000/76/EC) have to be met [59, European Commission, 2000]. If waste is used in cement kilns, often emissions of TOC and mercury, especially in the case of using sewage sludge, are monitored from the exhaust gas of cement kilns (in some cases continuously), additionally to the regular continuous measurements of dust, NO_x, SO_2 and CO emissions, which are carried out. Further information regarding continuous measurements of mercury in German cement plants can be found in the conclusions and recommendations section for the cement industry (see Section 1.7). Depending on the input and the types of waste fuels used, process conditions and the relevance of the emissions, additional measurements are carried out for HCl, HF, heavy metals, benzo-a-pyrene, benzene and polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs). Furthermore, for the use of waste often recurrent measurements are carried out, e.g. once a year [76, Germany, 2006].

It is appropriate to have all these substances measured on at least one occasion to provide data when applying for the plant's first IPPC permit.

Additional useful information can be found in the Reference Document on the General Principles of Monitoring [151, European Commission, 2003].

1.4 Techniques to consider in the determination of BAT

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

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

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

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

The standard structure used to outline each measure/technique is shown in Table 1.30. However, as the boundaries between the elements mentioned below may overlap to a certain extent, the structure is kept flexible, reflecting the individual case.

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

Table 1.30: Information breakdown for each measure/technique described in this section

The costs for abatement measures/techniques have to be evaluated in relation to the type of cement kiln used, the size of the installations, the effectiveness of the measures/techniques and the circumstances of the individual application.

In this context, Section 1.4.8 gives examples of costs data, e.g. investment, maintenance and operational costs for different flue-gas measures/techniques, such as for the abatement of dust, inorganic gaseous compounds and organic gaseous compounds.

1.4.1 Consumption of raw materials

Description and achieved environmental benefits
Recycling and/or re-use of collected dust to the production processes reduces the total consumption of raw materials. This recycling may take place directly in the kiln or kiln feed (the alkali metal content being the limiting factor) or by blending with finished cement products.

The use of suitable wastes as raw materials can reduce the input of natural resources, but should always be done with a satisfactory control of the substances introduced to the kiln process.

Cross-media effects
Saving of natural resources.

By using suitable wastes as raw material and depending on their characteristics, it may be possible that different emissions occur.

Costs for the quality control of wastes and emissions monitoring may increase.

Operational data
See Section 1.2.4.2.

Applicability
This measure is, in principle, applicable to the cement industry regarding quality control, volatile organics and heavy metal content.

Economics
Costs for raw materials can be reduced.

Driving force for implementation
Legal requirements.
Local conditions.
Economic consideration.

Example plants and reference literature
Cement plants in the EU-27.
[168, TWG CLM, 2007]

1.4.2 Reduction of energy consumption (energy efficiency)

In this context, useful information can also be found in the Reference Document on Best Available Techniques for Energy Efficiency (ENE) [181, European Commission, 2008].

1.4.2.1 Reduction of thermal energy use

Thermal energy use can be reduced by considering and implementing different measures/techniques, such as implementing thermal energy optimisation measures/techniques in the kiln system (see Section 1.4.2.1.1.). Several factors affect the energy consumption of modern cement kilns, such as raw material properties, e.g. moisture content, burnability (see Section 1.4.2.1.2), the use of fuels with different properties and varying parameters (see Section 1.4.2.1.3) as well as the use of a gas bypass system (see Section 1.4.2.1.4). The measures/techniques can be applied individually. However all measures/techniques have to be considered in context with each other.

Furthermore, the production capacity of the kiln has an influence on the energy demand.

1.4.2.1.1 Kiln systems

Description
Kiln systems with multistage (four to six stages) cyclone preheaters with an integral calciner and tertiary air duct are considered standard technique for new plants and major up grades. In some cases of raw material with a high moisture content, three stage cyclone plants are used. Under optimised circumstances such a configuration will use 2900 – 3300 MJ/tonne clinker.

Thermal energy optimisation measures/techniques can be implemented at the different units of the plant including:

- cooler:
  - installation of a modern clinker cooler, e.g. stationary preliminary grate
  - use of cooler grate plates offering a greater flow resistance to provide a more uniform cooling air distribution
  - controlled cooling air supply to the individual grate sections

- kiln:
  - high capacity utilisation
  - optimised length:diameter ratio
  - optimised kiln design with regards to the fuel type which is inserted
  - optimised kiln firing systems
  - uniform and stable operating conditions
  - optimisation of process controls
  - tertiary air duct
  - near-stoichiometric, but oxidising kiln conditions
  - use of mineralisers
  - reducing air-in leakage

- calciner:
  - low pressure drop
  - uniform distribution of the hot meal in the kiln riser
  - minimal coating formation due to low circulation of alkalis
  - extensive precalcination of the raw meal

- preheater:
    - low pressure drop and a high degree of heat recuperation in the cyclones
    - high cyclone collection rate
    - uniform meal distribution over the gas duct cross-sections
    - uniform distribution of solid and gas streams in a two-string preheater
    - cyclone stages (three to six cyclones in total)

- material handling:
    - low moisture content of raw materials and fuels
    - easily combustible fuels with a high calorific value
    - homogenising and even feeding (precise metering) of kiln feed material
    - homogenising and even feeding of fuels

- mills:
    - compound operation of mills.

Achieved environmental benefits
Reduction of thermal energy consumption.

Cross-media effects
The use of a gas/air exchanger or a quench system for long kilns as well as a gas bypass in preheater/precalciner kilns increases fuel energy.

For the use of flame cooling, additional heat could be required to evaporate the water which decreases the energy efficiency.

Lower numbers of cyclones induces higher thermal losses with the flue-gas leaving the preheater.

Operational data
Under the optimised conditions of a short-term performance test (e.g. 36 hours performance test) the thermal energy use is 2900 – 3300 MJ/tonne clinker. Due to events deviating from the regular operating conditions (e.g. start-ups and shutdowns) the yearly average values are about 160 – 320 MJ/tonnes clinker higher.

In cases when plants are suitable and designed especially for the use of certain types of waste fuels, thermal energy consumption can still be in the range of between 3120 – 3400 MJ/t clinker. Properties of the waste fuels used, e.g. calorific value, reactivity, coarseness, influence the energy efficiency (see Sections 1.2.4.3 and 1.3.3.3) [92, Austria, 2006], [162, A TEC, 2006], [171, A TEC, 2007].

Values are calculated and valid for a kiln system with a capacity of 3000 t/d. The production capacity has an influence on the energy demand as well. Burning clinker in kilns with a higher capacity of, e.g. 5000 t/d, saves about 100 MJ/tonne clinker while the energy consumption of smaller kilns, e.g. producing 1500 t/d, is up to 200 MJ/tonne clinker higher. These effects are mainly due to different wall heat losses per tonne of clinker produced. An evaluation of a kiln's energy consumption necessarily has to take these effects into account [84, CEMBUREAU, 2006].

The more cyclone preheater stages there are, the higher the energy efficiency of the kiln process will be. The lowest energy consumption can be achieved with five or six cyclones (see Section 1.3.3.1 and Table 1.17). However, the number of cyclone stages is mainly determined by the moisture content of the raw material (see also Section 1.4.2.1.2).

Applicability

The appropriate number of cyclone stages is determined by the throughput and the moisture content of raw materials and fuels which have to be dried by the remaining exhaust gas heat because local raw material situations vary widely regarding moisture content or burnability [76, Germany, 2006].

Several impacts can affect the energy consumption of up-to-date plants with precalciners and cyclone preheaters, e.g.:

- raw material properties like moisture content or burnability (see Sections 1.2.2, 1.2.4.2 and 1.4.2.1.2)
- the use of fuels with varying properties (see Sections 1.2.3, 1.2.4 and 1.4.2.1.3)
- the use of a gas bypass system (see Sections 1.2.5.4.1 and 1.4.2.1.4)
- target clinker quality
- kiln size and capacity.

Economics

Energy use (thermal and electrical) typically accounts for 30 – 40 % of the production costs.

Driving force for implementation

Legal requirements.

Local conditions.

Energy costs as well as emissions trading lead a way towards energy efficiency.

Example plants and reference literature

Cement plants in the EU-27.

[9, CEMBUREAU, 1997 November], [60, VDI 2094 Germany, 2003], [76, Germany, 2006], [81, Castle Cement UK, 2006], [84, CEMBUREAU, 2006], [86, EURITS, 2006], [92, Austria, 2006], [136, European Commission, 1993], [153, Castle Cement UK, 2007], [154, CEMEX UK, 2006], [162, A TEC, 2006], [168, TWG CLM, 2007], [171, A TEC, 2007], [181, European Commission, 2008].

1.4.2.1.2 Raw material properties

Description and achieved environmental benefits

The desired throughput and the moisture content of the raw materials influence the overall energy efficiency. These parameters determine the appropriate number of cyclone stages to be used, as the materials will have to be dried, preferably by the exhaust gas heat (see Sections 1.2.4.2, 1.3.3 and Table 1.17). The higher the moisture content, the higher the energy demand will be. It has to be noted that higher numbers of cyclones induces lower thermal losses which leave the preheater with the flue-gases.

Cross-media effects

Some fuels also contain a part of wet minerals used as raw material which are dried within the kiln system resulting in an increase of the specific energy consumption per tonne of clinker.

Operational data

For raw material input to the kiln which contains less than 8.5 % moisture, on a modern cement plant the drying can be completed using the exhaust gas from a four, five or six stage preheater. The sixth cyclone stage will save about 60 MJ/tonne clinker compared with a five stage preheater in the case of, where a reduced need for drying energy exists.

Calculated for the kiln preheater system alone, a four stage instead of a five stage cyclone preheater, requires an additional 90 MJ/tonne clinker approximately. With three cyclone stages the difference in energy demand rises further to above 250 MJ/tonne clinker. Three cyclone stages are only used in special cases with very wet material.

However, at raw material moistures greater than 8.5%, fewer cyclone stages are preferable so that the heat can be utilised in the drying process (raw mill).

Applicability
Applicable, in principle, to the cement industry.

Economics
No data available.

Driving force for implementation
Legal requirements.
Local conditions.

Example plants and reference literature
Cement plants in the EU-27.
[9, CEMBUREAU, 1997 November], [60, VDI 2094 Germany, 2003], [76, Germany, 2006], [84, CEMBUREAU, 2006], [81, Castle Cement UK, 2006], [86, EURITS, 2006], [92, Austria, 2006], [136, European Commission, 1993], [137, Klein/Hoenig, 2006], [153, Castle Cement UK, 2007], [154, CEMEX UK, 2006], [168, TWG CLM, 2007]

1.4.2.1.3 Fuel properties

Description
Characteristics of the fuels used such as adequate calorific value, low moisture content, adequate content of sulphur, metals, halogen compounds and volatiles as well as air-entraining injection have positive influences on the specific energy consumption of the kiln.

Preparation of fossil fuels like coal or lignite partly or completely dried outside of the kiln system, even outside of the cement plant, lead to improved energy efficiency of the kiln system because it is one of the main impacts on energy consumption. Lignite, for example, can be extracted with a moisture content of above 50 % and needs to be dried before delivery to the cement plant. Furthermore, the use of excess heat for drying fuels leads to thermal energy savings. Replacing fuels containing higher levels of moisture by dried fuels results in a decrease of the energy consumption per tonne of clinker in the kiln system.

Achieved environmental benefits
The practice to operate the calciner with a wide range of fuel grades, from highly reactive to extremely unreactive influences the energy efficiency. The use of a finely ground, dry and adequate calorific fuel compared to a low reactive or coarse fuel leads to an improved energy efficiency.

Cross-media effects
Some fuels also contain a part of wet minerals used as raw material which are dried into the kiln system resulting in an increase of the specific energy consumption per tonne of clinker.
By using wastes and depending on their characteristics, it may be possible that different emissions occur.

A high substitution rate of waste fuels along with less reactive or coarse fuels will relate to an increased amount of fuels that have to be used in order to achieve the thermal energy demand (see Sections 1.3.3, 1.3.3.3, 4.2.2.2 and Table 4.21).

Additional energy may be used for drying fuels outside of the kiln system.

Operational data
A comparison between identical kiln systems fired with hard coal on the one hand and lignite on the other hand, both of which commonly use fossil fuels, shows a difference of nearly 100 MJ/tonne clinker due to diverse fuel qualities.

The use of a finely ground coal compared to the use of a low reactive or coarse fuel can lower the energy demand of, e.g. more than 300 MJ/tonne clinker. Low thermal energy demand can be achieved (also for smaller plants) by using easily combustible fuels with a low moisture content.

In cases when plants are suitable and designed especially for the use of certain types of waste fuels, thermal energy consumption can still be as low as 3120 – 3400 MJ/t clinker. Parameters and properties of the waste fuels used, e.g. adequate calorific value, reactivity, coarseness, influence the energy efficiency (see Sections 1.2.4.3 and 1.3.3.3) [92, Austria, 2006], [162, A TEC, 2006], [171, A TEC, 2007]. Furthermore, an energy consumption of 3473 kJ/kg has been reported for a five stage precalciner kiln [81, Castle Cement UK, 2006], [163, Castle Cement UK, 2006], [168, TWG CLM, 2007].

Applicability
Applicable, in principle, to all cement kiln types.

When defining a fuel mix, the local availability of the fuels, the technical possibilities and the long term guarantee of supply are the main parameters that are taken into consideration.

By using waste fuels, the calorific value of these wastes has to be taken into account. It has to be noted that by using waste fuels with a lower calorific value, it can be necessary to burn a higher amount of waste fuels in comparison to fossil fuels in order to achieve the thermal energy demand.

Economics
The costs of different types of fossil and/or waste fuels and their preparation vary widely.

Driving force for implementation
Legal requirements.
Economical requirement.
Local conditions.

Example plants and reference literature
Cement plants in the EU-27 specifically in Austria and the UK.
[9, CEMBUREAU, 1997 November], [60, VDI 2094 Germany, 2003], [76, Germany, 2006], [81, Castle Cement UK, 2006], [84, CEMBUREAU, 2006], [86, EURITS, 2006], [92, Austria, 2006], [136, European Commission, 1993], [153, Castle Cement UK, 2007], [154, CEMEX UK, 2006], [162, A TEC, 2006], [163, Castle Cement UK, 2006], [168, TWG CLM, 2007], [171, A TEC, 2007]

1.4.2.1.4 Gas bypass system

Description and achieved environmental benefits
Raw material and fuels containing low levels of chlorine, sulphur and alkalis can minimise the enrichment cycle resulting from the internal circulation between the kiln and preheater. Furthermore, the deposit formation in the area of the kiln inlet, the calciner and the two bottom stages can be minimised which can be caused by higher concentrations. As a uniform kiln operation with minimised disturbances is the basis for energy efficient clinker production, shutdowns resulting from coating formation should be avoided. A low circulation of alkalis, chlorine and, to a lesser extent, sulphur can minimise the use of a gas bypass at the kiln inlet. By removing part of the process gas not only are chlorine, sulphur and alkalis discharged, but also other substances (see Section 1.2.5.4.1).

Cross-media effects

The removal of hot raw material and hot gas leads to a higher specific energy consumption of about 6 – 12 MJ/tonne clinker per per cent of removed kiln inlet gas. Hence, minimising the use of gas bypass has a positive effect on the specific energy consumption.

Operational data

See Section 1.3.3 for the use of energy.

Applicability

Applicable, in principle, to the cement industry.

Economics

No data available.

Driving force for implementation

Requirements of process technique.

Example plants and reference literature

Cement plants in the EU-27.

[9, CEMBUREAU, 1997 November], [60, VDI 2094 Germany, 2003], [76, Germany, 2006], [84, CEMBUREAU, 2006], [86, EURITS, 2006], [81, Castle Cement UK, 2006], [92, Austria, 2006], [136, European Commission, 1993], [153, Castle Cement UK, 2007], [154, CEMEX UK, 2006].

1.4.2.1.5 Reduction of the clinker content of cement products

Description

A technique to reduce energy use and emissions from the cement industry, expressed per unit mass of cement product, is to reduce the clinker content of cement products. This can be done by adding fillers and additions, for example, sand, slag, limestone, fly ash and pozzolana, in the grinding step.

Achieved environmental benefits

Reduction of energy use.
Reduction of emissions to air.
Saving of natural resources.
Avoidance of landfilling waste materials.

Cross-media effects

Adding fillers and additions into the final product at the cement plant ensures controlling of storage and handling materials as well as controlling quality requirements of the finished cement.

Operational data

In Europe, the average clinker content in cement is 80 – 85 %. Many manufacturers of cement are working on techniques to lower the clinker content further. One reported technique claims to exchange 50 % of the clinker with maintained product quality/performance and without increasing production costs. Cement standards define some types of cement with less than 20 % clinker, the balance being made up of blast furnace slag. However, cement types with a low clinker content are for special use only.

Applicability

Applicable, in principle, to the cement industry.

Economics

No data available.

Driving force for implementation

Legal requirements.
Economic requirements.
Availability of suitable waste materials.
Requirements regarding technical specification and carbon efficiency.
Requirements in accordance with cement standards.

Example plants and reference literature

Cement plants in the EU-27.
[9, CEMBUREAU, 1997 November], [168, TWG CLM, 2007]

1.4.2.2 Reduction of electrical energy use

Description

Electrical energy use can be minimised through the installation of power management systems and the utilisation of energy efficient equipment such as high pressure grinding rolls for clinker comminution and variable speed drives for fans as well as, in some cases, replacing old raw material mills with new mills (see Section 1.3.3.2). By using improved monitoring systems and reducing air leaks into the system, the use of electricity can also be optimised. Some of the reduction techniques described in the next sections will also have a positive effect on energy use, for example, process control optimisation.

Achieved environmental benefits

Reduction and minimisation of electrical use.
Saving of resources and reduction of emissions and waste.

Cross-media effects

No issues.

Operational data

A comparison of key characteristics from grinding technique examples are shown in Section 1.3.3 and Table 1.19. In some cases, the use of electricity was minimised by replacing old raw material mills with new alternatives.

Applicability

Applicable, in principle, to all cement kilns.

Economics

In 2006, electrical energy use typically accounted for 15 – 25 % of the total cement production costs (see Section 1.3.3.2).

Driving force for implementation

Legal requirements.
Economic requirements, cost savings.
Local conditions.

Example plants and reference literature

Cement plants in the EU-27.
[76, Germany, 2006], [81, Castle Cement UK, 2006], [168, TWG CLM, 2007], [181, European Commission, 2008], [182, TWG CLM, 2008]

1.4.2.3 Process selection

Description

The selected process will affect the emissions of all pollutants, and will also have a significant effect on the energy use, as also shown from a study concerning energy technologies in the cement sector commissioned by the European Commission in 1993. A series of technical improvements or modifications along with corresponding energy saving potentials were identified, e.g. process modifications, improvements for the grinding process and raw meal preparation as well as development of energy management systems [136, European Commission, 1993].

The thermal energy required for raw material drying and preheating mainly depends on the moisture content of the raw material as shown by examples in Section 1.3.3.1 and Table 1.17. The lower the moisture content is, the lower the energy demand will be.

For new plants and major upgrades, a dry process kiln with multistage preheating and precalcination is considered to be state of the art. The wet process kilns operating in Europe are generally expected to convert to the dry process when renewed [12, Netherlands, 1997], and so are semi-dry and semi-wet processes.

Achieved environmental benefits

Reduction of energy consumption.
Saving of resources and reduction of emissions and waste.

Cross-media effects

No issues.

Operational data

On modern cement plants, if the raw material input is less than 8.5 % moisture, the drying can be completed using the exhaust gas from a four or five stage preheater and without supplementary heat. From an example, the strategy for having the most efficient plant required the closure of plants that were located on chalk-based raw materials with a high moisture content; chalk contains over 20 % moisture.

In the UK (Padeswood Works), two wet process kilns with a total heat requirement of 5649 MJ/t clinker were replaced with a single precalciner. In comparison to these two wet process kilns, in 2006 the new dry precalciner kiln had a total heat requirement of 3473 MJ/t clinker which refers to an improvement of about 2176 MJ/t clinker and a reduction in the need for energy of approximately 36 %. However, this heat requirement is higher than would be expected from a five stage precalciner kiln because the organic carbon present in the waste which is used as raw material, burns in the upper cyclone stages of the preheater tower leading to high top of tower temperatures. As part of the process development, the tower temperatures will be reduced which will decrease the overall heat consumption to around 3150 MJ/t. The kiln is permitted to use up to 100 % waste fuel; however, in 2008, operational performance was around 30 %[81, Castle Cement UK, 2006], [163, Castle Cement UK, 2006], [182, TWG CLM, 2008].

Applicability

Applicable, in principle, to the cement industry for new installations/major upgrades.

Economics

Process changes from wet to dry are highly cost-intensive and may cost up to EUR 100 million.

Driving force for implementation

Legal requirements.
Local conditions.

Example plants and reference literature
Padeswood Works, Castle Cement UK.
[12, Netherlands, 1997], [81, Castle Cement UK, 2006] [136, European Commission, 1993] [163, Castle Cement UK, 2006], [168, TWG CLM, 2007], [182, TWG CLM, 2008]

1.4.2.4 Energy recovery from kilns and coolers/cogeneration

Description
The employment of cogeneration plants for steam and electricity or of combined heat and power plants is, in principle, applied in cement manufacturing. This is due to the simultaneous demand of heat and electric power which has for a long time been pursued (see Section 1.2.5.8). The Organic Rankine Cycle (ORC) process and conventional steam cycle processes are in operation. Furthermore, excess heat is recovered from clinker coolers or kiln off-gases for district heating.

The essential feature of the cogeneration plant is the driving engine; however, generating power from low temperature exhaust gas is applied in two cement plants. Most commonly excess heat is recovered from the clinker cooler and, to a lesser extent, from the kiln off-gases.

Achieved environmental benefits
Recovery of excess heat from the process and cogeneration of steam and electrical power along with increased independency from energy costs and reduction of CO_2 emissions.

Saving of resources and reduction of emissions.

Cross-media effects
No issues.

Operational data

Conventional steam cycle process and Organic Rankine Cycle (ORC) process
At Slite cement plant in Sweden, the conventional steam cycle process is used. The recoverable heat is sent to an existing electricity plant situated adjacent to the cement works, operated by a third party who re-utilises a steam turbine to generate electricity. The steam is generated in a two step heat recovery boiler system, one at the clinker cooler and one in the down duct of the kiln. This plant supplies energy of about 6 MW. Calculating from 1999, the investment costs were EUR 8 million for the boiler and steam distribution system, of which 25 % was subsidised. The re-used existing steam turbine contributed significantly to the economics of the installation; however, no costs were accounted for. The annual electricity production is approximately 50 GWh equalling ¼ of the plants total power need. A more detailed description can be found in Section 4.2.3.1.

The Organic Rankine Cycle (ORC) is used at a cement plant in Lengfurt in Germany to recover low temperature waste heat from the clinker cooler for generating power. This technique is essentially based on the use of an organic motive medium (pentane). Results have shown that 1.1 MW electrical power can be generated with the given mode of operation. The achieved availability was 97 % of the operation time of the cement kiln. The clinker cooler has a waste heat output via the clinker cooler exhaust air of 14 MW and an exhaust gas temperature of between 300 – 350 °C of which approx. 9 MW on average is extracted. This ORC technique at Lengfurt cement plant has been operating well for about 10 years. Further descriptions can be found in Section 4.2.3.2.

Recovery from clinker coolers or kiln off-gases for district heating
Waste heat can also be recovered from the clinker cooler for supplying hot water. In most cases, the boiler is on the clean gas side of the filter, as the dust collector needs to be an ESP in such cases. Alternatively, a sturdy, abrasion safe waste heat boiler is needed if a fabric filter is installed as a dedusting device after the boiler. Plants having waste heat recovery hot water

systems fitted include amongst others Burglengenfeld in Germany, and Büyükcekmece and Canakkale both in Turkey.

The Swedish cement plant at Skövde also has a heat recovery boiler situated in the kiln off-gas down duct. As at the Slite cement plant, the heat recovery is less than expected here with 1.2 MW, rather than the design of 2.5 MW. The situation is similar to that in Slite: the properties of the typical fine dust from the preheater tower prevent effective heat exchange. This remains a problem and challenges the use of preheater off-gas as a heat source, technically as well as economically.

Applicability
Applicable, in principle, to all cement kilns if sufficient excess heat is available and appropriate process parameters can be met. Local conditions and cost aspects have to be considered.

Economics
A large full sized power plant costs on average approximately between EUR 0.8 and 1.2 million per MW power generation installed. The plant at Lengfurt in Germany (Organic Rankine Cycle (ORC) process) is to a factor of approx. 3.3 above that. The ORC plant of Lengfurt with 1 MW is particularly small; however, it is economically feasible due to being part funding by the German government.

The situation is similar for the Slite cement plant (conventional steam cycle process), the steam turbine generator is set with 25 % funding and the availability of a vital and expensive part of the equipment. With the sole proceeds from the operation, justification for a full investment in a water steam boiler and power generation system is difficult.

With more new effective preheater towers and clinker coolers coming on line, the excess unutilised heat will be reduced and the scale of economics for cogeneration may not be favourable, especially where the majority of the heat is needed for material drying processes. Waste heat recovery from the kiln and clinker cooler for power generation may be assessed case by case. The economic viability may also be dependent on the local electricity price and the size of the plant.

Other than heat recovery for district heating, especially from a clinker cooler, heat recovery can be feasible if:

- a certain amount of excess heat is available
- recovered heat is saleable via the district heating
- district heating exists or is financed and operated by a partner
- a generator generates electricity, which can be used either for the plant or can be supplied to the public power grid.

Driving force for implementation
Legal requirements, e.g. the Cogeneration Directive [94, European Commission, 2004].
Reduction of costs.
Saving of resources.

Example plants and reference literature
Along with the two cogeneration power plants from waste heat which are described above (cement plants in Sweden and Germany), there are also other plants such as Alpena (40 MW) in Michigan, US; Halla (10.6 MW) in Korea; Tagada and Kanda both in Japan [133, CEMBUREAU/Federhen, 2007].
[76, Germany, 2006], [78, E. Baatz + G. Heidt, 2000], [79, Germany, 2001], [94, European Commission, 2004], [168, TWG CLM, 2007], [181, European Commission, 2008]

1.4.3 General techniques

1.4.3.1 Process control optimisation

Description

Optimisation of the clinker burning process is usually done to reduce the heat consumption, to improve the clinker quality and to increase the lifetime of the equipment (the refractory lining, for example) by stabilising process parameters. Reduction of emissions, such as NO_x, SO_2 and dust, are secondary effects of this optimisation. Smooth and stable kiln operation close to design values for process parameters is beneficial for all kiln emissions. Optimisation includes measures/techniques like homogenising the raw material, ensuring uniform coal dosing and improving the cooler's operation. To ensure that the feed rate of solid fuel is steady with minimal peaks, it is essential to have good designs of hoppers, transport conveyors and feeders, such as a modern, gravimetric solid fuel feed system.

NO_x reduction is caused by the reduced flame and burning temperatures and the reduced consumption of fuel, as well as zones with a reducing atmosphere in the kiln system (see also Section 1.4.5.1.6). Control of oxygen content (excess air) is critical to NO_x control. Generally, the lower the oxygen content (excess air) at, for instance, a cement kiln back-end, the less NO_x is produced. However, this has to be balanced against increases in CO and SO_2 at lower oxygen levels [37, UK, 1996].

The effect of kiln process optimisation on SO_2 emissions is considerable for long wet and dry kilns, and marginal for preheater kilns. The SO_2 reduction is caused by CaO resulting from the calcination process, the reduced SO_2 volatility at lower flame and burning temperatures, and the oxidising atmosphere in the kiln, together with stable kiln operation [9, CEMBUREAU, 1997 November].

Avoidance of kiln upsets and of CO trips when ESPs are applied, reduces dust emissions, and in doing so also reduces emissions of any substances adsorbed to the dust, for example metals. Modern control systems with faster measuring and control equipment can allow higher switch off criteria and thereby reduce the number of CO trips (see also Sections 1.3.4.1.1, 1.4.5.3 and 4.2.6).

Several cement equipment suppliers have developed expert automatic control systems based usually on the control of the burn by monitoring NO_x levels [37, UK, 1996].

Monitoring and measurement of process parameters and emissions are an essential part of process control optimisation and of achieving a stable kiln process.

Achieved environmental benefits

Reduced flame and burning temperatures cause NO_x emissions reductions. Furthermore, fuel consumption can be reduced. Dust emissions are reduced by avoidance of kiln upsets and avoidance of CO trips by using ESPs.

Cross-media effects

Reduction of emissions and fuel consumption.

Operational data

Depending on initial NO_x levels, NO_x reductions of up to 30 % and SO_2 reductions of up to 50 % have been reported for long wet and long dry kilns and is marginal for preheater kilns [9, CEMBUREAU, 1997 November].

Applicability

Process control optimisation is applicable to all kilns and can include many elements ranging from instruction/training of the kiln operators to installation of new equipment such as dosing systems, homogenisation silos, preblending beds and new clinker coolers. The effect of process control optimisation on SO_2 emissions is considerable for long wet and long dry kilns, and marginal for preheater kilns.

By using ESPs, CO trip management is applicable in the cement industry (see Section 1.4.5.3).

Economics

The costs of process control optimisation measures/techniques vary widely, up to EUR 5 million.

The investment required for developed expert automatic control systems based usually on the control of the burn by monitoring NO_X levels, i.e. a computer-based high level control system, is about EUR 300000, and additional investment may be necessary to install the required measuring and dosing systems at the plant.

Kiln optimisation is primarily done to reduce operating costs, increase capacity and improve product quality. The operating cost of an optimised kiln is usually reduced compared to the non-optimised state. The savings result from reduced fuel and refractory consumption, lower maintenance costs and higher productivity among other factors.

Driving force for implementation

Legal requirements.

Local conditions.

Example plants and reference literature

Cement plants in the EU-27.

[9, CEMBUREAU, 1997 November], [37, UK, 1996] [168, TWG CLM, 2007]

1.4.3.2 Choice of fuels and raw materials

Description

Careful selection and control of substances entering the kiln can reduce emissions. For example, limiting the sulphur content of both raw materials and fuels can reduce releases of SO_2. The same is valid for raw materials and fuels containing other substances, for example nitrogen, metals and organic compounds, e.g. chlorinated compounds. There are, however, some differences between different kiln systems and feeding points. For example, fuel sulphur is not a problem for dry preheater and precalciner kiln systems, and all organic compounds in fuels fed through the main burner will be completely destroyed.

Limiting the chlorine content of input materials reduces formation of alkaline chlorides (and other metal chlorides), which can cause build-ups and upset kiln conditions and therefore can impair the performance of electrostatic precipitators, which in turn causes increased dust emissions. High alkali materials may also require some of the dust to be bled off, rather than be recycled within the kiln system, to avoid high alkali contents in the final product. In this case, use of low alkali materials can allow the dust to be returned to the process, thus reducing the waste generated by the process.

Different types of wastes can replace conventional fuels and raw materials. However, a careful quality control on specific characteristics and parameters of these wastes is essential (see Sections 1.2.4 and 1.2.4.3.2). Waste used as fuel selected with an appropriate calorific value and reactivity as well as a low content of moisture and pollutants can save fossil fuels (see Sections 1.3.3 and 1.4.3.3). Wastes used as raw materials which contain VOCs, halogenated compounds and mercury can be particularly problematic regarding emissions. Feeding materials with a high content of volatile metals into the kiln system should be avoided (see Sections 1.3.4.7, 1.3.4.7.1 and 1.4.7). The mercury content in materials has to be minimised and it can be necessary to limit mercury input into the kiln system (see Section 1.3.4.13). In this context, see also Section 4.2.2.1.1, where examples of concentration ranges for substances in waste are presented. Wastes containing VOCs/halogenated compounds can only be used if the volatile components can be decomposed at high temperatures along with a sufficient residence time. When waste is used, systematic monitoring is required.

Achieved environmental benefits
Careful selection of fuels and raw materials can limit the input of substances that can cause emissions. The use of waste fuels can save fossil fuels which, furthermore, can reduce landfilling.

Cross-media effects
Any types of fuels and raw materials including wastes may have an effect on emissions (especially those occurring from volatile metals, such as mercury).

Operational data
No data available.

Applicability
The measures/techniques can, in principle, be carried out in the cement industry. The use of suitable waste materials is applicable where complete combustion of organic matter is assured and waste input control as well as emissions control guarantees a low level of emissions, e.g. metals and dioxins.

Economics
No data available.

Driving force for implementation
Legal requirements.
Local conditions.

Example plants and reference literature
Cement plants in the EU-27.
[74, CEMBUREAU, 2006], [76, Germany, 2006], [168, TWG CLM, 2007], [182, TWG CLM, 2008]

1.4.3.3 Use of wastes as fuels

Description
Selected wastes with adequate (net) calorific values (see Section 1.3.3.3 and Table 1.20) can be used as fuels in a cement kiln, replacing conventional fossil fuels, like coal, if they meet certain specifications and characteristics (see Section 1.2.4.1, Section 1.2.4.3). Often, they can only be used after a certain pretreatment to provide tailor-made fuels for the clinker burning process (see Section 1.2.4.3.2). Different criteria play a decisive role in the selection of waste fuels as they can have an impact on kiln operation and on emissions, such as:

- physical criteria, e.g. air entrainability
- chemical criteria, e.g. chlorine, sulphur, alkali and phosphate content, reactivity and volatile metal content.

To guarantee the characteristics of the waste fuel, a quality assurance system is required. In particular, this includes provisions for the sampling, the sample preparation, the analysis and the external monitoring. More useful information can be found in the technical specifications of the European Committee for Standardisation, such as CEN/TC 343 ‘Solid Recovered Fuels’. In this context, see also Section 4.2.2.1.1, where examples of concentration ranges for substances in waste are presented.

Depending on the types of waste used and their characteristics, the points at which the fuels are added to the kiln have to be considered (see Section 1.2.5.1) because the way the fuels are fed into the kiln can have an effect on the emissions. In general, the highest combustion temperatures are experienced by fuels fed through the main burner. For all feed points, temperatures and residence times depend on kiln design and kiln operation (see Section 1.2.4.1). To meet the requirements of the Waste Incineration Directive (WID), process gases have to maintain a temperature of 850 °C for two seconds (see Sections 1.2.4.3.2 and 1.3.4.5). When using waste with more than 1 % chlorine content then the operating conditions have to be 1100 °C and two seconds residence time.

To control emissions, some additional environmental equipment may be installed. Special control and process measures/techniques are needed to maintain environmental, safety and quality standards.

For the use of hazardous wastes (liquid waste fuels), safety management has to be taken into account when handling, e.g. storage, feeding (see Section 1.2.4.3.3). Furthermore, safety management for potentially self igniting materials should be considered when using waste fuels derived from pretreated and sorted waste fractions.

Achieved environmental benefits

The selection of waste fuels is driven by a number of interrelated considerations, including the following main points:

- reduction of emissions, e.g. fossil CO_2, NO_x
- reduction of the use of natural resources, e.g. fossil fuels and raw materials.

Cross-media effects

The characteristics of the different types of waste fuels, e.g. moisture, calorific value, can affect the specific energy consumption per tonne clinker, e.g. a low (net) calorific value and a high moisture content could result in an increase of the specific energy consumption per tonne of clinker. To achieve the same energy demand, the amount of used waste fuels with lower calorific values is higher compared to conventional fuels.

Depending on their characteristics, e.g. high volatile metal concentrations, waste fuels may have an effect on emissions. This can be controlled and minimised by appropriate input control.

Operational data

When changing the fuel mix used, the specific energy consumption per tonne of clinker can vary due to various reasons, depending on the type of fuel and the calorific value of the fuels used. Literature shows that fossil fuels have calorific values (average, net.) of, e.g. 26 – 30 MJ/kg for typical coal, 40 – 42 MJ/kg for typical fuel oil and plastic material has a calorific value of between 17 and 40 MJ/kg. It has to be noted that, of these wastes, the calorific values vary very widely, by up to 40 MJ/kg. Calorific values of animal meal (carcase meal) used in cement kilns is reported as being within a range of between 14 to 22 MJ/kg.

Applicability

The measures/techniques can, in principle, be carried out in the cement industry provided that there is complete combustion of organic matter. Waste input control as well as emissions control guarantees a low level of emissions, e.g. metals and PCDD/F.

Economics

In comparison to the use of fossil fuels, the use of waste fuels can reduce operational costs. Energy use typically accounts for 30 – 40 % of the production costs. The costs for fuels are, therefore, a significant part of the costs for manufacturing cement. Waste fuels may be less expensive than conventional fossil fuels although costs will vary with the type of waste fuels and local conditions. However, waste fuels have frequently be pretreated and made sufficiently homogeneous to be used in a cement kiln which can cause additional costs. Furthermore, additional monitoring and analysis costs can occur.

Driving force for implementation

Economical requirements.
Reduction of fuel costs.
Local conditions.
Availability of resources.

Example plants and reference literature

Cement plants in the EU-27.
[59, European Commission, 2000], [60, VDI 2094 Germany, 2003], [74, CEMBUREAU, 2006], [76, Germany, 2006], [92, Austria, 2006], [168, TWG CLM, 2007], [182, TWG CLM, 2008]

1.4.4 Emissions of dust (particulate matter)

In this section, measures/techniques to prevent channelled (See Sections 1.3.4.1.1 and 1.3.4.1.2) and diffuse (see Section 1.3.4.1.3) dust emissions are described. In this context, additional information can also be found in the BREF on Emissions from Storage and in the BREF on Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector [95, Sweden, 2006], [96, European Commission, 2006]

1.4.4.1 Measures/techniques for dusty operations

Description

Diffuse dust emissions sources mainly arise from the storage and handling of raw materials, fuels and clinker as well as from vehicle traffic used at the manufacturing site. A simple and linear site layout is advisable to minimise possible sources of diffuse dust. Proper and complete maintenance of the installation always has the indirect result of reducing diffuse dust by reducing air leakages and spillage points. The use of automatic devices and control systems also helps diffuse dust reduction, as well as continuous trouble-free operation.

Several different measures/techniques for diffuse dust abatement are presented here, which can be applied individually or in combination (see 1.3.4.1):

- enclose/encapsulate dusty operations, such as grinding, screening and mixing
- cover conveyors and elevators, which are constructed as closed systems, if diffuse dust emissions are likely to be released from dusty material
- reduce air leakages and spillage points, completion of installation
- use automatic devices and control systems
- ensure trouble-free operations
- mobile and stationary vacuum cleaning for proper and complete maintenance of the installation:
    - during maintenance operations or in cases of trouble with conveying systems, spillage of materials can take place. To prevent the formation of diffuse dust during removal operations, vacuum systems should be used. New buildings can easily be equipped with stationary vacuum cleaning systems, while existing buildings are normally better fitted with mobile systems and flexible connections

  - in specific cases, a circulation process could be favoured for pneumatic conveying systems
- ventilation and collection in fabric filters:
  - as far as possible, all material handling should be conducted in closed systems maintained under negative pressure. The suction air for this purpose is then dedusted by a fabric filter before being emitted into the air
- use closed storage with an automatic handling system:
  - clinker silos and closed fully automated raw material storage areas are considered the most efficient solution to the problem of diffuse dust generated by high volume stocks. These types of storage are equipped with one or more fabric filters to prevent diffuse dust formation in loading and unloading operations
  - use storage silos with adequate capacities, level indicators with cut out switches and with filters to deal with dust-bearing air displaced during filling operations
- use flexible filling pipes for dispatch and loading processes, equipped with a dust extraction system for loading cement, which are positioned towards the loading floor of the lorry.

Achieved environmental benefits
Reduction of diffuse dust emissions.
Noise reduction is also possible by enclosing machinery.

Cross-media effects
Increase in energy consumption from the use of vacuum systems.
When maintenance is carried out, additional waste may occur.

Operational data
Depending on the particular individual case related measure/technique.

Applicability
The measures/techniques can, in principle, be carried out in the cement industry.

Economics
Depending on the particular individual case related measure/technique.

Driving force for implementation
Legal requirements.
Local conditions.
Health and safety requirements for the workplace.

Example plants and reference literature
Cement plants in the EU-27.
[76, Germany, 2006], [168, TWG CLM, 2007]

1.4.4.2 Measures/techniques for bulk storage areas and stockpiles

Description and achieved environmental benefits

In order to reduce diffuse dust emissions from storage locations of dusty mineral raw materials or fuels into the open air, such stockpiles or bulk storage areas can be covered or enclosed with screening, walling or an enclosure consisting of vertical greenery (artificial or natural wind barriers for open pile wind protection).

Some measures/techniques for diffuse dust abatement are:

- open pile wind protection:
  - outdoor storage piles of dusty materials should be avoided, but when they do exist it is possible to reduce diffuse dust by using properly designed wind barriers
- water spray and chemical dust suppressors:
  - when the point source of diffuse dust is well localised, a water spray injection system can be installed. The humidification of dust particles aids agglomeration and so helps dust settle. A wide variety of agents is also available to improve the overall efficiency of the water spray
- paving, road wetting and housekeeping:
  - areas used by lorries should be paved when possible and the surface should be kept as clean as possible. Wetting the roads can reduce diffuse dust emissions, especially during dry weather. They also can be cleaned with road sweepers. Good housekeeping practices should be used in order to keep diffuse dust emissions to a minimum
- humidification of stockpiles:
  - diffuse dust emissions at stockpiles can be reduced by using sufficient humidification of the charging and discharging points, and by using conveyor belts with adjustable heights.

If diffuse dust emissions at the charging or discharging points of storage sites cannot be avoided, they can be reduced by matching the discharge height to the varying height of the heap, if possible automatically, or by reduction of the unloading velocity.

Cross-media effects

The water consumption increases when keeping locations wet.

There is an increase in energy consumption from the use of vacuum systems and water spray systems.

When maintenance is carried out, additional waste may occur.

Operational data

Depending on particular individual case related measure/technique.

Applicability

The measures/techniques can, in principle, be carried out in the cement industry.

Economics

Depending on particular individual case related measure/technique.

Driving force for implementation

Legal requirements.

Local conditions.

Health and safety requirements for the workplace.

Example plants and reference literature

Cement plants in the EU-27, Gador plant in Spain.

[9, CEMBUREAU, 1997 November], [45, Schorcht, 2006], [168, TWG CLM, 2007], [182, TWG CLM, 2008]

1.4.4.3 Reduction of channelled dust emissions

There are different main point sources of dust emissions from cement plants. These are kiln systems, clinker coolers and mills for raw material, cement and coal as well as subsidiary processes. A major part of the fine dust (PM_{10}, $PM_{2.5}$) can be reduced by reduction of the total dust load and by using high efficiency dedusting systems. Various dedusting devices have been used in the past for these duties but in 2007 the main dry flue-gas filter systems used for dust reduction are fabric filters, electrostatic precipitators (ESPs) or a combination of both, the so-called hybrid filters. In some cases, the use of sintered lamellar filters is reported; however, not for cement kiln applications. Examples of system types of ESPs, fabric filters and the amount of filter dust and dust extraction are shown in Table 1.24. Diffuse dust emissions from the handling and storage of materials, and the crushing and grinding of raw materials and fuels can also be significant (see Sections 1.4.4.1 and 1.4.4.2). Table 1.31 shows a summary of operational data which are available within the text of this section. This table gives an overview and should be read in conjunction with the corresponding sections and paragraphs below.

ESPs and fabric filters both have their advantages and disadvantages. Both have a very high dedusting efficiency during normal operation. During special conditions, such as high CO concentration, kiln start-up, kiln shutdown or switching from compound operation (raw mill on) to direct operation (raw mill off), the efficiency of ESPs can be significantly reduced while the efficiency of fabric filters is less affected. However, whilst using ESPs, the effects of CO trips can be minimised as per Section 4.2.6. ESPs and fabric filters have a high overall efficiency of higher than 99 % particulate retention and both depend on particle size. Both types of filter systems have to be properly (periodically) maintained to maintain adequate efficiency. Depending upon the exhaust gas temperature, different types of filter media have to be used. A disadvantage of fabric filters is that used filter bags are waste and have to be disposed of according to national regulations [9, CEMBUREAU, 1997 November], [103, CEMBUREAU, 2006], [168, TWG CLM, 2007], [182, TWG CLM, 2008].

Measure/technique	Applicability	Emissions data 5)		Cost 3)	
		mg/Nm^3 1)	kg/tonne 2)	Investment million EUR	Operating EUR/t clinker
Electrostatic precipitators	All kiln systems, clinker coolers, cement mills	10 – <20 10 – <20 <10	0.02 – 0.05 0.02 – 0.05 0.02	2.1 – 6.0 0.8 – 1.2 0.8 – 1.2	0.1 – 0.2 0.09 – 0.18 0.09 – 0.18
Fabric filters	All kiln systems, clinker coolers, mills (raw material, cement, coal mills)	<10 <10 <10	0.02 0.02 0.02	2.1 – 6.0 4) 1.0 – 1.4 4) 0.3 – 0.5 4)	0.15 – 0.35 0.1 – 0.15 0.03 – 0.04
Hybrid filters	All kiln systems, clinker coolers, cement mills	<10 – 20	0.02 – 0.05		
Diffuse dust abatement	All plants	-	-	-	-

1) For kiln systems normally referring to daily averages, dry gas, 273 K, 101.3 kPa and 10 % O_2
2) kg/tonne clinker: based on 2300 m^3/tonne clinker
3) Cost for reducing the emissions to 10 – 30 mg/Nm^3, normally referring to a kiln capacity of 3000 tonne clinker per day and initial emissions of up to 500 g dust/Nm^3
4) Depends on the filter medium used, see Table 1.32, by separation efficiencies of higher than 99.9 %
5) Emissions data can be found in the corresponding paragraph of this section

Table 1.31: Overview of measures/techniques for controlling dust in the cement production process

Further examples of system types of ESPs and fabric filters along with the amount of filter dust and dust extraction are shown in Section 1.3.4.1.1 and Table 1.24. These values represent typical ranges and the overview also allows an estimation of filter dust and dust extraction where applicable [76, Germany, 2006].

1.4.4.3.1 Electrostatic precipitators (ESPs)

Description and achieved environmental benefits

Electrostatic precipitators (ESPs) generate an electrostatic field across the path of particulate matter in the air stream. The particles become negatively charged and migrate towards positively charged collection plates. The collection plates are rapped or vibrated periodically, dislodging the material so that it falls into collection hoppers below. It is important that ESP rapping cycles are optimised to minimise particulate re-entrainment and thereby minimise the potential to affect plume visibility. ESPs are characterised by their ability to operate under conditions of high temperatures (up to approximately 400 °C) and high humidity.

The performance of an ESP is dependent on a variety of operational parameters, such as:

- moisture content of the gas
- flue-gas chemistry
- flue-gas flowrate
- particle size distribution and chemical make-up
- particulate electrical resistivity
- particulate loading rate
- gas temperature
- start and stop operation
- strength of the electric field
- area and shape of the electrodes
- SO_2 concentration
- moisture content
- transition phases of different operating conditions.

In particular, performance can be impaired by the build-up of material forming an insulating layer on the electrodes and so reducing the electric field. This can happen if there are high chlorine and sulphur inputs to the kiln process, forming alkali metal chlorides and sulphates. The alkali metal chlorides can form sub-micron dust (0.1 – 1 μm) and have high specific dust resistivity (of between $10^{12} – 10^{13}$ Ω/cm) forming insulating layers on the electrodes and so leading to problems in dust removal.

Problems of high dust resistivity can partly be solved by water injection in evaporation coolers. Another way of solving the problem is to use fabric filters.

Cross-media effects

Alkali metal chlorides and sulphates with sub-micron dust particles can be formed.
Explosion risks arise at high CO concentrations (see Section 1.4.5.3).
Electricity energy consumption increases with increased removal efficiency.
When maintenance is carried out, additional waste may occur.
Dust can be re-used.

Operational data

Sufficiently dimensioned ESPs, together with good air conditioning and an optimised ESP cleaning regime, can reduce levels down to 5 – 15 mg/Nm^3 as the monthly average (dry gas, 273 K, 10 % O_2). The designed collection efficiency of the particulate is higher than 99.99 %, and therefore emissions of only a few mg/Nm^3 can be achieved. ESPs are very efficient devices for collecting ultrafine particles (<0.5 μm), providing the particles have the ability to agglomerate. ESPs are of a heavy-duty design leading to high applicability and also relatively insensitive to disturbances in the process. Existing ESP installations can often be upgraded without the need for total replacement thereby limiting costs. This may be done by fitting more modern electrodes or installing automatic voltage control on older installations. In addition, it may be possible to improve the gas passage through the ESP or add supplementary stages. In 2006, many well designed and well maintained ESPs achieved dust emission levels of <10 mg/Nm^3 (daily average value). An ESP with emissions of less than 10 mg/Nm^3 can be built with the application of the most modern process control, optimal high voltage supplies, proper sizing and an appropriate number of electrical fields.

Besides dust, the ESP also removes substances that adsorb to the dust particles, such as dioxins and metals if present.

The size and electric power consumption of ESPs rise exponentially with decreasing clean gas dust content. An ESP depends on defined raw gas conditions, such as temperature and humidity, for optimum operation. The lifetime of an ESP can be several decades, providing all recommended maintenance is properly carried out. Some parts, such as hammers and bearings, need regular replacement after a few years of operation as part of routine maintenance.

Applicability

Because of their high efficiency, low pressure loss, high availability and energy efficiency, electrostatic precipitators became successfully established for dust collection from rotary kiln exhaust gas and clinker cooler exhaust gas. The ESP can be used in almost every cement kiln application for the collection of dust from kiln exhaust gas, bypass gas dust or the exit air from grate coolers.

The available literature indicates that there are no restrictions on the applicability of ESPs to the various types of processes used in the cement industry. ESPs are, however, not often chosen for cement mill dedusting because of the investment costs and the efficiency (relatively high emissions) during start-ups and shutdowns.

ESPs are characterised by their ability to operate under conditions of high temperatures (up to approximately 400 °C) and high humidity. The major disadvantages of this measure/technique are their decreased efficiency with an insulating layer and a build-up of material that may be generated with high chlorine and sulphur inputs. For the overall performance of ESPs, it is important to avoid CO trips (see Sections 1.2.5.6.1, 1.4.5.3 and 4.2.6).

In some cases, ESPs will have to be shut down during elevated CO levels in the flue-gases for safety reasons (CO trips) (see also Sections 1.3.4.1.1, 1.4.3.1, 1.4.5.3 and 4.2.6).

Economics

In 2000, the investment cost for a new ESP for a kiln with a capacity of 3000 tonne clinker/day, initial emission levels of up to 500 g/Nm^3 and a clean gas dust content of 10 – 50 mg/Nm^3 was about EUR 1.5 – 3.8 million, and can be an extra EUR 0.6 – 0.8 million for the conditioning tower and filter fan if required. The operating cost for the same kiln ESP was about EUR 0.1 – 0.2 per tonne of clinker. For a clinker cooler for a kiln capacity of 3000 tonne clinker/day, initial emission levels of up to 20 g/Nm^3 and a clean gas dust content of 10 – 50 mg/Nm^3, and a cement ball mill with a capacity of 160 tonne cement/hour, initial emission levels of up to 300 g/Nm^3 and a clean gas dust content of 10 – 50 mg/Nm^3, the investment cost for an ESP was about EUR 0.8 – 1.2 million and the operating cost was EUR 0.09 – 0.18 per tonne of clinker.

In 2006, the investment costs were reported to be in a range from EUR 4.5 million to 6 million for dedusting the kiln exhaust gas (kiln: 3000 t/d). The wide range depends on local manufacturing costs, erection costs (which can vary significantly) and the size of the kiln and the ESP (which is a function of the efficiency). Operational and maintenance costs are normally low. The difference depends, to a great extent, on the local evaluation of the power consumption and maintenance costs (see also Section 1.3.4.1.1, Table 1.24) [76, Germany, 2006].

See also Section 1.4.8.1 and Table 1.39 where example cost data for dust abatement techniques are shown.

Driving force for implementation
Legal requirements.
Health and safety requirements for the workplace.
Local conditions.

Example plants and reference literature
Cement plants in the EU-27.
[3, Austria, 1997], [9, CEMBUREAU, 1997 November], [10, Cementa AB/Hagström, 1994], [12, Netherlands, 1997], [27, University of Karlsruhe, 1996], [76, Germany, 2006], [86, EURITS, 2006], [103, CEMBUREAU, 2006] [168, TWG CLM, 2007], [182, TWG CLM, 2008]

1.4.4.3.2 Fabric filters

Description and achieved environmental benefits
Fabric filters are efficient dust collectors. The basic principle of fabric filtration is to use a fabric membrane which is permeable to gas but which will retain the dust. Basically, the filter medium is arranged geometrically; however, a distinction is made between cylindrical filter bags (vertically hanging) as shown in Figure 1.60 and filter pockets that are usually installed horizontally. Initially, dust is deposited both on the surface fibres and within the depth of the fabric, but as the surface layer builds up the dust itself becomes the dominating filter medium. Off-gas can flow either from the inside of the bag outwards or vice versa. As the dust cake thickens, the resistance to gas flow increases. Periodic cleaning of the filter medium is therefore necessary to control the gas pressure drop across the filter. Depending on the type of cleaning, the most common cleaning methods include compressed air pulsing (pulse jet filters) reverse airflow, mechanical rapping or shaking and vibration. The fabric filter should have multiple compartments which can be individually isolated in case of bag failure and there should be sufficient of these to allow adequate performance to be maintained if a compartment is taken off line. There should be 'burst bag detectors' in each compartment to indicate the need for maintenance when this happens.

Filter bags are available in a range of woven and non-woven fabrics. High temperature applications will result in the need for more exotic fabric types than are 'normally' supplied. However, a good range of these is available. Modern synthetic fabrics can operate in quite high temperatures of up to 280 °C. The key characteristics of different fabric filters along with costs schedules are shown in Table 1.32.

Figure 1.60: Example of a fabric filter and filter material used in a cement plant in the UK [82, CEMEX Rugby UK, 2006]

Cross-media effects

Increased electrical energy use with increased removal efficiency.
Increased compressed air for the cleaning cycle.
When maintenance is carried out, additional waste may occur.
By using sintered lamella filters, noise emissions may occur.

Operational data

Modern synthetic fabrics include materials which can operate in quite high temperatures of up to 280 °C. Typical values of filter rating are between 0.5 and 2.0 m/min. The separation efficiency can be higher than 99.9 %, and therefore emissions of less than 5 mg/Nm^3 can be achieved by well designed and well maintained fabric filters (dry gas, 273 K, 10 % O_2). Besides dust, the fabric filter also removes substances that adsorb to the dust particles, such as dioxins and metals if present.

The key characteristics of different fabric filters along with costs schedules are shown in Table 1.32:

Technical application of fibres in cement manufacturing processes and cement plants											
Types of fibres (no brand nomination)		**Temperature (°C)**		**Resistance to acids**	**Resistance to alkalis (most)**	**Hydrolysis/hot moisture**	**Oxidation/oxygen >13 %**	**Abrasion resistance for cement plant application**	**Filtration efficiency <u>without</u> surface treatment**	**Chemical or mechanical surface treatment to improve filtration and economics**	**Relative costs per area unit installed**
		Nominal	**Peak**	**Resistance can be changed due to temperatures and combination constituencies**							
Cotton		80	80	Poor	Good			Good	Very good		Low
Polypropylene	PP	90	100	Excellent	Excellent	Excellent	Excellent	Excellent	Good	Not needed for applications	Low
Wool				Fair	Poor				Very good		Low
Polyester	PES	150	160	Low	Fair	Poor	Excellent	Excellent	Good	Yes for process, no for silos of diffuse dust collectors	Low
Polyacrylonitrile copolymer	PAN	110	120	Good	Fair	Excellent	Excellent	Good	Good		Low
Polyacrylonitrile hymopolymer >95 %		125	135						Good		Low
Nylon			205	Poor to fair	Excellent			Excellent	Excellent		
Aramide (meta)/aromatic polyamide	AR/PA	180	200	Fair	Good	Fair	Excellent	Good	Good	Yes for process gas treatment applications	Medium
Polyvelylenesulphide	PPS	180	200	Excellent	Excellent	Good	Poor	Good	Good		Medium
Polyimide	PI	180	240	Fair	Fair	Fair	Good	Good	Excellent	Not necessary due to fibre structure	High
Glass fibre woven	GF	280	280	Good, except HF	Excellent	Excellent	Excellent	Poor	Fair	Low filtration velocity recommended	Medium
Glass fibre with ePTFE membrane (expanded)	GF+Mem.	260	280					Fair	Superior	Included due to membrane	High
Polytetrafluoroethylene	PTFE	250	260	Superior	Superior	Superior	Superior	Fair	Poor	Highly recommended	Very high
Table shows average costs for medium to large scale purchasing, typical for cement plants. Costs will vary due to energy and filter medium.											
Costs schedule	Low	up to EUR 10 per m^2 filter cloth, ex-works, packed, not installed									
	Medium	from EUR 10 to 20 per m^2 filter cloth, ex-works, packed, not installed									
	High	from EUR 20 to 40 per m^2 filter cloth, ex-works, packed, not installed									
	Very high	above EUR 40 per m^2 filter cloth, ex-works, packed, not installed									

Table 1.32: Key characteristics of different filter media and costs schedules
[86, EURITS, 2006], [81, Castle Cement UK, 2006] [134, CEMBUREAU/Federhen, 2007]

Applicability

This measure/technique can, in principle, be carried out in the cement industry and can be used in almost every cement kiln application for the collection of dust from kiln exhaust gas, bypass gas dust or the exhaust air from grate coolers. The available literature indicates that there are no restrictions on the applicability of fabric filters to the various types of processes used in the cement industry. However, moisture and temperature have to be considered.

The performance of fabric filters is mainly influenced by different parameters, such as compatibility of the filter medium with the characteristics of the flue-gas and the dust, suitable properties for thermal, physical and chemical resistance, such as hydrolysis, acid, alkali, and oxidation and process temperature. Important characteristics of a filter are the size of the filtering surface, the separation efficiency and the resistance to filtration, the so-called 'filter differential pressure'. This value depends on the properties of the filter medium and dust. The basic parameter for the design of a filter is the volume flow. Therefore, the filter rating has to be determined, which depends on the type, the amount and the properties of the dust and the gas.

Service life, energy and maintenance requirements of fabric filters are influenced by thermal and mechanical stress. Gas flowrate, dust cake thickness, porosity and cleaning cycle can affect the removal efficiency. The improvements, such as reduced pressure drop across the medium, quick detection of potential leaks with continuous monitoring and by detectors, and cleaning systems, result in longer filter life and lower costs. Furthermore, cleaning cycles and cleaning methods of the filter material can affect the efficiency of the cleaning system. Tests show that, e.g. by using a low pressure pulse jet cleaning system the efficiency can be increased while at the same time minimising the power consumption and having great advantages with respect to noise emissions. This system can be used for dedusting exhaust gas from rotary kilns, but also for dedusting the alkali bypass, clinker cooler, mills and classifiers.

In combination with fabric filters, cyclones are applicable to clinker cooler systems. In a cyclone/centrifugal separator, the dust particles to be eliminated from an off-gas stream are forced out against the outer wall of the unit by centrifugal action and then eliminated through an aperture at the bottom of the unit. Centrifugal forces can be developed by directing the gas flow in a downward spiral motion through a cylindrical vessel (cyclonic separators) or by a rotating impeller fitted in the unit (mechanical centrifugal separators). In the cement industry, cyclones are combined with an air heat exchanger for temperature reduction and a fabric filter system (baghouse filter) for dust removal from, e.g. cooling exhaust gases. A cyclone can reduce the dust concentration by 70 %. In combination with an air heat exchanger and a baghouse filter, high cleaning efficiencies of up to 99.99 % are achievable along with low emission values of 5 – 7 mg/Nm^3. However, sufficient space for construction is necessary because of the great dimensions of the cyclone (e.g. 25 m length, 6.4 m height, 6.4 m diameter) and the combined heat exchanger. Furthermore, additional electrical energy is used while collection and recovery of separated dust may lead to reduced raw material consumption [148, Reitemeier, 2005].

Sintered lamella filters are sometimes used as filter media; however, not for cement kiln applications. Practical experience has shown that because of their fully sintered and compact form and the special PTFE coating, the sintered lamellae are very robust with a low maintenance requirement. The main advantages of this modern filter medium are a very high dust cleaning efficiency from off-gases in combination with a low pressure drops as well as a high resistance to abrasive wear. The filter geometry ensures a very compact structure and the filter can be installed under very constricted conditions. Noise emissions can be minimised by using a compact noise protection hood [144, Adlhoch, 1996].

Economics

The investment required to fit a new fabric filter to a kiln with a capacity of 3000 tonne clinker/day, with an initial emission level of up to 500 g/Nm^3 and a clean gas dust content of 10 - 50 mg/Nm^3 is about EUR 1.5 million – 6 million, and an extra EUR 0.6 million – 0.8 million are needed for the conditioning tower and filter fan if required. For separation efficiencies of higher than 99.9 % for dedusting the kiln exhaust gases, the investment costs for fabric filter plants (baghouse filters) can range between EUR 4 million to 8 million depending on the type and the number of filter bags used. Maintenance may appear to be low at costs of up to EUR 10 per Nm^2 for a filter bag as shown in Table 1.32. However, kiln exhaust filters can contain many thousands of bags and so a very large filter cloth area corresponds to many thousand Nm^2. Operational and maintenance costs depend, to a great extent, on the local evaluation of the power consumption and maintenance costs (see also Section 1.3.4.1.1 and Table 1.24).

Conditioning towers are generally applied to achieve applicable temperatures for fabric filter operations. The operating costs for the same kiln fabric filter are about EUR 0.10 – 0.35 per tonne clinker. A pulse jet fabric filter with an air to air heat exchanger and a filter fan for a grate clinker cooler for a kiln capacity of 3000 tonne clinker/day, with an initial emission level of up to 20 g/Nm^3 and a clean gas dust content of 10 – 50 mg/Nm^3 costs about EUR 1.0 million – 1.4 million and the operating cost is about EUR 0.10 – 0.15 per tonne clinker. For a cement ball mill with a capacity of 160 tonne cement/hour, and an initial emission level of up to 300 g/Nm^3 and clean gas dust content of 10 – 50 mg/Nm^3, the investment cost for a pulse jet fabric filter is about EUR 0.3 million – 0.5 million including a filter fan, and the operating cost is EUR 0.03 – 0.04 per tonne clinker [9, CEMBUREAU, 1997 November].

To optimise operating costs, different cement plants have installed optimised pressure pulse jet cleaning systems. The filter area loading, the filter differential pressure and the cleaning system are the three main important factors affecting the cost reduction for fabric filters. Because of the mutual interaction of these parameters, the aim is to achieve the highest possible air:cloth ratio, the lowest possible differential pressure and the lowest possible cleaning pressure. Total cost reductions (investment and operating costs) of between 12 and 25 % have been reported.

See also Table 1.32 above where the key characteristics for different fabric filters along with costs schedules are shown. Furthermore, see also Section 1.4.8.1 and Table 1.39 where example cost data for dust abatement techniques are shown.

Driving force for implementation
Legal requirements.
Local conditions.
Health and safety requirements for the workplace.

Example plants and reference literature
Cement plants in the EU-27; cement plant Dudfield, South Africa (use of cyclone in combination with an air-air heat exchanger and fabric filter plants (baghouse filter), cement plant in Germany (use of sintered lamella filters).
[3, Austria, 1997], [9, CEMBUREAU, 1997 November], [12, Netherlands, 1997], [76, Germany, 2006], [81, Castle Cement UK, 2006], [86, EURITS, 2006], [103, CEMBUREAU, 2006], [134, CEMBUREAU/Federhen, 2007], [144, Adlhoch, 1996], [145, Leibinger/Köberl, 2001], [146, Leibinger/Neumann, 2003], [147, Marmor/Petzold, 2006], [148, Reitemeier, 2005], [168, TWG CLM, 2007], [182, TWG CLM, 2008]

1.4.4.3.3 Hybrid filters

Description and achieved environmental benefits

Hybrid filters are the combination of ESPs and fabric filters in the same device. They generally result from the conversion of existing ESPs. They allow the partial re-use of the old equipment. The principle of a hybrid filter is shown in Figure 1.61.

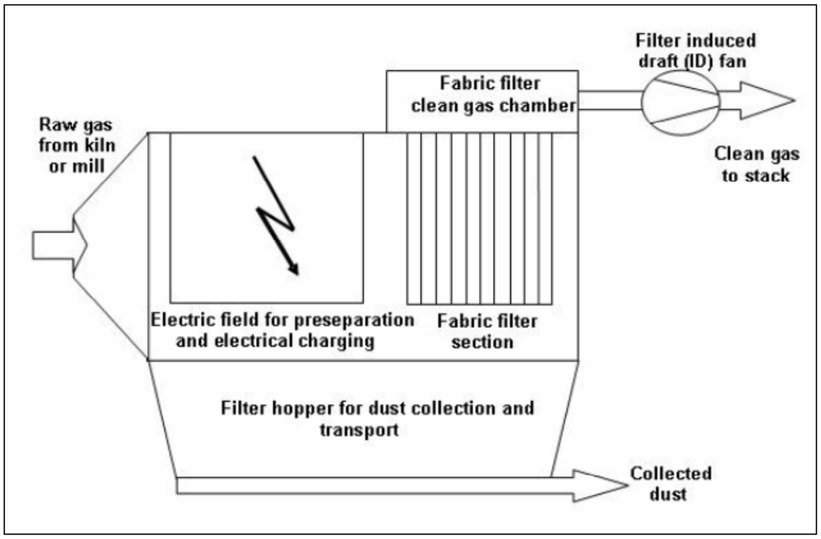


Figure 1.61: Hybrid filter for dust collection
[135, CEMBUREAU/Federhen, 2007]

Cross-media effects

Explosion risks arise in cases of high CO concentrations (CO trips).
When maintenance is carried out, additional waste may occur.
Reduced water use compared to ESPs.
Reduced amount of process losses/waste compared to fabric filters.

Operational data

Dust emissions figures from hybrid filters installed on kilns are reported to range from <10 to 20 mg/Nm^3 as a daily average value (see Section 1.3.4.1.1). However, dust emissions of less than 10 mg/Nm^3 are achieved by well maintained fabric filters (see Section 1.4.4.3.2).

Applicability

The measures/techniques are, in principle, applicable in the cement industry.

Economics

See also Section 1.4.8.1 and Table 1.39 where example cost data for dust abatement measures/techniques are shown.

Driving force for implementation

Legal requirements.
Local conditions.

Example plants and reference literature

Sagunto plant and Gador plant in Spain, cement plants in the EU-27.
[86, EURITS, 2006], [103, CEMBUREAU, 2006], [135, CEMBUREAU/Federhen, 2007], [168, TWG CLM, 2007], [182, TWG CLM, 2008]

1.4.5 Gaseous compounds

1.4.5.1 Reduction of NO_x emissions

For the reduction or controlling of NO_x emissions, one or a combination of primary and/or process-integrated and secondary measures/techniques are considered suitable. Primary measures/techniques are:

- flame cooling, e.g. high water content, liquid/solid wastes
- low NO_x burners
- mid kiln firing
- addition of mineralisers to improve the burnability of the raw meal (mineralised clinker)
- staged combustion (conventional or waste fuels) also in combination with precalciner and the use of optimised fuel mix
- process optimisation.

Furthermore, secondary measures/techniques can be used for NO_x reduction, such as:

- SNCR technique and high efficiency SNCR technique
- SCR technique.

For environmental/safety and economic reasons, the NO_x reduction process should preferably start with the implementation of general primary measures/techniques, such as process-integrated and control measures/techniques, staged combustion and flame cooling, improved firing technique, optimised cooler connections and fuel selection and these also reduce NO_x emissions (e.g. use of selected waste). Some well optimised preheater kiln systems and preheater/precalciner kiln systems are achieving less than 500 mg NO_x/Nm^3 with either primary measures/techniques only or combined with staged combustion as well as with a combination of fuel mix use and process-integrated measures/techniques. Raw material qualities, e.g. burnability of the raw mixes as well as fuel mixes and kiln system designs, are among the reasons for not being able to achieve this level. However, in many cement plants in the EU-27 (42 % in 2008), the SNCR technique is used in combination with primary measures/techniques for NO_x reduction, as shown in Table 1.33 [76, Germany, 2006], [85, CEMBUREAU, 2006]. Furthermore, two cement plants use the SCR technique (high dust).

Table 1.33 presents the number of full scale installations known in the EU-27 and the EU-23+ countries (see Glossary) using abatement measures/techniques to reduce NO_x emissions.

Measures/techniques for reducing/controlling NO_x emissions						
Country		**Flame cooling**	**Mineralised clinker**	**Staged combustion**	**SNCR**	**SCR**
Belgium	BE	2			2	
Bulgaria	BG					
Czech Republic	CZ				2[3]	
Denmark	DK		2		1	
Germany	DE			7	33	1[1]
Estonia	EE					
Greece	EL			1		
Spain	ES		4	2	3 + 5 (pilot phase)	
France	FR	2		7	14 + 4[6]	
Ireland	IE			1	2[5]	
Italy	IT	2		7	16[1]	1[2]
Cyprus	CY					
Latvia	LV					
Lithuania	LT					
Luxembourg[1]	LU					
Hungary	HU				3	
Malta	MT					
Netherlands	NL				1	
Austria	AT	3		2	8[3]	
Poland	PL			9		
Portugal	PT	6			4	
Rumania	RO					
Slovenia	SI					
Slovakia	SK					
Finland	FI				2	
Sweden	SE				3	
United Kingdom	UK			1	9[4]	
Switzerland	CH	2	1	1	4	
Norway	NO					
Turkey	TR	1	1	2		

[1] Reported to be in operation but reporting still lacking
[2] One plant has been in operation since the middle of 2006, second plant since 2007
[3] Scheduled for 2008
[4] Put into operation in 2007
[5] Scheduled for commissioning in 2007
[6] Scheduled for 2008

Table 1.33: Measures/techniques for reducing NO_x emissions used in the cement industries in the EU-27 and 0EU-23+ countries
[85, CEMBUREAU, 2006]

Table 1.34 gives an overview of the measures/techniques that have a positive effect on (but not necessarily cumulative), i.e. to reduce, the emissions of NO_x arising during the manufacture of cement. This table is a summary of operational data which are available within the text of this section and should be read in conjunction with the corresponding paragraphs in the following sections.

Measure/technique	Kiln systems applicability	Reduction efficiency (%)	Emissions data[15]		Cost data[3]	
			mg/Nm^3 [1]	kg/t[2]	Investment (EUR million)	Operating EUR/t clinker
Flame cooling[5]	All	0 – 35	Primary reduced to <500 – 1000[9]	1.15 – 2.3	Up to 0.2	Up to 0.5
Low NO_x burner	All	0 – 35	500 – 1000	1.15 – 2.3	Up to 0.45	0.07
Primary measures/techniques EGTEI 2003[4]	All	25	1400 reduced to 1050	2.4	0.25	0.056
Mid-kiln firing	Long	20 – 40	No Information	-	0.8 – 1.7	No information
Mineralised clinker	All	10 – 15	No information	-	No information	No information
Staged combustion	Precalciner	10 – 50	800[9] – 1000	1.84 – 2.3	0.1 – 2	No information
	Preheater				1 – 4	
SNCR [4] [5] [6] [12]	Preheater and precalciner	30 to 90[10]	200[10, 11] – 500[14]	0.4 – 1.15	0.5 – 1.2	0.1 – 1.7
	Grate preheater	35	580[5, 6]	1.15	0.5	0.84
SCR[7]	Possibly all, preheater and precalciner	43[13] – 95	200[8] – <500	0.23 – 1.15	2.2 – 4.5	0.33 – 3.0

[1] Normally refers to daily averages, dry gas, 273 K, 101.3 kPa and 10 % O_2

[2] kg/tonne clinker: based on 2300 m^3/tonne clinker

[3] Normally refers to a kiln capacity of 3000 tonne clinker/day and initial emissions of up to 2000 mg NO_x/Nm^3

[4] EGTEI costs estimation for a kiln capacity of 1100 t/d in 2000

[5] Experiment in France in co-operation with the Environment Ministry, ADEME and ATILH in 2000 (issue 2003)

[6] CEMBUREAU contribution on NO_x abatement 2006, yearly average values, see Section 1.3.4.2 and Figure 1.29

[7] Germany and Italy, see also Table 1.35 and Table 4.26, cost data based on a kiln capacity of 1500 m^3/tonne clinker

[8] Pilot test results from Germany, Italy and Sweden and test results in 2007 (200 mg/Nm^3) from an Italian cement plant using SCR; in 1997, two suppliers in Europe offered full scale SCR to the cement industry with guaranteed performance levels of 100 – 200 mg/Nm^3

[9] Test results from French cement plant (project 10), precalciner kiln, initial NO_x level 1000 mg/Nm^3

[10] Swedish cement plants, yearly average value, initial NO_x level 800 – 1000 mg/Nm^3, ammonia slip 5 – 20 mg/Nm^3 (see Section 4.2.4.1), high efficiency SNCR, the ammonia slip has to be considered

[11] Germany: 200 – 350 mg/Nm^3 as daily average value, the ammonia slip has to be considered

[12] The lower NO_x emissions range may result in higher NH_3 emissions (ammonia slip), depending on the NO_x level in the raw gas stream

[13] Results from pilot test and long term operation of the demonstration plant, see Table 1.35

[14]) In combination with process integrated measures/techniques; initial NO_x level 1200 mg/Nm^3; the French Cement Industry Guide to NO_x emissions reduction measures/techniques, France/ADEME/MEDD

[15] Emissions data can be found in the corresponding paragraph of this section

Table 1.34: Measures/techniques for reducing NO_x emissions occurring in cement manufacturing processes
[12, Netherlands, 1997], [76, Germany, 2006], [85, CEMBUREAU, 2006], [101, France/ADEME/MEDD, 2002], [114, Sweden, 2006], [140, Italy, 2007], [141, Leibacher/Bellin/Linero, 2007], [173, Germany, 2007], [182, TWG CLM, 2008]

1.4.5.1.1 Flame cooling

Description

The addition of water to the fuel or directly to the flame by using different injection methods, as shown in Figure 1.62, such as injection of one fluid (liquid) or two fluids (liquid and compressed air or solids) or the use of liquid/solid wastes with a high water content reduces the temperature and increases the concentration of hydroxyl radicals. This can have a positive effect on NO_x reduction in the burning zone.

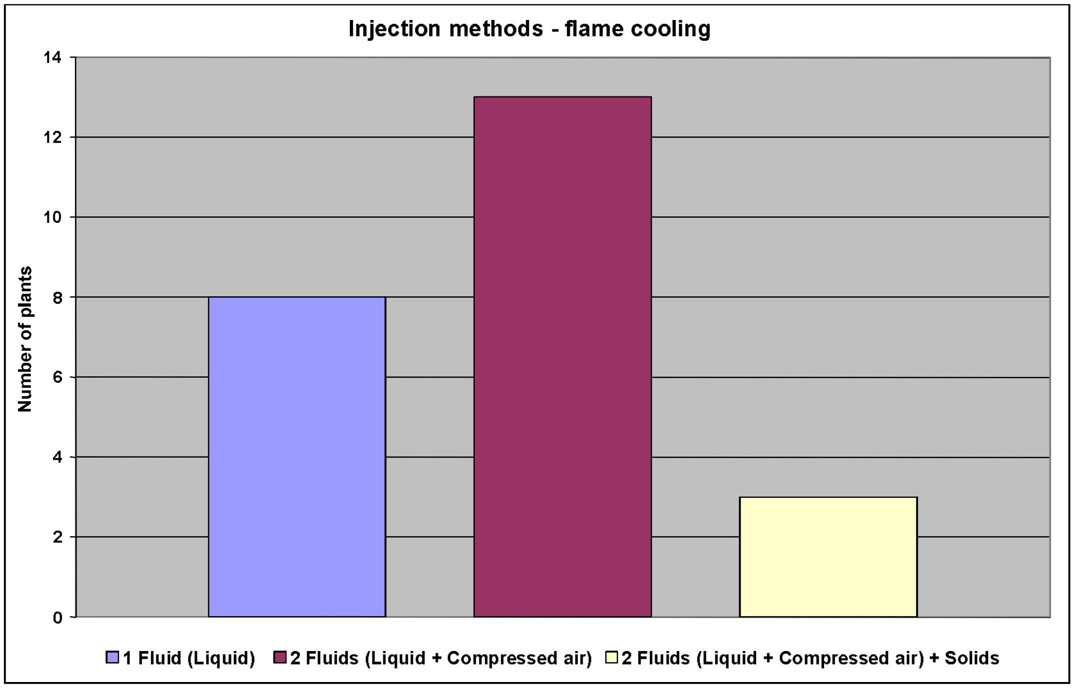


Figure 1.62: **Injection methods used for flame cooling in cement manufacture in EU-23+ countries**
[85, CEMBUREAU, 2006]

Achieved environmental benefits

Reduction of NO_x in the burning zone.
Reduction of NO_x emissions.

Cross-media effects

Additional heat may be required to evaporate the water, which causes slightly more CO_2 emissions (approximately 0.1 – 1.5 %) compared to the total CO_2 emissions of the kiln.
Energy efficiency of the kiln firing process decreases.
Water injection can cause kiln operation problems, such as reduced clinker output and may affect the clinker quality.

Operational data

Reduction rates/efficiencies from 10 – 35 % have been reported. Emissions ranges of <500 – 1000 mg/Nm^3 were reported (yearly average values) (see Section 1.3.4.2, Figure 1.27 and Figure 1.28).

Applicability

Flame cooling can be applied for all types of kilns used for cement manufacturing. As shown in Figure 1.63, nearly 40 suspension preheater kilns are equipped with flame cooling.

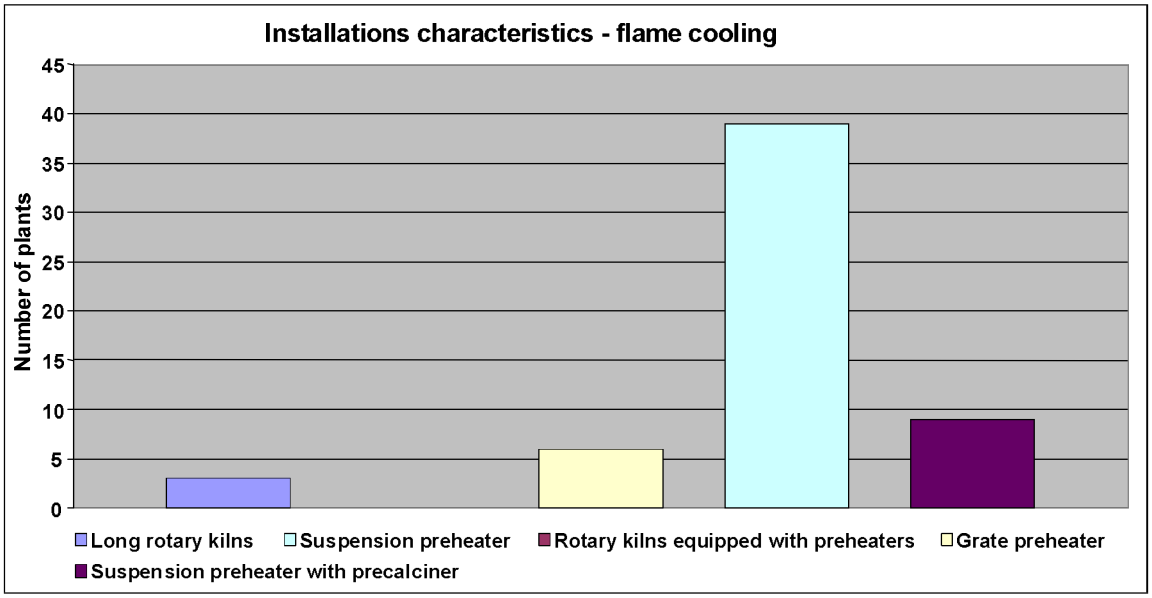


Figure 1.63: **Installation characteristics for flame cooling application in EU-23+ countries [85, CEMBUREAU, 2006]**

Economics

For a kiln capacity of 3000 t/d the investment costs are estimated to be up to EUR 0.2 million and the operating costs up to EUR 0.25 per tonne clinker. Furthermore as shown in Table 1.34, for a reduction efficiency of NO_x emissions of up to 35 %, investment costs of up to EUR 0.2 million and operating costs of up to EUR 0.5/t clinker were reported.

Driving force for implementation

Legal requirements.
Local conditions.

Example plants and reference literature

Cement plants in the EU-27
[8, CEMBUREAU, 2001], [9, CEMBUREAU, 1997 November], [76, Germany, 2006], [85, CEMBUREAU, 2006], [168, TWG CLM, 2007], [182, TWG CLM, 2008]

1.4.5.1.2 Low NO_x burners

Description and achieved environmental benefits

Designs of low NO_x burners (indirect firing) vary in detail but essentially the fuel and air are injected into the kiln through concentric tubes. The primary air proportion is reduced to some 6 – 10 % of that required for stoichiometric combustion (typically 10 – 15 % in traditional burners). Axial air is injected at high momentum in the outer channel. The coal may be blown through the centre pipe or the middle channel. A third channel is used for swirl air, its swirl being induced by vanes at, or behind, the outlet of the firing pipe.

The net effect of this burner design is to produce very early ignition, especially of the volatile compounds in the fuel, in an oxygen-deficient atmosphere, and this will tend to reduce the formation of NO_x.

Cross-media effects

No issues.

Operational data

NO_x reductions of up to 35 % are achievable in successful installations and emission levels of around 500 – 1000 mg/Nm^3 (daily average value) have been reported.

Applicability

Low NO_x burners can be applied to all rotary kilns, in the main kiln as well as in the precalciner. However, the application of low NO_x burners is not always followed by a reduction of NO_x emissions.

The set-up of the burner has to be optimised. If the initial burner runs on a low percentage of primary air, a low NO_x burner will have a marginal effect.

Economics

The investment cost for a new low NO_x burner is about EUR 150000 to 450000 for a kiln capacity of 3000 tonne clinker/day. However, by replacing a burner by a low NO_x burner, investment costs can rise up to EUR 600000 and additional work is required for modifying fine coal storage and metering. If the existing firing system uses direct firing, it should be changed to an indirect firing system to allow combustion with a low primary airflow; this will mean an additional investment cost of about EUR 600000 to 800000 for a kiln capacity of 3000 tonne clinker/day.

See also Table 1.34 and Table 1.40 (Section 1.4.8.2) where example costs are shown.

Driving force for implementation

Legal requirements.
Local conditions.

Example plants and reference literature

Cement plants in the EU-27.
[9, CEMBUREAU, 1997 November], [12, Netherlands, 1997], [20, Rother, 1996 January,] [76, Germany, 2006], [85, CEMBUREAU, 2006], [101, France/ADEME/MEDD, 2002], [168, TWG CLM, 2007], [182, TWG CLM, 2008]

1.4.5.1.3 Staged combustion

Description and achieved environmental benefits

Staged combustion is applied at cement kilns with an especially designed precalciner. The first combustion stage takes place in the rotary kiln under optimum conditions for the clinker burning process. The second combustion stage is a burner at the kiln inlet, which produces a reducing atmosphere that decomposes a portion of the nitrogen oxides generated in the sintering zone. The high temperature in this zone is particularly favourable for the reaction which reconverts the NO_x to elementary nitrogen. In the third combustion stage, the calcining fuel is fed into the calciner with an amount of tertiary air, producing a reducing atmosphere there, too. This system reduces the generation of NO_x from the fuel, and also decreases the NO_x coming out of the kiln. In the fourth and final combustion stage, the remaining tertiary air is fed into the system as ‘top air’ for residual combustion.

Calciners differ from one another essentially in the location of the fuel input, the way in which the fuel, kiln feed and tertiary air are distributed, and the geometric configuration.

Staged firing technique can, in general, only be used with kilns equipped with a precalciner. Substantial plant modifications are necessary in cyclone preheater systems without a precalciner. If this cannot be combined with an increase in production capacity, the manufacturers offer a solution with so-called ‘small’ tertiary air ducting and a calciner. In this case, only a small proportion of about 10 – 25 % of the total heat needed from the kiln is passed through the calciner, but this is sufficient to produce a reducing zone for decomposing nitrogen oxides. On the other hand, experiences from a kiln with 10 % firing in the kiln inlet shows that this is not always sufficient to produce a sufficient reducing zone.

Lump waste fuel (for example tyres) firing is a possible variant of the staged combustion technique as a reducing zone is created when the lump fuel is burned. In preheater/precalciner kilns, the lump fuel can be introduced at the kiln inlet or at the precalciner. Lump fuel firing is reported to have a positive effect on NO_x reduction (up to 20 – 30 % reduction) [76, Germany, 2006]. However, it is very difficult to produce a controlled reduction atmosphere with lump fuel firing [9, CEMBUREAU, 1997 November].

Cross-media effects

Emissions of CO and SO_2 can increase if the combustion process is not completed in the precalciner and problems with CO and clogging have been reported when attempting high efficiencies.

Operational data

Some modern well optimised plants achieve emission levels of below 450 mg NO_x/Nm^3 (daily average value) with multistage combustion and by using an appropriate fuel mix, such as highly reactive fuels, whereas with low reactive fuels, 800 – 1000 mg/Nm^3 (daily average value) might be achieved, as also shown from experience in Spain. Similar NO_x reduction has been reported when using secondary fuels.

During tests in France in 2002 (e.g. precalciner operating on staged combustion by using 100 % sulphurated petcoke as fuel), a NO_x reduction of about 200 mg/Nm^3 was achieved with initial NO_x levels of 1000 mg/Nm^3. However, this was only obtained during short periods of the tests and by using an optimal raw meal for burnability. More extreme operating conditions may allow lower NO_x emission levels to be achieved. However, often these operating conditions lead to operational problems like increasing build-ups in kilns and calciners. An increase of the CO emissions is only observed in very few plants designed with relatively short residence times or where combustion is not properly optimised.

In some cases, possible reductions in NO_x by up to 50 % were specified by the suppliers of the different staged firing systems. However, it is difficult to maintain the guaranteed values for this level of NO_x abatement while at the same time limiting the CO emissions.

Applicability

Staged firing technique can, in general, only be used with kilns equipped with a precalciner. Substantial plant modifications are necessary in cyclone preheater systems without a precalciner.

Precalciner kilns allow independent settings of the oxidation/reducing levels in the cement kiln and in the precalciner kiln. Injection of parts of the fuel can lead to decreased NO_x emissions.

Adding fuel to the grate of the *Lepol kiln* can lead to a significant NO_x reduction, but may develop/increase other emissions.

Cyclone preheater kilns without a precalciner allow a reduction of NO_x emissions; however, emissions of SO_2 and VOC may increase because of the local reducing zone. These emissions should be continuously monitored.

In the UK, a *long kiln with mid-kiln staged combustion* has been in operation for several years.

Economics
The investment costs for installing staged combustion at a precalciner kiln are EUR 0.1 million to 2.0 million, depending on the design of the existing calciner. The investment costs for a precalciner and the tertiary duct for a 3000 tonne/day preheater kiln with a grate cooler into a precalciner kiln are about EUR 1 million to 4 million. The investment costs for the transformation of a 3000 tonne/day preheater kiln with a satellite cooler into a precalciner kiln with a grate cooler are about EUR 15 million to 20 million.

See also Table 1.34 and Table 1.40 (Section 1.4.8.2) where example costs are shown.

Driving force for implementation
Legal requirements.
Local conditions.

Example plants and reference literature
Cement plants in the EU-27.
[9, CEMBUREAU, 1997 November], [12, Netherlands, 1997], [42, Billhardt/Kuhlmann/Ruhland/Schneider/Xeller, 1996 October], [76, Germany, 2006], [85, CEMBUREAU, 2006], [101, France/ADEME/MEDD, 2002], [168, TWG CLM, 2007], [182, TWG CLM, 2008]

1.4.5.1.4 Mid-kiln firing

Description and achieved environmental benefits
In long wet and long dry kilns, the creation of a reducing zone by firing lump fuel can reduce NO_x emissions. As long kilns usually have no access to a temperature zone of about 900 – 1000 °C, mid-kiln firing systems have been installed at some plants in order to be able to use waste fuels that cannot pass the main burner (for example tyres) [9, CEMBUREAU, 1997 November].

Cross-media effects
The rate of burning waste fuels can result in the chains being burned out or can have an effect on product quality.

Operational data
A few of these installations exist and NO_x reductions of 20 – 40 % have been reported in some cases.

Applicability
Mid-kiln firing can, in principle, be applied to rotary kilns.

The rate of the burning of fuels can be critical. If it is too slow, reducing conditions can occur in the burning zone, which may severely affect product quality. If it is too high, the kiln chain section can be overheated – resulting in the chains being burned out.

Mechanical design considerations mean that the fuel can only be injected intermittently, once per kiln revolution. To maintain continuity of the heat input, solid, slow burning fuels such as tyres or other waste fuels in containers may be used.

The temperature range excludes the use of hazardous waste with a chlorine content of greater than 1 %.

Economics
Capital costs may be in the region of EUR 0.8 million – 1.7 million for the kiln conversion and fuel handling equipment, and the annual labour and maintenance costs may be of a similar order.

Driving force for implementation
Legal requirements.
Local conditions.

Example plants and reference literature
Cement plants in the EU-27.
[9, CEMBUREAU, 1997 November], [21, BCA, 1997 October], [168, TWG CLM, 2007], [182, TWG CLM, 2008]

1.4.5.1.5 Mineralised clinker

Description and achieved environmental benefits
The addition of mineralisers, such as fluorine, to the raw material is a technique to adjust the clinker quality and allow the sintering zone temperature to be reduced. By reducing/lowering the burning temperature, NO_x formation is also reduced.

Cross-media effects
Excessive additions of calcium fluoride could lead to an increase in HF emissions.
Reduced energy demand.
Additions could affect the final product quality.

Operational data
The NO_x reduction might be between 10 and 15 %, but reductions of up to 50 % have been reported.

Applicability
This measure/technique can, in principle, be applied to rotary kilns.

Economics
Depending on the price of the mineralisers.

Driving force for implementation
Legal requirements.
Local conditions.

Example plants and reference literature
Cement plants in the EU-27.
[10, Cementa AB/Hagström, 1994], [103, CEMBUREAU, 2006], [168, TWG CLM, 2007]

1.4.5.1.6 Process optimisation (NO_x)

Description and achieved environmental benefits
Optimisation of the process, such as smoothing and optimising the kiln operation and firing conditions, optimising the kiln operation control and/or homogenisation of the fuel feedings, can be applied for reducing NO_x emissions. General primary optimisation measures/techniques, such as process control measures/techniques, an improved indirect firing technique, optimised cooler connections and fuel selection, and optimised oxygen levels have been applied. Until 2007, progress was observed in the reduction of NO_x emissions by using process-integrated measures/techniques.

Cross-media effects
Reduced energy demand.

Operational data

NO_x emissions, by applying process control optimisation measures/techniques, range between 500 and 1000 mg/Nm^3. Some modern well optimised preheater kiln systems and preheater/precalciner kiln systems may achieve NO_x emission levels of less than 500 mg/Nm^3 by applying all process-integrated measures/techniques.

Applicability

The quality of the raw materials (the firing properties of the raw mix), the availability of high volatile fuels and the design of the kiln system are among the reasons for not being able to achieve the level quoted above.

Economics

The aim of process optimisation is to improve costs.

Driving force for implementation

Legal requirements.
Local conditions.

Example plants and reference literature

Cement plants in the EU-27.
[76, Germany, 2006], [101, France/ADEME/MEDD, 2002], [103, CEMBUREAU, 2006], [168, TWG CLM, 2007], [182, TWG CLM, 2008]

1.4.5.1.7 Selective non-catalytic reduction (SNCR)

Description and achieved environmental benefits

In 2008, there were about 100 full scale SNCR installations in operation in the EU-27 and EU-23+ countries (see Glossary). Selective non-catalytic reduction (SNCR) involves injecting ammonia water (up to 25 % NH_3), ammonia precursor compounds or urea solution into the combustion gas to reduce NO to N_2. The reaction has an optimum effect in a temperature window of about 830 to 1050 °C, and sufficient retention time must be provided for the injected agents to react with NO.

Laboratory experiments as well as full scale trials have to be performed to identify the optimised temperature window for urea or ammonia water. The right temperature window can usually be obtained in suspension preheater kilns, precalciner kilns and in Lepol kilns. However, also plants using long rotary kilns have been equipped with SNCR in order to reduce the NO_x emissions. Figure 1.64 gives an overview of the characteristics of the cement plants where SNCR has been applied.

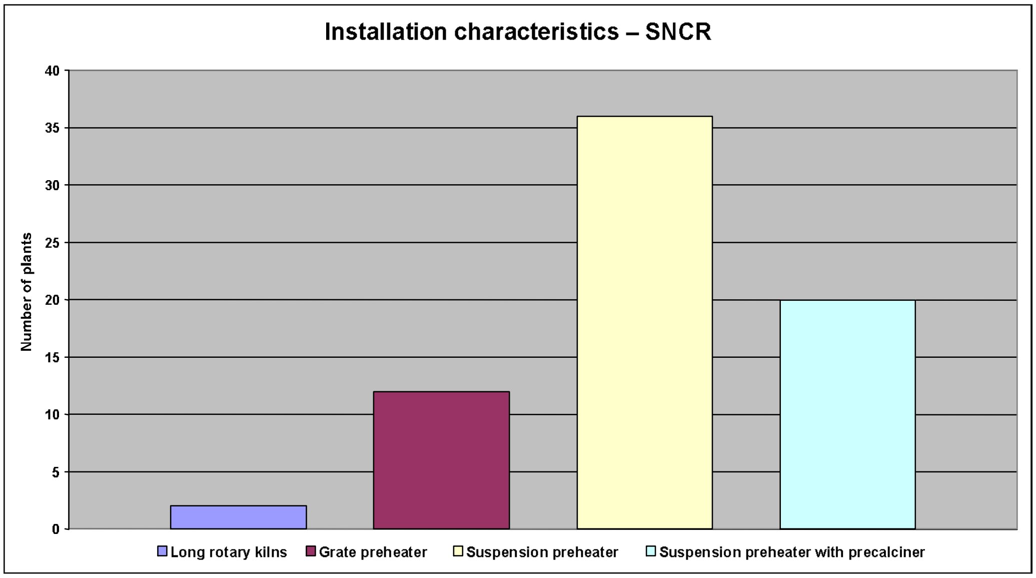


Figure 1.64: Cement plant characteristics with SNCR application in EU-23+ countries [85, CEMBUREAU, 2006]

The most common NH_2-X agent is urea up to 32 % followed by ammonia water up to 27 %, as shown in Figure 1.65 [85, CEMBUREAU, 2006]. Waste solutions from other production processes can be utilised as ammonia carriers as well [76, Germany, 2006]. Other possible reduction agents which can be employed on an industrial scale are ammonia gas, ammonium salt solutions, dried urea (urea pills), urea solutions, nitrolime or cyanamide and similar other substances [20, Rother, 1996 January,]. Storage and transport facilities have to be designed according to the physico-chemical properties of the respective agent and can require additional safety measures/techniques. Experience shows that for most applications ammonia water is the best agent for SNCR at preheater and precalciner kiln systems [9, CEMBUREAU, 1997 November]. A favourable good ammonia stoichiometric distribution is important in order to achieve the highest efficiency of NO_x reduction and to reduce the ammonia slip. In order to achieve an optimal utilisation of the injected reduction reagent – ammonia water or urea solution – and to cater for high NO_x reduction efficiency, the following points are to be considered for the SNCR design and operation. These considerations will allow an optimal technical and economic operation of an SNCR system:

- inject the agent in the appropriate temperature window of 830 to 1050 °C; aim to avoid ammonia slip or combustion of ammonia – the latter being a potential source of secondary NO_x
- if the temperature window changes – adjust the location of injection nozzles; probably multiple layers of nozzles are appropriate to cover this issue; possibly manufacture a temperature profile of the injection and monitor continuously to cater for such a demand
- adjust the spray angle and penetration depth of the injected aqueous solution by varying:
  - the water content of the solution
  - the pressure level of the atomising air
  - the location of the nozzle and
  - the direction of the injected ammonia
- nozzles in levels temporarily not used – cool ideally with air to avoid heat related wear; nozzles which are only occasionally used, extract to avoid undue air consumption
- make sure that the area of injection is covered properly with the correct amount of ammonia solution to avoid over- and under stoichiometric injection. By doing this, undue ammonia slip or untreated NO bypassing the SNCR can be avoided
- if needed, measure the NO_x level in each cyclone string where applicable (i.e. double riser ducts) and trim injection accordingly

- check stoichiometry via mass balance of abated NO_x to injected ammonia, that no excess ammonia is injected. By doing so, the ammonia slip can be minimised. Furthermore, the nearer the stoichiometry is to one – the better the economics will be.

Figure 1.65 shows the different nitrogen carriers/NH_2-X agents used for NO_x reduction by SNCR in several cement plants in EU-23+ countries.

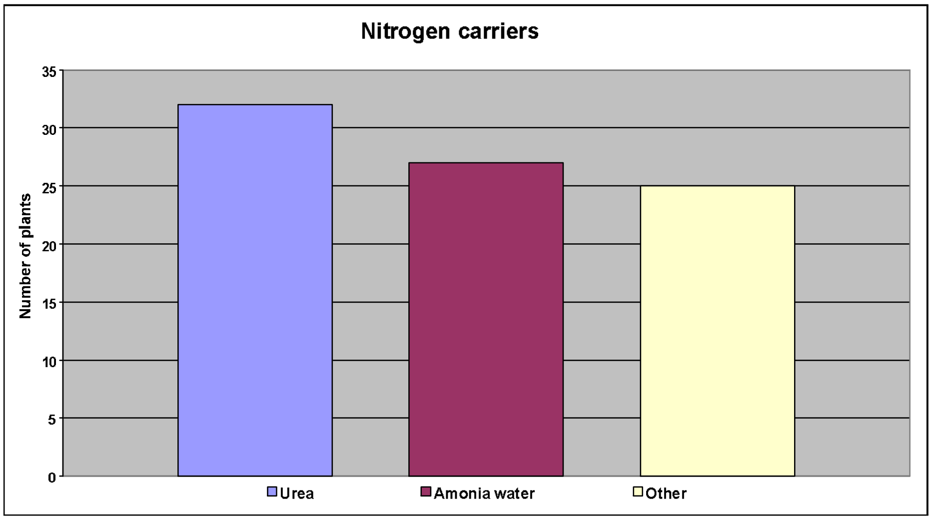


Figure 1.65: Nitrogen carriers/NH_2-X agents used by SNCR in EU-23+ countries
[85, CEMBUREAU, 2006]

Further development in the use of SNCR technique is necessary if the plant is already equipped with a staged combustion system. Simultaneous use of these techniques requires the temperatures, residence times and gas atmosphere in the reaction section to be adjusted to suit one another. In order to gather experience with simultaneous application of these two abatement techniques, operational trials were carried out at several kiln plants equipped with precalciners. Trials have shown that it is possible, in principle, to combine the two techniques. NO_x emissions reduction can be achieved by injecting the reducing agent into the oxidising zone as well as into the reducing zone of a staged calciner. The injection into the oxidising zone is favourable as the probability of increased CO emissions is lower as if the injection occurs in the reducing zone. Due to the different calciner techniques, design and control of the SNCR installation has to be adapted and optimised to the respective technique. If the reducing agent is added just before the bottom cyclone stage, the retention time of the reacting agents in the right temperature window is no longer sufficient to achieve a significant NO_x abatement. Consequently, an increased ammonia slip is likely. On the other hand, several trials showed that when injecting the reducing agent before the mixing chamber of the calciner in an area where the combustion of the calciner fuel is still taking place, an increase in CO emissions can occur.

High efficiency SNCR

The high efficiency SNCR technique is a further development of the SNCR technique which is used in cement plants. Under controlled conditions over layers of nozzles (lances), ammonia water (25 % ammonia solution) is injected into the preheater. The arrangement of the lances is determined by the temperature profile in the riser duct. The injection of ammonia water is process controlled by the measured temperature profile in the preheater near the lances. Because of a favourable good ammonia distribution, the NH_3 slip and the consumption of ammonia water can be reduced. This SNCR technique was installed in 1996/97 at two Swedish plants and at at least one German plant.

Ammonia slip

It is important that ammonia is injected into the kiln system where a temperature range of 830 - 1050 °C exists. If the temperature falls below this level, unconverted ammonia is emitted (so-called NH_3 slip) and at significantly higher temperatures the ammonia is oxidised to NO_x. NH_3 slip may also occur at elevated NH_3:NO_2 molar ratios, i.e. from a molar ratio of about 1.0 - 1.2. In other sectors of industry, NH_3 slippage has sometimes resulted in the formation of aerosols of ammonia salts which has passed through the filter and become visible as a white plume above the exhaust gas stack. Investigations have shown that considerably lower aerosol levels are produced by cement plants. Unused ammonia may be oxidised and transformed into NO_x and water in the atmosphere and NH_3 slippage may also result in ammonia enriched dust which may not be recycled to the cement mill. The possible NH_3 slip should be taken into account in the design of SNCR installations. The NO_x reduction rate cannot simply be increased at will, as a higher dosage might cause NH_3 slippage (see also Figure 2.50 in the lime chapter). Correct operation (appropriate control system, optimised injection of NH_3 water) of the SNCR system does not entail any higher ammonia emissions than normal.

Cross-media effects

By using ammonia water solution as the reducing agent, ammonia slip may occur as described above and unconverted ammonia is emitted. Emissions of nitrous oxide (N_2O) may also occur; however, they only play a minor role, as spot tests revealed concentrations of between 1 and 5 mg/Nm^3 which is approximately equal to the detection limit. Furthermore, an increase of carbon monoxide (CO) emissions may occur when injecting the reducing agent before the mixing chamber of the calciner in an area where the combustion of the calciner fuel is still taking place.

Additional heat for the evaporation of water is balanced with heat released in the exothermic DeNO_x reaction which causes a small increase in CO_2 emissions. The transport and storage of aqueous ammonia is a potential danger for the environment and requires some additional safety measures/techniques. Consideration is also required as to the impacts associated with the production of ammonia and the transportation of water associated with the dilution of the solution.

By using urea as the reducing agent, the main end-products are ammonia and carbon dioxide. Emissions of nitrous oxide (N_2O) and various concentrations of isocyanic acid (HNCO) and nitric oxide (NO) are reported from urea decomposition. The N_2O level from urea is always significantly higher than from aqueous ammonia. The generation of nitrous oxide from urea varies with the temperature. Studies show that high NO_x reduction and maximum N_2O generation have the same temperature window. Most of the isocyanic acid will be hydrolysed to ammonia and carbon dioxide; however, isocyanic acid slip from SNCR installations is reported. Furthermore, one study shows that in addition to nitrous oxide (N_2O) and isocyanic acid (HNCO), injected urea will also generate cyanic ions (NCO). This product is not formed when ammonia is used under SNCR conditions. It also has to be noted that the use of urea will generate higher emissions of carbon monoxide (CO) than the use of ammonia.

Operational data

Most SNCR installations operating in 2006 were designed and/or operated for NO_x reduction rates of 30 – >50 % (with NH_3:NO_2 molar ratios of 0.5 – 0.9) and NO_x emission levels of between <350 – 800 mg/Nm^3 (daily average values), depending on the initial NO_x level.

Installations designed and/or operated for higher reduction rates will do better as described below (high efficiency SNCR). Two plants with SNCR installations delivered by two different suppliers, which both guaranteed 80 % reduction, are achieving reduction rates of 80 – 90 % (with an initial NO_x level of between 800 – 1100 mg/Nm^3) which corresponds to NO_x emissions of less than 200 mg/Nm^3, measured as the yearly average value (see Section 4.2.4). Furthermore, NO_x emissions of 190 mg/Nm^3 (yearly average value) were reported from a Swedish plant in 2006.

In combination with process-integrated measures/techniques and with highly efficient SNCR installations operating at reduction rates of 80 – 90 %, daily average concentrations of less than 500 mg/Nm^3 are achievable, also when initial levels are above 2000 mg/Nm^3 [43, Wulf-Schnabel/Lohse, 1998].

High efficiency SNCR and ammonia slip
High efficiency SNCR was installed in 1996/97 at two Swedish plants and at at least one German plant. These Swedish plants (altogether with three kilns) use dry process cyclone preheater/precalciner kilns. A reduction of >80 % has been achieved when applying a NH_3:NO molar ratio of 1.0 – 1.2 and so far an increase of up to 20 mg/Nm^3 as the daily average of NH_3 has been measured. No significant increases in N_2O and CO emissions have been measured and no traces of any NH_3 have been found in the cement. In 2001 at one plant, the initial molar ratio was found to be 1.0 – 1.2 (mol NH_3 to present mol of NO_x) which was computed to 1.2 to 1.4 for removed NO_x with an average removal efficiency of 80 % while at the second plant the ammonia ratio was in the range of 1.2 – 1.4 mol/mol (present NO_x to injected NH_3) or 1.5 – 1.8 (reduced NO_x to injected NH_3). A NO_x emission level of 200 mg/Nm^3 was reported (yearly average value). It has to be noted that this NO_x emission level of 200 mg/Nm^3 has been achieved since 1998 from both Swedish plants with the presence of an initial NO_x level of 800 – 1000 mg/Nm^3, a reduction rate of 80 % and a stable operating process.

In Germany, SNCR (reducing agent ammonia water by 25 %) was installed at a four stage cyclone preheater kiln with a production capacity of about 3000 t clinker/day. Initial NO_x levels of between 500 – 1200 mg/Nm^3 (on a daily basis) were reported. Over a period of several years, long term experience showed that an emission levels of 500 mg NO_2/Nm^3 and less (daily average value) could constantly be achieved without any significant ammonia slip.

In 2007, the latest results from a long term test (six months performance test) showed that NO_x emission values of 350 mg/Nm^3 and 200 mg/Nm^3 (daily average values) were achieved by applying corresponding NH_3:NO molar ratios of 0.7 – 0.8 and 1.4 – 1.5. During these performance tests, NH_3 emissions were measured continuously. The NH_3 measurements however resulted in significant ammonia slip by keeping 200 mg/Nm^3 NO_x particularly during mill-off operation (max. 50 – 200 mg/Nm^3). Altogether, the ammonia slip was twice as high in order to achieve the emission level of 200 mg/Nm^3 (NH_3: three months average value of 11 mg/Nm^3) compared to a level of 350 mg/Nm^3 (NH_3: three months average value of 21 mg/Nm^3). The mill-off operation ratio in this case was about 10 – 20 %. A relevant enrichment of ammonia in the raw meal and the ESP dust could not be observed during the performance test. The tests showed that ammonia emissions should carefully be considered (see also Section 4.2.4.2). The ammonia slip, which occurs because of the above process, sets the limits to the overstoichiometric addition of reducing agents [160, Germany, 2007], [173, Germany, 2007].

In 2004 in Ireland, investigations carrying out short term SNCR trials showed low NH_3 concentrations of between 4 and 26 mg/Nm^3 (10 % O_2) in the raw gas after the preheater of the kiln. This was because of an optimised injection configuration resulting in a highly efficient reduction reaction and only in minor amounts of unreacted ammonia. These concentrations were measured by testing two injection configurations (standard conditions; NH_3:NO molar ratio of one (1) with a NO_x reduction rate of 50 %). The NH_3 slip sets limits to the overstoichiometric addition of reducing agent [123, Ireland, 2005].

Detailed descriptions of a high efficiency SNCR technique used in the EU can be found in Section 4.2.4. Ammonia emissions from cement manufacturing are described in Section 1.3.4.9.

Applicability
SNCR and high efficiency SNCR are, in principle, applicable at rotary cement kilns. The injection zones vary with the type of kiln process.

In long wet and dry process kilns it is very difficult to obtain the right temperature and retention time needed. Only one plant with a long dry kiln and one plant (Denmark) with a long wet kiln have successfully applied SNCR reduction and reach efficiencies of between 40 and 50 %.

Ammonia related storage risks are reduced by storing ammonia water solution by 25 % concentration.

Economics

For a 3000 tonnes/day preheater kiln with initial NO_x emissions of up to 2000 mg/Nm^3 and with a NO_x reduction of up to 85 % (i.e. up to 300 mg NO_x/Nm^3) the investment cost for an SNCR using ammonia water as the reducing agent is EUR 0.5 – 1.2 million, with the cost being very influenced by local regulations on the storage of ammonia water. The operating cost for the same kiln is EUR 0.3 – 0.5 per tonne clinker, the cost mainly determined by the cost of the injected ammonia [9, CEMBUREAU, 1997 November], [85, CEMBUREAU, 2006].

SNCR was installed in 1996/97 at two Swedish plants. For one kiln, the investment costs were about EUR 1.2 million (EUR 0.65 million for the SNCR installation and another EUR 0.55 million for the ammonia water storage) and the operating cost was about EUR 0.55 per tonne clinker. The total cost (investment + operating costs) was less than EUR 0.6 per tonne clinker. The investment costs for the other kiln were about EUR 0.55 million and the operating cost was about EUR 0.3 per tonne clinker. The driving force for these plants to invest in high-performing SNCR installations was the Swedish policy regarding NO_x emissions. According to this policy any investment in abatement that has a total cost (investment + operating) of less than EUR 4.5 (SEK 40) per kilo of abated NO_x (as NO_2) may be acceptable.

A survey covering 26 cement plants using the SNCR technique, which was carried out in 2004 by the German cement industry, revealed average investment costs of between EUR 0.5 and 0.75 million. However, France reported costs of up to EUR 1 million. The construction of the storage for the reducing agent amounted to about 50 % of the investment costs. Total costs of between EUR 0.5 and 0.7 per tonne clinker were given for the use of ammonia solution and medium to high NO_x abatement rates. Detailed cost calculations for a rotary kiln with a clinker capacity of 1500 t/d resulted in specific costs of between EUR 0.4 and 1.2 per tonne clinker, dependent on the NO_x reduction rate. Additional calculations for a 3500 t/d kiln and a NO_x reduction from 850 to 250 mg/Nm^3 resulted in investment costs of EUR 0.88 million and operating costs of EUR 0.40 per tonne clinker.

See also Table 1.34 and Table 1.40 (Section 1.4.8.2) where example cost data for the SNCR technique are shown.

Driving force for implementation

Legal requirements.
Local conditions.

Example plants and reference literature

Plants in the EU-27, high efficiency SNCR plants in Sweden and Germany (Maerker).
Descriptions of example plants from Sweden and Germany are given in Sections 4.2.4.1 and 4.2.4.2 respectively.
[8, CEMBUREAU, 2001], [9, CEMBUREAU, 1997 November], [10, Cementa AB/Hagström, 1994], [20, Rother, 1996 January,], [24, Junker, 2001], [41, Kupper/Brentrup, 1992], [42, Billhardt/Kuhlmann/Ruhland/Schneider/Xeller, 1996 October], [43, Wulf-Schnabel/Lohse, 1998], [76, Germany, 2006]], [85, CEMBUREAU, 2006], [101, France/ADEME/MEDD, 2002], [105, YARA, 2006], [114, Sweden, 2006], [123, Ireland, 2005], [131, YARA, 2007], [160, Germany, 2007], [168, TWG CLM, 2007], [173, Germany, 2007], [182, TWG CLM, 2008]

1.4.5.1.8 Selective catalytic reduction (SCR)

Description
SCR reduces NO and NO_2 to N_2 with the help of NH_3 and a catalyst at a temperature range of about 300 – 400 ºC. This technique is widely used for NO_x abatement in other industries (coal fired power stations, waste incinerators). In the cement industry, basically two systems are considered: low dust configuration between a dedusting unit and stack, and a high dust configuration between a preheater and a dedusting unit. Low dust exhaust gas systems require the reheating of the exhaust gases after dedusting, which may cause additional energy costs and pressure losses. High dust systems are considered preferable for technical and economical reasons. These systems do not require reheating, because the waste gas temperature at the outlet of the preheater system is usually in the right temperature range for SCR operation.

Large NO_x emissions reductions of 85 – 95 % are potentially achievable by SCR high dust systems and until 2008, only high dust systems have been tested in the cement industry.

In 2008 in the EU-27, in total two full scale production runs have been carried out and experience has been collected in order to remove the technical and economic uncertainties related to upscaling of the SCR technique. The main uncertainties are related to the high dust concentration of up to 100 g/Nm^3 in the gases, dust removal measures/techniques, type and lifetime of the catalysts, total investment and operating costs. Experience also shows that appropriate design and chemical composition of the catalysts are very important.

Considering the high reduction potential, the successful pilot tests, the two full scale SCR installations and the fact that SCR is state-of-the-art technique for comparable installations in other sectors, SCR is an interesting technique for the cement industry. There are at least two suppliers in Europe that offer full scale SCR to the cement industry with guaranteed performance levels of 100 – 200 mg/Nm^3. However, SCR capital expenditure is still higher than for SNCR [12, Netherlands, 1997].

Achieved environmental benefits
Reduction of NO_x emissions.

As the catalysts remove hydrocarbons as well and if this technique is designed for, SCR will, in general, also reduce emissions of VOC and PCDD/Fs.

Cross-media effects
Electrical energy demand may increase due to the internal dedusting system of the SCR reactor and additional pressure losses.

Low dust exhaust gas systems require reheating the exhaust gases after dedusting, which may cause additional energy costs and pressure losses.

Catalysts have to be recycled or disposed of.

Operational data
In the 1990s, early pilot plant trials in Germany, Italy and Sweden showed promising results. The NO_x emission levels were approximately 100 – 200 mg/Nm^3 with no loss of catalyst activity. In Austrian cement plants between 1996 and 2000, three pilot tests on small portions (3 % of the exhaust gas) and with a high dust configuration took place. One of these was successful in NO_x reduction efficiency which, however, was not continued. One concern raised was the operational availability of the catalysts. Two pilot trials were not successful because of the deactivation of the catalysts after a few weeks due to heavy metals and alkali metal compounds. In one plant, considerable abrasion of the catalysts occurred after a working period of about 5000 hours [18, Göller, 2001], [92, Austria, 2006].

In 2000, the first full scale SCR demonstration plant by using a high dust SCR system was built in Germany with government funding and was in operation from 2001 until 2006. However in 2008, the plant is waiting for improved catalyst types. In comparison with SNCR, this system has a lower consumption of NH_3 resulting in lower ammonia operational costs. At the top of the four stage preheater, the waste gas has a temperature of 320 – 350 °C that is suitable for SCR and does not require reheating, as is necessary in the case of configuration between the fabric filter and stack, thus reducing energy costs. The NO_x abatement efficiency is usually in the range of 59 to 67 %. However, if the operating conditions were not usual with raw gas concentrations of 3000 mg/Nm^3 and higher, NO_x abatement efficiencies of more than 80 % were observed. In regular operation, the SCR reduces NO_x emissions from initial raw gas concentrations of 1000 to 1600 mg/Nm^3 to about 400 to 550 mg/Nm^3. With a molar ratio of 0.8 to 0.9, the consumption of NH_3 is significantly lower than by the application of SNCR. It has to be noted that NH_3 from the raw material also serves as the reduction agent in the reactor, thus the emission level of residual NH_3 is very low. At this German plant, the SCR usually led to NH_3 emissions of below 1 mg/Nm^3 by achieving a NO_x emission level of 300 mg/Nm^3. These results may indicate the potential of the technique, especially as they were also achieved with three catalytic layers only, and the emission level of residual NH_3 was still around 1 mg/Nm^3. A more detailed description of this plant, achieved emissions ranges and costs are shown in Section 4.2.5.

In Italy, one SCR plant is in operation for NO_x reduction. Since 2006, a full scale high dust SCR system for NO_x abatement has been in operation on a kiln line having a kiln capacity of 1720 t/d (permitted capacity of 2400 t/d). The dimensions of the chamber holding the modules which are envisaged for seven layers (levels) of catalysts are 4 m in width, 6 m in length and 27 m in height, as shown in Figure 1.66.

The volume of catalysts installed is 21 m^3 for each level, in total 63 m^3 for three levels with an uninstalled backup capacity of 42 m^3 for an additional two levels to meet the permitted capacity of 2400 t/d. The catalysts are automatically cleaned by compressed air at 5 or 6 bar with a consumption of 2.5 kWh/t of clinker for the compressor line. After 7000 hours of operation, no reduction inactivity of the catalysts was found.

Figure 1.66: Example of an SCR installation
[140, Italy, 2007]

Figure 1.67: Example of an individual catalyst used for the SCR technique
[140, Italy, 2007]

Figure 1.68: Example of a module position used for the SCR technique
[140, Italy, 2007]

An ammonia solution of 25 % concentration is used as the reducing agent. The flow varies from 30 to 300 litres per hour depending on kiln conditions and the type of fuels used, while the gas flowrate is 110000 m^3/h. The ammonia solution is injected into the gas stream below the uppermost cyclone where the appropriate temperature regime of 320 – 350 °C exists. During the first 10 months of operation, the mean consumption of ammonia solution was 0.7 – 1 kg/t clinker with a reduction of NO_x emissions to less than 450 mg/Nm^3 (10 % O_2). However, from this Italian plant, reports and test results show that the design of this SCR technique can reduce the NO_x emissions at the stack to <200 mg/Nm^3 (at actual % O_2). Depending on the inlet NO_x level and the NH_3 injection rate, the NO_x reduction efficiency ranges from 43 – 95 %. Corrections to 10 % O_2 would yield even lower NO_x concentrations. Before the installation of the SCR technique, ammonia in the flue-gas was measured at 50 – 150 mg/Nm^3 which originated from raw materials. This amount of ammonia has since been used by the SCR process resulting in NH_3 emissions of less than 1 mg/Nm^3 and a molar ratio (injected NH_3:NO_x) of less than unity. Parameters, emissions and costs of the SCR technique, reported from the German cement plant and the Italian cement plant using this NO_x reduction technique, are shown in Table 1.35.

Technique	**Kiln system applicability**	**Reduction efficiency (%)**	**Reported emissions**		**Reported costs**	
			mg/Nm^3 (daily average value)	**kg NO_x/t clinker**	**Investment (EUR/tonne clinker)**	**Operating (EUR/tonne clinker)**
SCR	Possibly all	43 – 97	300 – 500[1)]	0.15 – 1.0	2.5[2)] 3.2 – 4.5[3) 4)]	1.75 – 2[3)]

[1)] Results from pilot tests and long term operation of the demonstration plant
[2)] Costs estimated by UBA Germany for a full scale installation (kiln capacity 1500 t clinker/d, initial emissions of 1200 mg/Nm^3 and final levels of 200, 500 and 800 mg/Nm^3 (daily average value)
[3)] Costs calculated by the Association of the German Cement Industry (VDZ) covering operating costs, plus depreciation on the investment of a full scale installation (kiln capacity 1500 t clinker/d, initial emissions of 1200 mg/Nm^3 and a final level of 200, 500 and 800 mg/Nm^3)
[4)] Highest value belongs to the SCR system from the Italian cement plant, where EUR 0.9 million for catalysts elements are included (three layers of modules in place plus two in store)

Table 1.35: SCR parameters, emissions and costs reported
[85, CEMBUREAU, 2006]

Applicability

SCR has only been tested on preheaters and pilot tested on semi-dry (Lepol) kiln systems, but it is, in principle, applicable to other kiln systems as well depending on the temperature window.

The high dust levels impose high demands on the durability and the operation of the catalysts and the design and chemical composition of the catalysts are very important. Catalysts designed for low dust operation in other industries might not be suitable for high dust operation in a cement plant. High dust operation of an SCR reactor requires a high mechanical durability of the catalyst, a wider pitch than usual for low dust operation and an integrated dedusting system, in order to avoid plugging and activity losses. The appropriate chemical composition of the catalyst has to be evaluated by trials with high dust off-gases of cement kilns. Furthermore, because of the dimensions of the chamber holding the modules and the amount of layers which are used, sufficient space has to be available in order to install the SCR technique.

There are not yet standard catalysts available that are adequate for the cement industry. The various types of catalysts being used are still undergoing trials.

Economics

The results from the use of the SCR technique have shown a cost level of EUR 1.25 to 2.00 per tonne, depending on the plant size and the NO_x removal efficiency required. The SCR technique, in contrast to the SNCR technique, is dominated by the investment costs, which are 4 to 9 times higher than for a SNCR system. The use of catalysts increase the operational costs. Furthermore, the energy consumption is essentially due to pressure drop and cleaning air for the catalyst. Specific costs of SCR have declined to around EUR 1.75 per tonne.

Cementa AB in Slite, Sweden, has a 5800 tonne clinker/day dry process suspension preheater/precalciner kiln. In 1993, they operated a pilot high dust SCR, downstream of an SNCR, for about a year and have investigated how much a full scale SCR installed downstream of the SNCR would cost. This means initial NO_X levels into the SCR of less than 200 mg/Nm^3. The estimated investment cost was about EUR 11.2 million and the operating cost was about EUR 1.3 per tonne clinker, giving total costs of EUR 3.2 per tonne clinker. The costs per additional kilo of abated NO_X were EUR 5.5 – 7.3 for the SCR. These costs were too high and not reasonable according to the company.

Investment costs for a 3000 tonne clinker/day preheater kiln were estimated to be EUR 3.5 million – 4.5 million, remarking that investment cost indications are only known from the supplier but did not including the plant modifications.

Feasibility studies have been carried out in Austria, Germany, the Netherlands and Sweden. The estimated costs for the SCR technique in the cement industry varies greatly, with the production costs and lifetime of the catalysts being major variables.

See also Table 1.34 and Table 1.35 in Section 1.4.5.1 as well as Table 1.40 in Section 1.4.8.2 where example costs data are shown.

Driving force for implementation
Legal requirements. The implementation of SCR may be suitable to achieve a higher NO_X abatement efficiency or to achieve a simultaneous reduction of NO_X and other pollutants, e.g. ammonia from raw materials.

Example plants
Solnhofer Portland-Zementwerke (Germany), Monselice cement plant (Italy).

Reference literature
[4, Austria, 1998] [8, CEMBUREAU, 2001], [9, CEMBUREAU, 1997 November], [12, Netherlands, 1997], [18, Göller, 2001], [23, de Jonge, 2001] [24, Junker, 2001], [43, Wulf-Schnabel/Lohse, 1998], [57, European Commission, 2005], [76, Germany, 2006], [80, Alvaro A. Linero, 2006], [85, CEMBUREAU, 2006], [92, Austria, 2006], [140, Italy, 2007],[141, Leibacher/Bellin/Linero, 2007],[168, TWG CLM, 2007], [182, TWG CLM, 2008]

1.4.5.2 Reduction of SO_2 emissions

The first step with respect to SO_2 control is to consider primary process optimisation measures/techniques, such as optimising the clinker burning process including the smoothing of kiln operation, uniform distribution of the hot meal in the kiln riser and prevention of reducing conditions in the burning process as well as the choice of raw materials and fuels. Moreover, the oxygen concentration in the kiln inlet area is crucial to SO_2 capture in the kiln charge. Increasing the oxygen content in long kilns decreases the SO_2 level and increases the NO_X level. However, to achieve the specified product quality, the clinker burning process requires an excess of oxygen. Accordingly, there is always a sufficient supply of oxygen to ensure the formation of sulphates in the bottom section of the cyclone preheater or the hot gas chamber of the grate preheater, which are discharged from the kiln system via the clinker. A balance for protecting the environment should be sought by optimising $NO_X/SO_2/CO$ by adjusting the back-end oxygen content. In those cases where these measures/techniques are not enough, additional end-of-pipe measures/techniques can be taken. Table 1.36 and Table 1.37 give an overview of measures/techniques that have a positive effect on, that is reduce, the emissions of SO_2 arising from the manufacture of cement, mainly from the preheater and the bypass process. Table 1.36 is a summary of operational data which are available within the text of this section and should be read in conjunction with the corresponding paragraphs in following sections (see Sections 1.4.5.2.1 – 1.4.5.2.3). In this context, it has to be noted that, when co-incinerating waste, the requirements of the WID have to be met [59, European Commission, 2000].

Measures/ techniques	Kiln systems applicability	Reduction efficiency	Emissions data		Cost	
			mg/Nm^3 1)	kg/tonne 2)	Investment (million EUR)	Operating (EUR/t)
Absorbent addition	All	60 – 80 %	<200 – 400 5)	0.23 – 0.92	0.2 – 0.3	0.1 – 0.4
Wet scrubber	All	>90 %	10 – 300 4)	0.02 – 0.69	5.8 – 23 6)	0.5 – 2 6)
Activated carbon	Dry	Up to 95 %	<50	<0.11	15 3)	No info.

1) Normally refers to daily averages, dry gas, 273 K, 101.3 kPa and 10 % O_2
2) kg/tonne clinker: based on 2300 m^3/tonne clinker
3) This cost also includes an SNCR process, referring to a kiln capacity of 2000 tonne clinker/day and initial emissions of 50 – 600 mg SO_2/Nm^3, cost data from 1997
4) The final achievable emission level is dependent on the initial SO_2 value prior to the installation of the wet scrubber and could be higher
5) For an initial SO_x level of 1200 mg/Nm^3 (see Section 1.4.5.2.1)
6) 2008

Table 1.36: Overview of techniques for controlling and reducing SO_2

Table 1.37 presents the number of full scale installations known in the EU-27 and EU-23+ countries to be using abatement measures/techniques to reduce SO_2 emissions in 2008.

Measures/techniques for reducing/controlling SO_2 emissions				
Country		Absorbent addition	Wet scrubber	Activated carbon
Belgium	BE	2		
Bulgaria	BG			
Czech Republic	CZ	1		
Denmark	DK		2	
Germany	DE	11		
Estonia	EE			
Greece	EL			
Spain	ES			
France	FR	3		
Ireland	IE			
Italy	IT	1		
Cyprus	CY			
Latvia	LV			
Lithuania	LT			
Luxembourg	LU			
Hungary	HU			
Malta	MT			
Netherlands	NL			
Austria	AT	1	1	
Poland	PL			
Portugal	PT	3		
Romania	Ro			
Slovenia	SI		1	
Slovakia	SK			
Finland	FI			
Sweden	SE		1	
United Kingdom	UK		2	
Norway	NO			
Switzerland	CH	1	1	1
Turkey	TR			
	TOTAL	23	8	1

Table 1.37: Abatement techniques for SO_2 reduction used in the EU-27 and EU-23+ countries in 2008
[73, CEMBUREAU, 2006], [182, TWG CLM, 2008]

No semi-wet and dry scrubbers are used in the European cement industry. The principle of these techniques is the neutralisation of SO_2 from the exhaust gas by the injection of chemical or physical sorption agents. The reaction products are dissolved or dry salts, following the techniques. In Untervaz, Switzerland in 2003, the only plant in Europe to have installed a circulating fluidised bed dry scrubber was shut down due to economic and, to a lesser extent, technical reasons.

1.4.5.2.1 Absorbent addition

Description and achieved environmental benefits

Secondary emissions control measures/techniques employed in the cement industry are hydrate-of-lime addition using the so-called ‘dry additive process’ (sorbent addition to raw material) or the ‘dry sorption process’ (sorbent injection into the gas stream). Hydrate-of-lime addition offers the additional advantage that the calcium-bearing additive forms reaction products that can be directly incorporated into the clinker burning process.

The optimum temperature ranges for hydrate-of-lime addition are 350 to 400 °C and below 150 °C if the gas is enriched with water. Suitable locations for hydrate-of-lime addition in cement rotary kiln systems are the upper cyclone stages or the raw gas duct.

Alternatively, hydrate-of-lime can be charged into the raw mill together with the raw material constituents or directly added to the kiln feed. Hydrate or slaked lime ($Ca(OH)_2$), quicklime (CaO) or activated fly ash with a high CaO content, is injected into the exhaust gas path at temperatures close to the water dew point, which results in more favourable conditions for SO_2 capture. In cement kiln systems, this temperature range is available in the area between the raw mill and the dust collector. The hydrate-of-lime reacts with the SO_2 in the upper cyclone stages and is carried out of the system as raw gas dust (dust collector) which is returned to the downstream grinding-drying unit with the raw gas. Factors limiting the reduction efficiency of this process are the short gas retention times in the upper cyclone stages (minimum two seconds) and the high exhaust gas CO_2 levels of over 30 %.

Cross-media effects

Intensive lime injection impacts on raw meal quality.

Operational data

The SO_2 reduction potential of hydrate-of-lime addition is determined by the initial SO_2 level and the exhaust gas conditions on the one hand, and the concentration level of the sulphur cycles forming in the respective plant on the other. SO_2 reductions of 60 to 80 % can be achieved by absorbent injection in suspension preheater kiln systems. With initial levels not higher than 400 mg/Nm^3, it is theoretically possible to achieve around 100 mg/Nm^3. For initial SO_2 levels of up to 1200 mg/Nm^3, it is possible to achieve a reduction to 400 mg/Nm^3. Higher initial SO_2 levels above 1200 mg/Nm^3 require significant amounts of absorbent which might not be cost effective. Moreover, a higher initial concentration of the sulphur cycles leads to process upsets due to the formation of deposits in the calcining area. Therefore, there might be a risk of higher sulphur recirculation and kiln instability as higher levels of sulphur are returned to the kiln when this technique is applied.

Applicability

Absorbent addition is, in principle, applicable to all kiln systems, although it is mostly used in suspension preheaters. There is at least one long wet cement kiln injecting dry $NaHCO_3$ to the exhaust gas before the ESP is used to reduce peak emissions of SO_2. Lime addition to the kiln feed reduces the quality of the granules/nodules and causes flow problems in Lepol kilns.

The dry sorption process (absorbent injection into the gas stream) can be applied in a dry or a wet form. For preheater kilns it has been found that direct injection of slaked lime into the exhaust gas is less efficient than adding slaked lime to the kiln feed. The SO_2 will react with the lime to $CaSO_3$ and $CaSO_4$, which then enters the kiln together with the raw material and is incorporated into the clinker. This technique is suitable for cleaning gas streams with moderate SO_2 concentrations and can be applied at an air temperature of more than 400 °C. The highest reduction rates can be achieved at temperatures exceeding 600 °C. It is recommended that a $Ca(OH)_2$ based absorbent with a high specific surface area and high porosity should be used. Slaked lime does not have a high reactivity, therefore $Ca(OH)_2/SO_2$ molar ratios of between 3 and 6 have to be applied. Gas streams with high SO_2 concentrations require 6 – 7 times the stoichiometric amount of absorbent, implying high operational costs.

Economics

Absorbent addition is in use at several plants to ensure that the limits are not exceeded in peak situations. This means that, in general, it is not in continuous operation, but only when required by specific circumstances. With an initial SO_2 concentration of up to 3000 mg/Nm^3, a reduction of up to 65 % and a slaked lime cost of EUR 85 per tonne, the investment costs for a 3000 tonne clinker/day preheater kiln are about EUR 0.2 million – 0.3 million and the operating costs are about EUR 0.1 – 0.4 per tonne clinker.

See also Table 1.36 and Section 1.4.8.3 where example cost data are shown.

Driving force for implementation

Legal requirements.
Local conditions.

Example plants and reference literature

Cement plants in the EU-27.
[8, CEMBUREAU, 2001], [9, CEMBUREAU, 1997 November], [12, Netherlands, 1997], [30, Marchal, 2001], [76, Germany, 2006], [97, CEMBUREAU, 2007], [101, France/ADEME/MEDD, 2002], [168, TWG CLM, 2007]

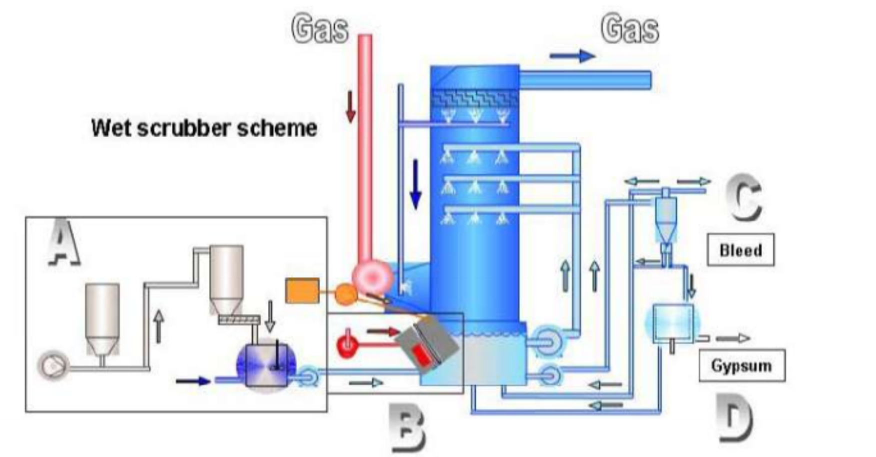
1.4.5.2.2 Wet scrubber

Description and achieved environmental benefits

The wet scrubber is the most commonly used technique for flue-gas desulphurisation in coal-fired power plants. For cement manufacturing processes, the wet process for reducing SO_2 emissions is an established technique. Wet scrubbing is based on the following chemical reaction:

$$SO_2 + \frac{1}{2} O_2 + 2\, H_2O + CaCO_3 \longleftrightarrow CaSO_4 \bullet 2\, H_2O + CO_2$$

The SO_x is absorbed by a liquid/slurry which is sprayed in a spray tower. The absorbent is calcium carbonate. Wet scrubbing systems provide the highest removal efficiencies for soluble acid gases of all flue-gas desulphurisation (FGD) methods with the lowest excess stoichiometric factors and the lowest solid waste production rate. However, wet scrubbers also significantly reduce the HCl, residual dust and, to a lesser extent, metal and NH_3 emissions. The basic principle of the working system of a wet scrubber is shown in Figure 1.69.



A SO_2 gaseous dissolution in the countercurrent sprayed liquid which is a mix between water and limestone coming from the kiln feeding material, followed by the precipitation of sulphites as sulphates ($CaSO_4$, $2(H_2O)$); In the liquid phase.

B Blowers inject fresh air in the active slurry to guarantee the total oxidisation of sulphites.

C Inerts (SiO_2, Al_2O_3, dust) brought by the reagent go inside the slurry and a hydro cyclone system produces bleed stream in order to purge the vessel.

D An auxiliary function is dedicated to the slurry dewatering: slurry extraction and dewatering/separation (gypsum and bleed production).

Figure 1.69: Basic operational features of a wet scrubber
[91, CEMBUREAU, 2006]

There are seven wet scrubbers currently in use in 2008 and one is planned to be used in the European cement industry, all of them spray towers. The slurry is sprayed in countercurrently to the exhaust gas and collected in a recycle tank at the bottom of the scrubber where the formed sulphite is oxidised with air to sulphate and forms calcium sulphate dihydrate. The dihydrate is separated and depending upon the physico-chemical properties of gypsum this material can be used in cement milling and the water is returned to the scrubber.

In comparison to the dry scrubber, the potential to generate cement kiln dust (CKD) in a wet process is much lower and natural gypsum recourses are saved. In Untervaz, Switzerland, the only installed circulating fluidised bed dry scrubber in Europe was retired in 2003, due to economic – and to a lesser extent – technical reasons. Normally, during the cement manufacturing process or from gas scrubbing applications, the aim is not to generate waste dust. In wet desulphurisation processes, $CaSO_4 \bullet 2\ H_2O$ is formed – which is used as a natural gypsum replacement and in the follow-up integrated as a modulating agent in the cement. In a dry/semi-dry desulphurisation process, a large quantity of the product $CaSO_3 \bullet ½\ H_2O$ is formed, the latter of which is harmful for the cement quality and integration possibilities in the cement are limited. The majority of the dry scrubber product would therefore have to be taken either back to the kiln or would need to be disposed of.

Cross-media effects

Increased energy consumption.
Increased waste production from flue-gas desulphurisation (FGD), and when maintenance is carried out, additional waste may occur.
Increased CO_2 emissions (see the chemical reaction above where it is shown how CO_2 is derived from the wet scrubber process)
Increased water consumption.
Emissions to water and increased risk of water contamination.
Increased operational cost.
Replacement of natural gypsum by artificial gypsum.

Operational data

The SO_2 reduction achieved can be more than 95 %. Cementa AB in Sweden operates a 5800 tonne clinker/day preheater kiln and has an initial SO_2 concentration in the flue-gas of 800 – 1000 mg/Nm^3, resulting in levels of <10 mg/Nm^3. Castle Cement in the UK operates a 2500 tonne clinker/day preheater kiln and has an initial SO_2 concentration in the flue-gas of about 800 – 1400 mg/Nm^3 as a daily average with peak values of more than 2000 mg/Nm^3 at times. Furthermore, SO_2 emissions of 207 mg/Nm^3 as a yearly average over the years between 2002 and 2006 have been reported and the maximum daily averages have varied from 248 to 296 mg/Nm^3 due to the high sulphur content in the raw material.

Applicability

A wet scrubber can be fitted to all cement kiln types with appropriate (sufficient) SO_2 levels in order to manufacture the gypsum.

Economics

In 2008, capital expenditure costs for a wet scrubber of Ribblesdale works, Castle Cement in the UK, were estimated by the supplier to be around EUR 23 million, when considering inflation. In 2000, the investment costs for the scrubber of Castle Cement (including plant modifications) were reported to be EUR 7 million and the operating costs were about EUR 0.9 per tonne clinker. In 1998 for Cementa AB in Sweden, the investment costs were about EUR 10 million and the operating costs were about EUR 0.5 per tonne clinker. With an initial SO_2 concentration of up to 3000 mg/Nm^3 and a kiln capacity of 3000 tonne clinker/day, the investment costs in the late 1990s were EUR 6 million – 10 million and the operating costs EUR 0.5 – 1 per tonne clinker. Furthermore in 1998 at an Austrian cement plant, the investment costs for a wet scrubber (SO_2 emissions reduction to less than 200 mg/Nm^3) were EUR 5.8 million and until 2008, the yearly operational costs were EUR 140000. In 2008, the European cement industry reported investment costs of between EUR 6 million and 30 million and operational costs of between EUR 1 – 2 per tonne clinker.

Example costs data along with a set of different data calculated for a reference plant with a capacity of 1100 t/d can be found in Table 1.41 in Section 1.4.8.3.

Driving force for implementation

Legal requirements.
Local conditions.

Example plants and reference literature

Cementa AB (Sweden), Castle Cement (UK), Retznei plant (Lafarge, Austria), Dunbar (UK), Trebovlje (Slovenia), Untervaz (Switzerland).
[8, CEMBUREAU, 2001], [9, CEMBUREAU, 1997 November], [10, Cementa AB/Hagström, 1994], [11, Coulburn, 2001], [24, Junker, 2001], [81, Castle Cement UK, 2006], [86, EURITS, 2006], [92, Austria, 2006], [103, CEMBUREAU, 2006], [114, Sweden, 2006], [132, CEMBUREAU/Federhen, 2007], [168, TWG CLM, 2007], [175, Lafarge, 2007], [182, TWG CLM, 2008], [183, Szednyj/Schindler, 2005]

1.4.5.2.3 Activated carbon

Description and achieved environmental benefits

Pollutants such as SO_2, organic compounds, metals, NH_3, NH_4 compounds, HCl, HF and residual dust (after an ESP or fabric filter) may be removed from the exhaust gases by adsorption on activated carbon. The activated carbon filter is used for the injection technique or is constructed as a packed-bed with modular partition walls. The modular design allows the filter sizes to be adapted for different gas throughputs and kiln capacity. The used activated coke is periodically extracted to a separate silo and replaced with fresh adsorbent. By using the saturated coke as fuel in the kiln, the trapped substances are returned to the system and to a large extent become fixed in the cement clinker.

Cross-media effects
Wastes resulting from activated carbon have to be managed as hazardous wastes.

Operational data
The only activated carbon filter still existing in the European cement industry is installed at a cement works in Siggenthal, Switzerland. The Siggenthal kiln is a four stage cyclone preheater kiln with a capacity of 2000 tonne clinker/day. Measurements showed high removal efficiencies for SO_2, metals and PCDD/F. During a 100 days trial, the SO_2 concentrations at the filter inlet varied between 50 and 600 mg/Nm^3, whereas the outlet concentrations were always significantly below 50 mg/Nm^3. Dust concentrations dropped from 30 mg/Nm^3 to significantly below 10 mg/Nm^3.

Applicability
An activated carbon filter can be fitted to all dry kiln systems. Wastes, such as used activated carbon with PCDD/Fs and other pollutants like mercury, have to be managed as hazardous wastes. Monitoring and control of temperature and CO are especially important for such processes, to prevent fires in the coke filter.

Economics
The system at Siggenthal also includes an SNCR process and in 1999, the city of Zürich financed about 30 % of the total investment cost of approximately EUR 15 million. The investment in this abatement system was made to enable the cement works to use digested sewage sludge as fuel.

Operating costs may increase.

Driving force for implementation
Legal requirements.
Local conditions.

Example plants and reference literature
Siggenthal, Switzerland
[9, CEMBUREAU, 1997 November], [10, Cementa AB/Hagström, 1994], [12, Netherlands, 1997], [86, EURITS, 2006], [168, TWG CLM, 2007], [182, TWG CLM, 2008]

1.4.5.3 Reduction of carbon oxides (CO) emissions and CO trips

Description
The kiln/raw mill exhaust gas contains, besides different other constituents such as CO_2, N_2, water vapour and oxygen and to a lesser extent NO and SO_x, to a lesser extent also CO.

The selection, when possible, of raw materials with a low content of organic matter also reduces the emissions of CO. When resulting from incomplete combustion, carbon monoxide (CO) emissions generally represent a loss of efficiency. Therefore, the operator tends to limit the CO emissions of its kilns. Improvement in combustion such as optimisation and quality of the fuel feed, burner properties and configuration, kiln draft, combustion temperature and residence time can reduce CO emissions.

Furthermore, all measures/techniques that reduce fuel energy use also reduce the CO_2 emissions. The selection, when possible, of raw materials with a low organic matter content and fuels with a low ratio of carbon content to calorific value reduces CO_2 emissions.

CO trips

Dust emissions due to CO trips can occur at ESPs and, to some extent, at hybrid filters. ESPs will have to be shut down during elevated CO levels in the flue-gases for safety reasons.

In order to reduce ESP downtime, a systematic stepwise approach is needed:

- set objectives and assess the situation in respect of the main factors influencing CO trips, such as causes of CO trips due to the following:
    - process upset
    - high levels of background CO due to high organics in the raw material
    - disruption to the fuel feed system
    - combustion process upset
- compare and evaluate current and optimum situations, identification of optimisation potential and setting priorities – gap analysis
- optimisation of the process, the analysis system, ensuring availability, reliability and speed, optimisation of reaction measures/techniques.

Furthermore, to identify any cause and address counter measures/techniques, the following information is needed:

- information on reliability, availability and dynamic behaviour of analysing equipment
- information on CO development statistics
- information on the fuels used, the fuel feeding system and the process.

Fuel feeding systems, which are designed to prevent surges of fuel into the kiln system to keep a stable operation of the combustion system, can minimise CO trips.

In order to control the CO level in a cement kiln, an automatic CO measurement is used to continuously monitor CO from the flue-gases. This measure/technique needs to be optimised for reaction time as well as the shutdown procedure and needs to be properly maintained. The ideal CO monitoring system has a short response time and should be situated close to the source of the CO, such as at a preheater tower outlet, or at a kiln inlet in the case of a wet kiln application. Still, a dead time analysis of the entire system – including hold up time due to duct volume – needs to be carried out. Ideally the dead time for the CO gas sample to travel from the suction point to the analyser will be in the region of 20 – 30 seconds (analysing lag time). Adding an additional 10 – 30 seconds lag time, as the analysing reaction time, should give the total maximum dead time before approximately 85 % of the maximum value has been reached. The total dead time determines when action has to be taken – not too early and not too late. If a more detailed analysis of the slope of the CO signal is carried out, a more precise prediction can be made when the ESP high tension system has to be shut down and when it can be put back into full operation again – hence accounting for when the CO trip has left the critical area.

The CO monitoring lag time can be reduced by an increased sample flow, shortening the distance from the sampling point to the analyser, reduced volume in the analysing system and a quick electronic reporting signal. Rapid in situ systems with response times of <3 seconds are available, but these have limitations in high dust-laden gases. In general, a strict maintenance and calibration regime is essential. However, analyser ranges and components have to appropriately address critical limits of up to 5 % for CO and 3 % for CH_4.

If the CO trip cannot be suppressed, any ignition sources, particularly the high tension equipment of the ESPs, require special attention. A trip of the high tension equipment as such is the last resort and is undesirable. Other potential ignition sources can be static loads caused by solid/solid friction or also fans, possible for any dust collector system. In general, the critical limit is >8 % CO or – CH_4 – in the presence of >6 % O_2. In reality, the CO trip travels through the gas train swiftly and will reach the critical area for an ignition source before the analysing system is able to indicate an alarm. Therefore, the action level has to be significantly lower than the theoretical level, and is further dependent on the CH_4 and H_2 concentrations, especially when natural gas is used as fuel.

Disruptions predominantly happen during the start-up operation phase. For safe operation, the gas analysers for ESP protection have to be on-line during all operational phases. Plant downtime can be reduced by using a backup system which is in operation.

Achieved environmental benefits

Reduction of explosion risks, CO trips, CO and dust (particulate matter) emissions.

Cross-media effects

Dust (particulate matter) emissions due to CO trips can occur.

Operational data

CO can be found in flue-gas at concentrations of up to 0.1 % with additional CO originating from carbon in the raw materials.

CO emissions of between 200 and 2200 mg/Nm^3 (yearly average value) have been reported from continuous measurements (see Figure 1.34 in Section 1.3.4.4.2).

CO trips can occur within a couple of minutes, or even seconds, rapidly reaching an operational interruption limit (see Sections 1.3.4.1.1 and 1.4.4.3.1). Frequencies of CO trips can be minimised and examples of total duration ranges of between 1 – 29 minutes per year, respectively <0.001 – 0.009 % of the total kiln operation have been reported (see Section 1.3.4.1.1) [158, Germany, 2007].

An example of primary measures/techniques which can be used to prevent CO trips in ESPs is described in Table 1.38. Standard staged actions may firstly include reducing fuel feed and the high tension level. Thereafter, cutting the fuel feed entirely and tripping the high tension transformers automatically. The system then needs to be purged by keeping the fans in operation. The necessary purge time can be determined in the same way as the lag time.

Primary measures/techniques to prevent CO trips		
Measuring point	**CO level (%)**	**Measure**
In a preheater tower	0.5	Alarm, shutdown of precalciner/kiln inlet firing system
	1.2	Shutdown of main firing system
	2.5	Shutdown of electric precipitator high tension
After a preheater tower	0.5	Alarm, shutdown of precalciner/kiln inlet firing system
	0.8	Shutdown of main firing system
	1.5	Shutdown of electric precipitator high tension
	0.5	Restart of ESP high tension equipment

Table 1.38: Example of primary measures/techniques to prevent CO trips from ESPs [60, VDI 2094 Germany, 2003], [83, CEMBUREAU, 2006]

Applicability

Measures/techniques for reducing CO trips can be applied to all kiln types.

By applying an automatic CO monitoring device for continuously monitoring the flue-gases on kilns with secondary firing, further operational reliability of the filters can be secured through sequential shutdown of the firing system during a CO trip.

The use of different fuels, especially solid fuels, can lead to unstable operation of the combustion system and can cause CO trips. The fuel feeding systems should be designed to prevent surges of fuel into the kiln system at any time. The conveying properties of solid fuels is a particularly critical factor in this respect and must be carefully controlled to prevent hold ups or blockages in the fuel preparation and feeding systems.

Fabric filters
Fabric filters operated in overcritical atmospheres may also experience problems. Therefore the operational CO level should also be kept as low as possible. As with ESPs, additional combustible gas components such as CH_4 and H_2 will lower the critical level, i.e. if hydrogen of approximately 2 % is present, the critical level is reduced to approximately 5 %.

Specific potential ignition sources for fabric filters can be static loads caused by the friction of man-made fibres or in the event of hybrid filters (combination of an ESP with a fabric filter) the accumulated static load on the bags. To prevent interruptions, especially for coal mills, bags are fitted with a stainless steel fibre mesh or a conducting surface and are grounded to the baghouse cell plate. Similarly for hybrid dust collectors, the grounding of the bag support cage with the cell plate is recommended. As with the ESP system, the CO has to be purged out. Purging of coal mills is preferably done by means of inert gas, such as kiln gas, CO_2 or N_2.

Economics
No data available.

Driving force for implementation
Legal requirements.
Local conditions.

Example plants and reference literature
Cement plants in the EU-27.
Guideline regarding the control of CO trips (see Section 4.2.6) [83, CEMBUREAU, 2006]
[60, VDI 2094 Germany, 2003], [158, Germany, 2007], [168, TWG CLM, 2007], [182, TWG CLM, 2008]

1.4.5.4 Reduction of total organic carbon emissions (TOC)

Description and achieved environmental benefits
Under normal circumstances, emissions of volatile organic compounds (VOCs) are generally low but can be higher because of the organic volatile content in the raw material which is used at the plant. Natural or waste raw materials with a high content of volatile organic compounds should not, if a choice is possible, be fed into the kiln system via the raw material feeding route and fuels with a high content of halogens should not be used in a secondary firing.

If elevated concentrations of VOCs occur, adsorption on activated carbon can be considered as in other sectors.

Cross-media effects
No issues.

Operational data
TOC emissions reported from European cement kilns are in the range of between 1 and 40 mg/Nm^3 (yearly average values) and can be higher depending on the raw material characteristics (see Section 1.3.4.5).

When co-incinerating waste, the requirements of the WID have to be met [59, European Commission, 2000].

Applicability
These measures/techniques are, in principle, applicable to cement kilns.

Economics
No data provided.

Driving force for implementation
Legal requirements.

Example plants and reference literature
Cement plants in the EU-27.
[9, CEMBUREAU, 1997 November], [59, European Commission, 2000], [76, Germany, 2006], [97, CEMBUREAU, 2007], [168, TWG CLM, 2007], [182, TWG CLM, 2008]

1.4.5.5 Reduction of hydrogen chloride (HCl) and hydrogen fluoride (HF)

Description and achieved environmental benefits
The use of raw materials and fuels containing low chlorine and low fluorine levels can reduce chlorine and fluorine emissions (see also Sections 1.4.3.2 and 1.4.3.3). Furthermore, the use of absorbent injection or scrubber techniques may also have an influence on HCl and HF emissions.

Chlorine compounds condense on the kiln feed or the kiln dust at temperatures of between 700 and 900 °C. They show a cyclic behaviour and may become enriched in the area between the rotary kiln and the preheater. The use of a bypass at the kiln inlet allows an effective reduction of alkali chloride cycles. Furthermore, the use of low levels of chlorine in the raw materials and fuels result in a low circulation of chlorine and can minimise the enrichment cycle resulting from the internal circulation between the kiln and preheater.

90 to 95 % of the fluorine which is present in rotary kilns is captured in the clinker, and the remainder is bound with dust in the form of calcium fluoride (CaF_2) which is stable under the conditions of the burning process.

Cross-media effects
The use of a bypass system (removal of hot raw material and hot gas) leads to a higher specific energy consumption (see Section 1.4.2.1.4) and increased waste for disposal.

Operational data
Best performance data for HCl emissions in a range of between 0 and 8 mg/Nm^3 (yearly average value) were reported but depended on the chlorine content in raw materials and fuels (see Section 1.3.4.8.1).

Best performance data for HF emissions from cement kilns are below 0.6 mg/Nm^3 (yearly average value), expressed as HF (see also Section 1.3.4.8.2).

When co-incinerating waste, the requirements of the Waste Incineration Directive have to be met [59, European Commission, 2000].

Applicability
These measures/techniques are, in principle, applicable to the cement industry.

Economics
No data available.

Driving force for implementation
Legal requirements.
Local conditions.

Example plants and reference literature
Cement plants in the EU-27.
[59, European Commission, 2000], [76, Germany, 2006], [97, CEMBUREAU, 2007], [168, TWG CLM, 2007], [182, TWG CLM, 2008]

1.4.6 Reduction of polychlorinated dibenzo-p-dioxin (PCDD) and polychlorinated dibenzofuran (PCDF) emissions

Description and achieved environmental benefits
Cement kilns generally emit very low levels of PCDD/F emissions; however, general primary measures/techniques can be applied to minimise them, such as:

- a smooth and stable kiln process, operating close to the process parameter set points, is beneficial for all kiln emissions as well as for the energy use. This can be obtained by applying:
  - process control optimisation including a computer-based automatic control system
  - use of modern fuel feed systems
- minimising fuel energy use by means of:
  - preheating and precalcination, considering the existing kiln system configuration
- careful selection and control of substances entering the kiln
  - selection and use of homogeneous raw materials and fuels with a low content of sulphur, nitrogen, chlorine, metals and volatile organic compounds, if practicable.

To minimise the possibility of PCDD/F reformation, the following primary measures/techniques are considered to be the most important:

- quick cooling of kiln exhaust gases to lower than 200 °C in long wet and long dry kilns without preheating. In modern preheater and precalciner kilns, this feature is already inherent
- limitation or avoidance of waste used as raw material feed as part of the raw material mix, if it includes organic chlorinated materials
- not using waste fuel feeding during start-ups and shutdowns
- monitoring and stabilisation of critical process parameters, i.e. homogenous raw mix and fuel feed, regular dosage and excess oxygen [86, EURITS, 2006], [88, SINTEF, 2006]
- fuels with a high content of halogens should not be used in a secondary firing.

However, if elevated concentrations of PCDD/PCDFs occur, adsorption on activated carbon can be considered as in other sectors.

Cross-media effects
Using exhaust gas quench systems which consist of a water spray system within the flue duct may have an influence on the energy efficiency.

Operational data
Most cement kilns can meet an emission level of 0.1 ng I-TEQ/Nm^3 if primary measures/techniques are applied [88, SINTEF, 2006]. In 2004, spot measurements showed that high numbers of all kilns in the EU-27 and EU-23+ countries achieve emission levels of between <0.03 and 0.05 ng I-TEQ/Nm^3 by applying primary measures/techniques (see Figure 1.39 in Section 1.3.4.6). Furthermore, emission levels of <0.03 ng I-TEQ/Nm^3 as a yearly average value were achieved by many cement plants (see Figure 1.38 in Section 1.3.4.6)

Applicability
These measures/techniques are, in principle, applicable to cement kilns. In wet kilns, controlling post-kiln operating conditions can minimise PCDD/F emissions.

Economics
No data provided.

Driving force for implementation
Legal requirements.
Local conditions.

Example plants and reference literature
Cement plants in the EU-27.
[86, EURITS, 2006], [88, SINTEF, 2006], [168, TWG CLM, 2007], [182, TWG CLM, 2008]

1.4.7 Reduction of metal emissions

Description and achieved environmental benefits
Feeding materials with a high content of volatile metals into the kiln system should be avoided. The use of materials with a high content of volatile metals such as Hg and Tl should especially be controlled because they will lead to higher emissions whereas other metals will be found within the clinker and the dust. Careful selection and guaranteed characteristics of substances entering the kiln can reduce emissions, e.g. using a quality assurance system to guarantee the characteristics of the waste materials used (see Sections 1.4.3.2 and 1.4.3.3).

The accumulation of metals, especially thallium, in the internal and external cycles of a cement kiln system results in an increase of emissions with increasing kiln operating time. This can be reduced by partly or completely interrupting these cycles. However, the close interconnection between internal and external cycles means it is sufficient to interrupt only the external cycle. This can be done by discarding the dust collected in the dust collector, instead of returning it to the raw meal. When its chemical composition is suitable, this discarded cement kiln dust can be added directly to the cement milling stage [27, University of Karlsruhe, 1996].

As the emitted metals (except part of the mercury) are, to a large extent, bound to dust, abatement strategies for metals are covered by abatement strategies for dust. Effective dust removal reduces metal emissions. One way to minimise mercury emissions is to lower the exhaust temperature. Non-volatile elements remain within the process and exit the kiln as part of the cement clinker composition. When high concentrations of volatile metals (especially mercury) occur, the volatile metals content (especially mercury) in the materials has to be minimised and it can be necessary to limit the input of these substances into the kiln system (see Sections 1.3.4.13, 1.4.3.2 and 1.4.3.3).

Furthermore, absorption on activated carbon is an option. Semi-volatile metals condense as fine fumes and are captured but with a lower removal efficiency than for non-volatile metals. When non-volatile metals are introduced into the kiln system they are, to a great extent, captured within the clinker (see Section 1.3.4.7).

Cross-media effects
Effective dust removal also reduces metal emissions.

Operational data and applicability
By using powdered activated carbon injection, mercury is adsorbed by activated carbon. Removal efficiency for mercury (metallic and ionic) of about 85 and 95 % is reported for this measure/technique. This results in Hg emissions of 0.01 – 0.03 mg/Nm^3. However, there is no industrial reference method for this measure/technique.

The static activated carbon or coke filter involves the adsorption of mercury with PCDD/Fs on the activated carbon filter that is a packed-bed with modular partition walls. The use of this measure/technique provides Hg emissions of below 0.03 mg/Nm^3. The filter has to be periodically replaced when it is saturated. Wastes, such as used activated carbon with PCDD/Fs and other pollutants like mercury, is hazardous waste and has to be managed as such [86, EURITS, 2006].

However, there is only one activated carbon filter in use in EU-23+ countries which is in Siggenthal in Switzerland (see Section 1.4.5.2.3).

Furthermore, mercury emissions of between <0.01 – 0.05 mg/Nm^3 were also achieved without the injection of activated carbon as shown in Figure 1.46 (spot measurements) and Figure 1.47 (yearly average values, see Section 1.3.4.7.1).

When co-incinerating waste, the requirements of the Waste Incineration Directive have to be met [59, European Commission, 2000].

Economics
A required quality assurance system to guarantee the characteristics of materials fed to the kiln may result in additional costs.

Effective dust removal can avoid high costs for activated carbon filters.

For the Siggental plant in Switzerland, the City of Zurich financed about 30 % of the total investment cost of approximately EUR 15 million.

Driving force for implementation
Legal requirements.

Example plants
Siggental, Switzerland

Reference literature
[27, University of Karlsruhe, 1996], [59, European Commission, 2000], [86, EURITS, 2006], [168, TWG CLM, 2007], [182, TWG CLM, 2008]

1.4.8 Examples of cost data for different flue-gas abatement measures/techniques and primary measures/techniques which can be used for emissions reductions

1.4.8.1 Example cost data for dust abatement measures/techniques

Table 1.39 shows examples of cost calculations for dust abatement measures/techniques. Different dust abatement measures/techniques have been considered for investigation, such as ESPs and fabric filters. Variable operating costs include electricity, labour and dust disposal costs and are described separately within this table. Furthermore, key characteristics for different fabric filters along with cost schedules can be found in Section 1.4.4.3.2, where the technical applications of fibres are shown in Table 1.32. The information in Table 1.32 is compiled from 2003 and will be subject to local fixed costs with regards to energy and labour. It has to be noted that in Table 1.32 no account is taken of the replacement costs for filter media in the fabric filters.

Investments and costs of dust abatement measures/techniques					
Parameter	**Unit**	**Abatement measure/technique**			
		ESP		**Fabric filter**	
Description of reference installation		I[0)]	II	I[0)]	II
Capacity	t of clinker/d	1100	3000	1100	3000
Lifetime	yr	35		35	
Plant factor	h/yr	7680		7680	
Investment costs	k EUR	1500	2100 – 4600[8)] 4500 – 6000[9)]	1750	2100 – 6800[10)] 4000 – 8000[11)]
Annualised capital costs	k EUR				
Interest rate	%/100/yr	4		4	
Lifetime of the control equipment	yr	10		10	
Total	k EUR	184.94		215.76	
Total	k EUR/tonne clinker	5.25E-04		6.13E-04	
Fixed operating costs	%/yr [2)]	4		4	
Total	k EUR	60		70	
Total	k EUR/tonne clinker	1.70E-04		1.99E-04	
Variable operating costs	k EUR/tonne clinker	3.15E-04		3.77E-04	
Costs per tonne clinker	k EUR/tonne clinker	1.01E-03		1.19E-03	
Costs per tonne PM[3)] abated	k EUR/t PM abated				
Unabated emissions factor[1)]	t PM/t clinker	0.13 56.520 mg/Nm^3		0.13 56.520 mg/Nm^3	
Abated emissions factor[1)]	t PM/t clinker	0.000046 20 mg/Nm^3		0.000046 20 mg/Nm^3	
Total	k EUR/t PM abated	0.008		0.009	
Total operating costs	EUR/t clinker		0.1 – 0.3		0.1 – 0.35
Determination of the variable operating cost					
Electricity costs[4)]					
Additional electricity demand (λ^e) [5)]	kWh/t clinker	4.15 190 kW		5.24 240 kW	
Electricity price (c^e)	EUR/kWh	0.0569		0.0569	
Total	k EUR/tonne clinker	2.36E-04		2.98E-04	
Labour costs[6)]					

Investments and costs of dust abatement measures/techniques					
Parameter	**Unit**	**Abatement measure/technique**			
		ESP		**Fabric filter**	
Labour demand (λ^1)	man-year/t clinker	2.13E-06		2.13E-06	
Wages (c^1)	k EUR/man-year	37.234		37.234	
Total	k EUR/tonne clinker	7.93E-05		7.93E-05	
Dust disposal costs7)					
Total	k EUR/tonne clinker	0		0	
Total variable operating costs	k EUR/tonne clinker	3.15E-04		3.66E-04	

k EUR = EUR thousand

0) 2000 data, reference cement plant with a capacity of 1100 tonnes per day representing the average of the EU-15 in 1995

1) 10 % O_2 and dry gas

2) Of investment

3) Repartition 50 % of ESP and 50 % of fabric filter; use of average between ESP and fabric filter

4) Electricity costs = $\lambda^e \bullet c^e/10^3$ (k EUR/t)

5) Additional electricity demand = new total consumption - old total consumption

6) Labour costs = $\lambda^1 \bullet c^1$ (k EUR/t)

7) Dust disposal costs = $\lambda^d \bullet c^d \bullet ef_{unabated} \bullet \eta/10^3$ (k EUR/t)
$Ef_{unabated}$: unabated emissions factor of pollutant (t pollutant/t)
λ^d: demand for dust disposal (t/t pollutant removed)
c^d: specific dust disposal cost (EUR/t)
η: removal efficiency (=1-$ef_{abated}/ef_{unabated}$)

8) 2000 data, includes investment costs for conditioning tower and filter fan (EUR 0.6 million – 0.8 million)

9) 2006 data

10) Includes investment costs for conditioning tower and filter fan (EUR 0.6 million – 0.8 million)

11) For separation efficiency >99.9 %, depending on type and number of filter bags used

Table 1.39: Examples of cost data for dust abatement measures/techniques
[9, CEMBUREAU, 1997 November], [76, Germany, 2006], [100, France, 2006], [102, France/DFIU/IFARE Karlsruhe, 2003], [103, CEMBUREAU, 2006], [168, TWG CLM, 2007], [182, TWG CLM, 2008]

1.4.8.2 Example cost data for NO_X abatement measures/techniques

Table 1.40 shows examples of cost calculations for NO_X abatement measures/techniques for a reference cement plant with a capacity representing the average of the EU-15 in 1995 (1100 t/d) and example plants with different capacities. The investigated NO_X abatement measures/techniques are SNCR, SCR and NO_X primary measures/techniques. Variable operating costs include electricity and labour costs and costs for ammonia used for SNCR are described separately within this table.

Furthermore, comparison of costs for the NO_X abatement measures/techniques of SNCR versus SCR by German UBA for a German plant can be found in Section 4.2.4.2, Table 4.26. Both investment and operating costs were calculated for different NO_X levels which were achieved, i.e. 200 and 500 mg/Nm^3. As shown from Table 4.26, the operating costs for SNCR and SCR - including replacement costs for the catalyst – are roughly the same for a target NO_X level of 500 mg/Nm^3, while the total specific costs for SCR are approximately 50 % higher than for SNCR. At a target NO_X level of 200 mg/Nm^3, SCR seems to be more efficient regarding operating costs, but the total specific costs are still at the same level of magnitude as for SNCR [76, Germany, 2006].

Investments and costs of NO_x abatement measures/techniques

Parameter	Unit	Abatement measure/technique 1)				
		NO_x primary measures/ techniques 0)	**Flame cooling 8)**	**Staged 7) combustion**	**SNCR 0)**	**SCR**
Description of reference Installation						
Capacity	t of clinker/d	1100	3000	3000	1100	1500 7)
Capacity	t of clinker/yr	352000				
Lifetime	yr	35			35	
Plant factor	h/yr	7680			7680	
Investment costs	EUR million	0.25	up to 0.2	0.1 – 2 8) 1 – 4 9) 15 – 20 10)	0.6	
Specific investment costs	EUR/t clinker				0.08 – 0.14 7)	0.83 – 0.87 7)
Annualised capital costs	k EUR					
Interest rate	%/100/yr	4			4	
Lifetime of the control equipment	yr	8			10	
Total	k EUR	37.13			166.97	
Total	k EUR/t clinker	1.05E-04	up to 2.5E-04		4.74E-04	
Fixed operating costs	%/yr 2)	4			4	
Total	k EUR	10			24	
Total	k EUR/t clinker	2.84E-05			6.82E-05	
Variable operating costs	k EUR/t clinker	2.64E-05			5.69E-04	
Costs per tonne clinker	k EUR/t clinker	1.60E-04			1.11E-03	
Costs per tonne NO_x 3) abated	k EUR/t NO_x abated				330 – 450 7)	470 – 540 7)
Unabated emissions factor 1)	t NO_x/t clinker	0.00322 1400 mg/Nm^3			0.002415 1050 mg/Nm^3	
Abatement efficiency 1)	%	25			62	
Total	k EUR/t NO_x abated	0.2			0.74	
Catalysts Replacement costs	EUR/t clinker					0.10 – 0.13 7)
Determination of the variable operating costs						
Electricity costs 3)						
Additional electricity demand (λ^e) 4)	kWh/t clinker	0.44 20 kW			0.13 5.96 kW	
Electricity price (c^e)	EUR/kWh	0.0569			0.0569	
Total	k EUR/t clinker	2.48E-05			7.40E-06 0.03 – 0.06 7)	0.10 – 0.11 7)
Ammonia costs 6)						
NH_3 water storage	EUR million					
$ef_{unabated}$	T pollutant/t clinker	-			0.002415	

Investments and costs of NO_x abatement measures/techniques						
Parameter	**Unit**	**Abatement measure/technique**[1]				
		NO_x primary measures/ techniques[0]	**Flame cooling**[8]	**Staged** [7] **combustion**	**SNCR**[0]	**SCR**
NH_3/NO_x (mol/mol) ratio for NO_x emitted		-			1.5	
Specific NH_3 demand (λ^s)	t/t pollutant removed	-			0.89	
NH_3 price (c^s)	EUR/t	-			0.26 –0.64[7] 400	0.13 – 0.26[7]
Removal efficiency (η)	%	-			62	
Total	k EUR/t clinker	-			5.36E-04	
Labour costs[5]						
Labour demand (λ^1)	man-year/t clinker	7.10E-07			7.10E-07	
Wages (c^1)	k EUR/man-year	37.234			37.234	
Total	k EUR/t clinker	2.64E-05			2.64E-05	
Total variable operating costs	k EUR/t	2.48E-05			5.69E-04 0.30 – 0.70[7]	0.33 – 0.70[7]
Total costs (investment and operating)	EUR/t clinker				0.38 – 0.62[7] 0.85[11]	0.83 – 0.87[7] 2.3[11]

k EUR = EUR thousand

[0] 2000 data, reference cement plant with a capacity of 1100 tonnes per day representing the average of the EU-15 in 1995

[1] 10 % O_2 and dry gas

[2] Of investment

[3] Electricity costs = $\lambda^e \cdot c^e/10^3$ (k EUR/t)

[4] Additional electricity demand = new total consumption - old total consumption

[5] Labour costs = $\lambda^1 \cdot c^1$ (k EUR/t)

[6] Ammonia costs = $\lambda^d \cdot c^d \cdot ef_{unabated} \cdot \eta/10^3$ (k EUR/t)
$Ef_{unabated}$: unabated emissions factor of pollutant (t pollutant/t)
λ^d: specific NH_3 demand (t/t pollutant removed)
c^d: specific dust disposal cost (EUR/t)
η: removal efficiency ($=1-ef_{abated}/ef_{unabated}$)

[7] Germany, depends on level of NO_x reduction to 500 or 200 mg/Nm^3

[8] Precalciner kiln

[9] Precalciner and the tertiary duct for a 3000 t/d preheater kiln with a grate cooler into a precalciner kiln

[10] Transformation of a 3000 t/d preheater kiln with a satellite cooler into a precalciner kiln with a grate cooler

[11] Austria

Table 1.40: Examples of costs for NO_x abatement measures/techniques
[76, Germany, 2006], [85, CEMBUREAU, 2006], [100, France, 2006], [102, France/DFIU/IFARE Karlsruhe, 2003], [105, YARA, 2006], [168, TWG CLM, 2007], [182, TWG CLM, 2008]

1.4.8.3 Example cost data for SO_x abatement measures/techniques

Table 1.41 shows examples of cost calculations for SO_x abatement measures/techniques for a reference cement plant with a capacity of 1100 t/d. The investigated SO_x abatement measures/techniques are injection of absorbent and/or wet scrubbers. Variable operating costs include electricity and labour costs, and waste disposal and lime costs are described separately within this table.

Investments and costs of SO_x abatement measures/techniques			
		Abatement measure/technique	
	Unit	**Absorbent injection0)**	**Wet scrubber 75 %0)**
Description of reference installation			
Capacity	t of clinker/d	1100	1100
Capacity	t of clinker/yr	352000	352000
Exhaust gas flow1)	Nm^3/h		105417
Lifetime	yr	35	35
Plant factor	h/yr	7680	7680
Investment costs	k EUR	200	5500
Annualised capital costs	k EUR		
Interest rate	%/100/yr	4	4
Lifetime of the control equipment	yr	10	10
Total	k EUR	24.66	678.10
Total	k EUR/t clinker	7.01E-05	1.93E-03
Fixed operating costs	%/yr 2)	4	4
Total	k EUR	8	220
Total	k EUR/t clinker	2.27E-05	6.25E-04
Variable operating costs	k EUR/t clinker	6.98E-04	6.06E-04
Costs per tonne of clinker	k EUR/t clinker	7.91E-04	3.16E-03
Costs per tonne of SO_x abated	k EUR/t SO_x abated		
Unabated emissions factor	t SO_x/t clinker	0.0023 1000 mg/Nm^3	0.00368 1600 mg/Nm^3
Abatement efficiency	%	60	75
Total	k EUR/t SO_x abated	0.573	1.144
Determination of the variable operating costs			
Electricity costs3)			
Additional electricity demand (λ^e) 4)	kWh/t of clinker	1.53 70 kW	8.18 375 kW
Electricity price (c^e)	EUR/kWh	0.0569	0.0569
Total	k EUR/t clinker	8.69E-05	4.66E-04
Waste disposal costs			
Unabated emissions factor of pollutant ($ef_{unabated}$ 6))	t pollutant/t clinker	0.0023	-
Demand for waste disposal (λ^s)	t/t pollutant removed	0	-
Specific waste disposal costs (c^s)	EUR/t		-
Removal efficiency (η)	%	60	-
Total	k EUR/t clinker	0	0
Lime costs/limestone costs			
Unabated emissions factor of pollutant ($ef_{unabated}$ 6))	T pollutant/t clinker	0.0023	0.00368
	Ca/S (mol/mol) ratio for SO_x emitted	2.2	
	Ca/S (mol/mol) ratio for SO_x removed		1.02

Investments and costs of SO_x abatement measures/techniques			
		Abatement measure/technique	
	Unit	**Absorbent injection0)**	**Wet scrubber 75 %0)**
Specific sorbent demand (λ^s)	t lime/t pollutant removed	4.24	-
Specific limestone demand (λ^s)	t lime/t pollutant removed		1.59
Sorbent price (c^s)	EUR/t	100	20
Removal efficiency (η)	%	60	75
Total	k EUR/t clinker	5.85E-05	8.80E-05
Labour costs5)			
Labour demand (λ^1)	man-year/t clinker	7.10E-07	1.42E-06
Wages (c^1)	k EUR/man-year	37.234	37.234
Total	k EUR/t clinker	2.64E-05	5.29E-05
Total variable operating costs	k EUR/t clinker	6.98E-04	6.06E-04

k EUR = EUR thousand

0) 2000 data, reference cement plant with a capacity of 1100 tonnes per day representing the average of the EU-15 in 1995

1) 10 % O_2 and dry gas

2) Of investment

3) Electricity costs = $\lambda^e \bullet c^e/10^3$ (k EUR/t)

4) Additional electricity demand = new total consumption - old total consumption

5) Labour costs = $\lambda^1 \bullet c^1$ (k EUR/t)

6) Lime costs = $\lambda^s \bullet c^s \bullet ef_{unabated} \bullet \eta/10^3$ (k EUR/t)

$ef_{unabated}$: unabated emissions factor of pollutant (t pollutant/t)
λ^s: specific lime demand (t/t pollutant removed)
c^s: lime price (EUR/t)
η: removal efficiency ($=1-ef_{abated}/ef_{unabated}$)

Table 1.41: Example of costs for SO_x abatement measures/techniques
[100, France, 2006], [102, France/DFIU/IFARE Karlsruhe, 2003], [168, TWG CLM, 2007]

1.4.9 Process losses/waste

Description
Collected dust can be recycled back into the production processes whenever practicable. This recycling may take place directly into the kiln or kiln feed (the alkali metal content being the limiting factor) or by blending with finished cement products. Alternative uses may be found for material that cannot be recycled.

Achieved environmental benefits
Reduction of waste materials occurring from the process along with raw material savings.

Cross-media effects
The content of metals in the collected dust is the limiting factor for using collected dust as raw material and can have a negative effect on metal emissions.

Furthermore, the content of chlorine in the collected dust is a limiting factor for the use of collected dust and the recycling has to be adapted to comply with product quality requirements (kiln feed or blending with finished cement products).

Operational data
No data provided.

Applicability
The re-use of process losses/waste is, in principle, applicable in the cement industry (see Section 1.3.5).

Economics
No data provided.

Driving force for implementation
Legal requirements.

Example plants and reference literature
Cement plants in the EU-27.
[86, EURITS, 2006], [88, SINTEF, 2006], [75, Estonia, 2006], [103, CEMBUREAU, 2006], [168, TWG CLM, 2007]

1.4.10 Noise

Description
This section deals with possibilities for the reduction of noise occurring in several steps of the cement manufacturing processes.

A reduction of noise emissions can often be achieved by directly applying measures/techniques at the source of the noise. Sources of noise are, for example, extraction and processing of raw material as well as cement/clinker production, crushing units, grinding and preparation units, the cement kilns themselves, e.g. cement finishing mills, belt conveyors, filter units, the cooling systems of the kilns, such as satellite coolers, etc. Noise emissions occur throughout the whole process chain from blowing in the quarry to shipping of the final products.

Various measures/techniques for noise abatement can be applied at cement plants in order to reduce the noise levels for neighbourhood protection, such as:

- enclosure of the noisy unit
- vibration insulation of units
- using internal and external lining made of resistant material for chutes
- soundproof buildings to shelter any operations involving material transformation equipment
- building up noise protection walls
- outlet silencers for exhaust stacks
- lagging of ducts and finally blowers which are situated in soundproofed buildings.

If the above-mentioned noise protection measures/techniques cannot be applied and if a transfer of noisy units inside a building is not possible, e.g. because of the sizes of kilns and their facilities, secondary noise protection measures/techniques, e.g. construction of buildings or natural barriers, such as growing trees and bushes between the protected area and the noisy activity, e.g. the kiln or the storage area, have to be carried out. Doors and windows of covered areas have to be kept closed during noisy operations.

Achieved environmental benefits
Reduction of noise emissions.

Cross-media effects
No issues.

Operational data
No data available.

Applicability
Measures/techniques for noise reduction can, in principle, be applicable in the cement industry (see Section 1.3.7).

Economics
Additional investment and maintenance costs can occur due to the noise protection measures/techniques.

Driving force for implementation
Legal requirements.

Example plants and reference literature
Cement plants in the EU-27.
More information about noise abatement and a noise abatement scheme can be found in the lime chapter, Section 2.4.10.
[45, Schorcht, 2006] [81, Castle Cement UK, 2006] [168, TWG CLM, 2007]

1.4.11 General considerations for odour

Unpleasant smells caused by hydrocarbon emissions can be avoided by thermal after-burning, use of an activated carbon filter or by feeding the raw material responsible to the hot zone of the kiln.

If odour is caused by sulphur compounds, a change of fuel and/or raw material can be a solution, also see Section 1.4.5.2.

Unpleasant smells can also be caused by the storage of wastes which are used as raw materials or fuels. Storage places of waste materials can be covered or waste storage systems can be used.

1.4.12 Environmental management tools

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

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

All effective EMSs contain the notion of continuous improvement meaning that environmental management is a process, not a project which eventually comes to an end. There are various process designs, but most environmental management systems are based on the plan-do-check-act cycle (which is widely used in other company management contexts). The cycle is a re-iterative dynamic model, where the completion of one cycle flows into the beginning of the next, see Figure 1.70.

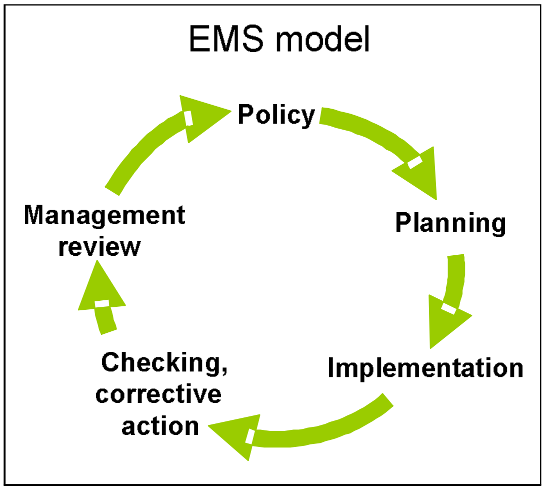


Figure 1.70: **Continuous improvement in an EMS model**

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

While both standardised systems (EN ISO 14001:2004 and EMAS) and non-standardised ('customised') systems in principle take the *organisation* as the entity, this document takes a more narrower approach, not including all activities of the organisation e.g. with regard to their products and services, due to the fact that the regulated entity under the IPPC Directive is the *installation* (as defined in Article 2 of the Directive).

An Environmental Management System (EMS) for an IPPC installation can contain the following components:

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

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

a. Commitment of top management:

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

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

b. Definition of an environmental policy

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

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

c. Planning and establishing objectives and targets:

It is important to have:

- procedures to identify the environmental aspects of the installation, in order to determine those activities which have or can have significant impacts on the environment, and to keep this information up-to-date
- procedures to evaluate proposals for new processes, units and equipment, change in raw and auxiliary materials or fuels, upgrades, rebuilds and replacements in order to identify the environmental aspects and to influence the planning and purchasing to optimise the environmental performance of the installation with regard to the objectives of the IPPC Directive
- procedures to authorise the modifications indicated above and to undertake checks after modifications have been implemented and before the process starts up
- procedures to identify and have access to legal and other requirements to which the organisation subscribes and that are applicable to the environmental aspects of its activities

- establishing and reviewing documented environmental objectives and targets, taking into consideration the legal and other requirements to which the organisation subscribes and the views of interested parties
- establishing and regularly updating an environmental management programme, including designation of responsibility for achieving objectives and targets at each relevant function and level as well as the means and timeframe by which they are to be achieved
- carrying out audits to review e.g. the efficient use of energy, water, raw and auxiliary materials.

d. Implementation and operation of procedures

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

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

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

(iii) Communication
  - ◦ establishing and maintaining procedures for internal communication between the various levels and functions of the installation, as well as procedures that foster a dialogue with external interested parties and procedures for receiving, documenting and, where reasonable, responding to relevant communication from external interested parties.

(iv) Employee involvement
  - ◦ involving employees in the process aimed at achieving a high level of environmental performance by applying appropriate forms of participation such as the suggestion-book system or project-based group works or environmental committees.

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

(vi) Efficient process control
  - ◦ adequate control of processes and equipment (including pollution prevention and control equipment) under all modes of operation, i.e. preparation, start-up, routine operation, shutdown and abnormal conditions
  - ◦ identifying the key performance indicators (e.g. flow, pressure, temperature, composition, quantity) and methods (e.g. weighting systems, metering systems, calculations, sampling and analysis) for measuring and controlling these parameters

- documenting and analysing abnormal operating conditions to identify the root causes and then addressing these to ensure that abnormal events do not recur (this can be facilitated by a 'no-blame' culture where the identification of causes is more important than apportioning blame to individuals).

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

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

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

(i) Monitoring and measurement
- establishing and maintaining documented procedures to monitor and measure, on a regular basis, the key characteristics of operations and activities that can have a significant impact on the environment. This includes the recording of information for tracking performance, relevant operational controls and conformance with the installation's environmental objectives and targets (see also the Reference Document on the General Principles of [151, European Commission, 2003])
- establishing and maintaining a documented procedure for periodically evaluating compliance with relevant environmental legislation and regulations.

(ii) Corrective and preventive action
- establishing and maintaining procedures for defining responsibility and authority for handling and investigating non-conformance with permit conditions, other legal requirements and commitments as well as objectives and targets
- taking action to mitigate any impacts caused by abnormal events and for initiating and completing corrective and preventive 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 programme (or programmes) and procedures for periodic environmental management system audits. Such a programme (or programmes) include discussions with personnel, inspection of operating conditions and equipment and reviewing of records and documentation. Each audit result in a written report, to be carried out impartially and objectively by employees (internal audits) or external parties (external audits), covering the audit scope, frequency and methodologies, as well as the responsibilities and requirements for conducting audits and reporting results, in order to determine whether or not the

  environmental management system conforms to planned arrangements and has been properly implemented and maintained
  - ◦ completing the audit or audit cycle, as appropriate, at intervals of no longer than three years, depending on the nature, scale and complexity of the activities, the significance of associated environmental impacts, the importance and urgency of the problems detected by previous audits and the history of environmental problems - more complex activities with a more significant environmental impact are audited more frequently
  - ◦ having appropriate mechanisms in place to ensure that the audit results are followed up.

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

f. Management review:

- reviewing, by top management, at intervals that it determines, of the environmental management system, to ensure its continuing suitability, adequacy and effectiveness
- ensuring that the necessary information is collected to allow management to carry out this evaluation
- documentation of the review.

g. Preparation of a regular environmental statement:

- preparing an environmental statement that pays particular attention to the results achieved by the installation against its environmental objectives and targets. It is regularly produced - from once a year to less frequently depending on the significance of emissions, waste generation etc. This statement considers the information needs of relevant interested parties and it is publicly available (e.g. in electronic publications, libraries etc.). When producing a statement, the operator may use relevant existing environmental performance indicators, making sure that the indicators chosen:

  i. give an accurate appraisal of the installation's environmental performance
  ii. are understandable and unambiguous
  iii. allow for year on year comparison to assess the development of the environmental performance of the installation
  iv. allow for comparison with sector, national or regional benchmarks as appropriate
  v. allow for comparison with regulatory requirements as appropriate.

h. Validation by certification body or an external EMS verifier:

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

i. Design considerations for end-of-life plant decommissioning

- giving consideration to the environmental impact from the eventual decommissioning of the installation at the stage of designing a new plant, as forethought makes decommissioning easier, cleaner and cheaper
- decommissioning poses environmental risks for the contamination of land (and groundwater) and generates large quantities of solid waste. Preventive techniques are process-specific but general considerations may include:

  i. avoiding underground structures
  ii. incorporating features that facilitate dismantling
  iii. choosing surface finishes that are easily decontaminated
  iv. using an equipment configuration that minimises trapped chemicals and facilitates drain-down or cleaning
  v. designing flexible, self-contained units that enable phased closure
  vi. using biodegradable and recyclable materials where possible.

j. Development of cleaner technologies:

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

k. Benchmarking, i.e.:

- carrying out systematic and regular comparisons with sector, national or regional benchmarks, including for energy efficiency and energy conservation activities, choice of input materials, emissions to air and discharges to water (using for example the European Pollutant Emission Register, EPER), consumption of water and generation of waste.

Standardised and non-standardised EMSs:
An EMS can take the form of a standardised or non-standardised ("customised") system. Implementation and adherence to an internationally accepted standardised system such as EN ISO 14001:2004 can give higher credibility to the EMS, especially when subjected to a properly performed external verification. EMAS provides additional credibility due to the interaction with the public through the environmental statement and the mechanism to ensure compliance with the applicable environmental legislation. However, non-standardised systems can in principle be equally effective provided that they are properly designed and implemented.

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

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

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

Operational data
All significant consumptions (including energy) and emissions are managed in a coordinated manner by the operator for the short, medium and long term, in conjunction with financial planning and investment cycles. This means that e.g. adapting short-term end-of-pipe solutions to emissions may tie the operator to long term higher energy consumption, and postpone investment in potentially more environmentally beneficial solutions overall. This requires some consideration of the cross-media issues, and guidance on these and the costing and cost-benefits issues is given in the Reference Document on Economics and Cross-Media Effects [179, European Commission, 2006] and in the Reference Document on Best Available Techniques for Energy Efficiency [181, European Commission, 2008]

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

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

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

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

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

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

Example plants
The features described under (b) to (f) above are elements of EN ISO 14001:2004 and the European Union Eco-Management and Audit Scheme (EMAS), whereas the features (g) and (h) are specific to EMAS. These two standardised systems are applied in a number of IPPC installations.

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[1] 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.

Reference literature

(Regulation (EC) No 761/2001 of the European parliament and of the council allowing voluntary participation by organisations in a Community eco-management and audit scheme (EMAS), OJ L 114, 24/4/2001, http://europa.eu.int/comm/environment/emas/index_en.htm), (EN ISO 14001:2004, http://www.iso.ch/iso/en/iso9000-14000/iso14000/iso14000index.html; http://www.tc207.org)

1.5 Best available techniques for the cement industry

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

- identification of the key environmental issues for the sector; for the manufacture of cement these are energy use including the use of wastes as fuel and emissions to air
- examination of the measures/techniques most relevant to address those key issues
- identification of the best environmental performance levels, on the basis of the available data in the European Union and worldwide
- examination of the conditions under which these performance levels were achieved; such as costs, cross-media effects, main driving forces involved in implementation of these measures/techniques
- selection of the best available techniques (BAT) and the associated emission and/or consumption levels for this sector in a general sense according to Article 2(12) and Annex IV to the Directive.

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

On the basis of this assessment, best available techniques, and as far as possible emission and consumption levels associated with their use, are presented in this section that are considered to be appropriate to the sector as a whole and in many cases reflect current performance of some installations within the sector. Where emission or consumption levels 'associated with best available techniques' are presented, this is to be understood as meaning that those levels represent the environmental performance that could be anticipated as a result of the application, in this sector, of the measures/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 measure/technique or combination of measures/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 measures/techniques.

Where available, data concerning costs have been given together with the description of the measures/techniques presented in Section 1.4. These give a rough indication about the magnitude of costs involved. However, the actual cost of applying a measure/technique will depend strongly on the specific situation regarding, for example, taxes, fees, subsidies and the technical characteristics of the installation concerned. It is not possible to evaluate such site-specific factors fully in this document. In the absence of data concerning costs, conclusions on economic viability of measures/techniques are drawn from observations on existing installations.

The BAT (including the associated emission and consumption levels) given in this section are 'BAT in a general sense' (i.e. considered to be appropriate to the sector as a whole). It is intended that they are a reference point against which to judge the current performance of an existing installation or to judge a proposal for a new installation. In this way, they will assist in the determination of appropriate 'BAT-based' conditions for the installation or in the establishment of general binding rules under Article 9(8) of the IPPC Directive. It is foreseen that new installations can be designed to perform at or even better than the BAT levels presented in this section. It is also considered that existing installations could move towards the BAT levels presented in this section or do better, subject to the technical and economic applicability of the measure/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 measures/techniques. The appropriate permit conditions for any specific case will need to be determined taking into account the objectives of the IPPC Directive and the local considerations.

'Best Available Techniques' for a specific installation will usually be the use of one individual or a combination of the BAT listed in this section.

Where measures/techniques identified individually as BAT can be used in combination, the effects of such combinations should be considered when drawing conclusions on BAT based permit conditions for individual cases.

Recommendation to help users/readers of this document:

It is strongly recommended to read this Section 1.5 in conjunction with Section 1.4, because the considerations regarding the applicability of the measures/techniques as mentioned in Section 1.4 have to be taken into account. To help the reader in this, references to Section 1.4 have been included in Section 1.5.

If not otherwise mentioned, BAT associated emission levels given in this section are expressed on a daily average basis and standard conditions. The following definitions regarding the standard conditions apply for volume flows and concentrations of kiln exhaust gases, and are also stated in the Glossary:

Nm^3/h	volume flow: if not otherwise mentioned in this section, the volume flows refer to 10 vol-% oxygen and standard state
mg/Nm^3	concentration: if not otherwise mentioned in this section, the concentrations of gaseous substances or mixtures of substances refer to dry flue-gas at 10 vol-% oxygen and standard state
standard state	refers to a temperature of 273 K, a pressure of 1013 hPa and dry gas

As described in the Preface, this document does not propose emission limit values. The best available techniques and presented ranges of emission or consumption levels associated with best available techniques (BAT-AEL ranges) are related to installations with different kiln sizes, different kinds of kiln operation, e.g. continuously or discontinuously, and different operational hours per year. In this document, special local considerations cannot be taken fully into account. 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. 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 here in Section 1.5 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.

1.5.1 Environmental management systems (EMS)

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

1. **BAT is to implement and adhere to an Environmental Management System (EMS) that incorporates, as appropriate to the local circumstances, the following features (see Section 1.4.12):**

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

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

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

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

(e) checking performance and taking corrective action, paying particular attention to:
- monitoring and measurement (see also the Reference Document on the General Principles of Monitoring [151, European Commission, 2003])
- corrective and preventive action
- maintenance of records
- independent (where practicable) internal auditing in order to determine whether or not the environmental management system conforms to planned arrangements and has been properly implemented and maintained

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

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

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

Specifically for the cement manufacturing industry, 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, and to follow developments
- where practicable, the application of sectoral benchmarking on a regular basis, including energy efficiency and energy conservation activities, choice of input materials, emissions to air, discharges to water, consumption of water and generation of waste.

1.5.2 General primary measures/techniques

2. **BAT is to achieve a smooth and stable kiln process, operating close to the process parameter set points, that is beneficial for all kiln emissions as well as the energy use by applying the following measures/techniques:**

    🟦 process control optimisation, including computer-based automatic control (see Section 1.4.3.1)
    🟦 using modern, gravimetric solid fuel feed systems (see Sections 1.4.2.1.1 and 1.4.3.1).

3. **BAT is to carry out a careful selection and control of all substances entering the kiln in order to avoid and/or reduce emissions (see Sections 1.4.3.2 and 1.4.3.3).**

4. **BAT is to carry out monitoring and measurements of process parameters and emissions on a regular basis, such as:**

    🟪 continuous measurements of process parameters demonstrating the process stability, such as temperature, O_2 content, pressure, flow rate, and of NH_3 emissions when using SNCR
    🟪 monitoring and stabilising critical process parameters, i.e. homogenous raw material mix and fuel feed, regular dosage and excess oxygen
    🟪 continuous measurements of dust, NO_x, SO_x and CO emissions
    🟪 periodic measurements of PCDD/F, metals emissions
    🟪 continuous or periodic measurements of HCl, HF and TOC emissions.

    In this context, when co-incinerating waste, the requirements of the Waste Incineration Directive (WID) have to be met [59, European Commission, 2000].

1.5.3 Energy consumption and process selection

1.5.3.1 Process selection

General considerations regarding process selection can be found in Section 1.4.2.3. Considerations regarding the heat demand can be found in Section 1.4.2.1.1.

The selected process has a major impact on the energy use and on air emissions from the manufacture of cement clinker.

5. **For new plants and major upgrades, BAT is to apply a dry process kiln with multistage preheating and precalcination. Under regular and optimised operational conditions, the associated BAT heat balance value is 2900 – 3300 MJ/tonne clinker (see Sections 1.4.2.3 and 1.4.2.1.1).**

1.5.3.2 Energy consumption

General considerations regarding energy consumption can be found in Sections 1.3.3 and 1.4.2.

6. **BAT is to reduce/minimise thermal energy consumption by applying a combination of the following measures/techniques (see Section 1.4.2):**

- applying improved and optimised kiln systems and a smooth and stable kiln process, operating close to the process parameter set points by applying:
  - I. process control optimisation, including computer-based automatic control systems
  - II. modern, gravimetric solid fuel feed systems (see Sections 1.4.2.1.1 and 1.4.3.1)
  - III. preheating and precalcination to the extent possible, considering the existing kiln system configuration

  In this context, see Section 1.4.2.1.1, where several different measures/techniques are presented, which can be applied to kiln systems, individually or in combination. Furthermore in this context, see the Reference Document on Best Available Techniques for Energy Efficiency [181, European Commission, 2008]

- recovering excess heat from kilns, especially from their cooling zone (see Sections 1.4.2.1.1 and 1.4.2.4). In particular, the kiln excess heat from the cooling zone (hot air) or from the preheater can be used for drying raw materials.
  In this context, see also the Reference Document on Best Available Techniques for Energy Efficiency [181, European Commission, 2008]

- applying the appropriate number of cyclone stages related to the characteristics and properties of raw material and fuels used (see Sections 1.4.2.1.2 and 1.4.2.1.3)

- using fuels with characteristics which have a positive influence on the thermal energy consumption

- when replacing conventional fuels by waste fuels, using optimised and suitable cement kiln systems for burning wastes (see Section 1.4.2.1.3)

- minimising bypass flows (see Section 1.4.2.1.4).

7. **BAT is to reduce primary energy consumption by considering the reduction of the clinker content of cement and cement products (see Section 1.4.2.1.5).**

8. **BAT is to reduce primary energy consumption by considering cogeneration/combined heat and power plants (see Section 1.4.2.4) if possible, on the basis of useful heat demand, within energy regulatory schemes where economically viable.**

   In this context, see the Reference Document on Best Available Techniques for Energy Efficiency [181, European Commission, 2008].

9. **BAT is to minimise electrical energy consumption by applying the following measures/techniques individually or in combination:**

   - using power management systems
   - using grinding equipment and other electricity based equipment with high energy efficiency
     In this context, see Section 1.4.2.2, where several different measures/techniques are presented.

1.5.4 Use of waste

General considerations regarding the use of waste can be found in Sections 1.2.4, 1.3.4.13, 1.3.4.14 and 1.4.3.3. Considerations regarding metal emissions can be found in Section 1.4.7.

BAT and BAT-AELs for emissions reduction can be found in the corresponding Sections 1.5.5 – 1.5.10 below. In this context, when co-incinerating waste, the requirements of the Waste Incineration Directive (WID) have to be met [59, European Commission, 2000].

1.5.4.1 Waste quality control

10. **BAT is:**

a) **to apply quality assurance systems to guarantee the characteristics of wastes and to analyse any waste that is to be used as raw material and/or fuel in a cement kiln for (see Section 1.4.3.3):**

   - constant quality
   - physical criteria, e.g. emissions formation, coarseness, reactivity, burnability, calorific value
   - chemical criteria, e.g. chlorine, sulphur, alkali and phosphate content and relevant metals content

b) **to control the amount of relevant parameters for any waste that is to be used as raw material and/or fuel in a cement kiln, such as chlorine, relevant metals (e.g. cadmium, mercury, thallium), sulphur, total halogen content**

c) **to apply quality assurance systems for each waste load.**

1.5.4.2 Waste feeding into the kiln

11. BAT is:

- **to use the appropriate feed points to the kiln in terms of temperature and residence time depending on kiln design and kiln operation (see Section 1.2.4.1)**
- **to feed waste materials containing organic components that can be volatilised before the calcining zone into the adequately high temperature zones of the kiln system**
- **to operate in such a way that the gas resulting from the co-incineration of waste is raised in a controlled and homogeneous fashion, even under the most unfavourable conditions, to a temperature of 850 °C for 2 seconds**
- **to raise the temperature to 1100 °C, if hazardous waste with a content of more than 1 % of halogenated organic substances, expressed as chlorine, is co-incinerated**
- **to feed wastes continuously and constantly**
- **to stop co-incinerating waste for operations such as start-ups and/or shutdowns when appropriate temperatures and residence times cannot be reached, as noted in a) to d) above**

1.5.4.3 Safety management for the use of hazardous waste materials

12. BAT is to apply safety management for the handling, e.g. storage, and/or feeding of hazardous waste materials (see Section 1.4.3.3), such as using a risk based approach according to the source and type of waste, for the labelling, checking, sampling and testing of waste to be handled.

1.5.5 Dust emissions

1.5.5.1 Diffuse dust emissions

General considerations regarding diffuse dust emissions can be found in Sections 1.3.4.1.3, 1.3.4.1.2, 1.4.4.1 and 1.4.4.2.

13. BAT is to minimise/prevent diffuse dust emissions by applying the following measures/techniques individually or in combination:

a) measures/techniques for dusty operations. In this context, see Section 1.4.4.1, where several different measures/techniques are presented, which can be applied individually or in combination

b) bulk storage area measures/techniques. In this context, see Section 1.4.4.2, where several different measures/techniques are presented, which can be applied individually or in combination.

1.5.5.2 Channelled dust emissions from dusty operations

This section presents BAT for dust emissions arising from dusty operations other than those from kiln firing, cooling and main milling processes. This covers processes such as the crushing of raw materials, raw material conveyors and elevators, the storage of raw materials, clinker and cement, the storage of fuels (petcoke, hard coal, lignite) and the dispatch of cement (loading). General considerations regarding these channelled dust emissions can be found in Sections 1.3.4.1.1, 1.3.4.1.2 and 1.4.4.3.

14. **BAT is to apply a maintenance management system which especially addresses the performance of filters of these sources. Taking this management system into account, BAT is to reduce channelled dust emissions from dusty operations (see Section 1.4.4.3) to less than 10 mg/Nm^3 (BAT-AEL), as the average over the sampling period (spot measurement, for at least half an hour) by applying dry exhaust gas cleaning with a filter.**

    It has to be noted that for small sources (<10000 Nm^3/h) a priority approach has to be taken into account.

    In this context, see Section 1.4.4.3, where several different measures/techniques are presented, which can be applied individually or in combination.

1.5.5.3 Dust emissions from kiln firing processes

This section presents BAT for dust emissions arising from kiln firing processes. General considerations regarding channelled dust emissions can be found in Sections 1.3.4.1.1, 1.3.4.1.2 and 1.4.4.3.

15. **BAT is to reduce dust (particulate matter) emissions from flue-gases of kiln firing processes by applying dry exhaust gas cleaning with a filter. The BAT-AEL is <10 – 20 mg/Nm^3, as the daily average value. When applying fabric filters or new or upgraded ESPs, the lower level is achieved.**

    In this context, see Section 1.4.4.3, where several different measures/techniques are presented, which can be applied individually or in combination. Furthermore in this context, when co-incinerating waste, the requirements of the Waste Incineration Directive (WID) have to be met [59, European Commission, 2000].

1.5.5.4 Dust emissions from cooling and milling processes

This section presents BAT for dust emissions arising from cooling and milling processes. General considerations regarding channelled dust emissions can be found in Sections 1.3.4.1.1, 1.3.4.1.2 and 1.4.4.3.

16. **BAT is to reduce dust (particulate matter) emissions from flue-gases of cooling and milling processes by applying dry exhaust gas cleaning with a filter. The BAT-AEL is <10 – 20 mg/Nm^3, as the daily average value or average over the sampling period (spot measurements for at least half an hour). When applying fabric filters or new or upgraded ESPs, the lower level is achieved.**

    In this context, see Section 1.4.4.3, where several different measures/techniques are presented, which can be applied individually or in combination.

1.5.6 Gaseous compounds

1.5.6.1 NO_x emissions

General considerations regarding NO_x emissions can be found in Section 1.3.4.2.

17. **BAT is to reduce the emissions of NO_x from the flue-gases of kiln firing processes by applying the following measures/techniques individually or in combination (see Section 1.4.5.1):**

- primary measures/techniques, such as:
  - flame cooling
  - low NO_x burners
  - mid kiln firing
  - addition of mineralisers to improve the burnability of the raw meal (mineralised clinker)
  - process optimisation (see Sections 1.4.5.1.1 to 1.4.5.1.6).

- staged combustion (conventional or waste fuels), also in combination with a precalciner and the use of optimised fuel mix (see Section 1.4.5.1.3)
- SNCR (see Sections 1.4.5.1.7)
- SCR, subject to appropriate catalyst and process development in the cement industry (see Section 1.4.5.1.8).

The following emission levels of NO_x are BAT-AELs:

Kiln type	**Unit**	**BAT-AEL (daily average value)**
Preheater kilns	mg/Nm^3	<200 – 450[2][3]
Lepol and long rotary kilns	mg/Nm^3	400 – 800[1]

[1] Depending on initial levels and ammonia slip

[2] BAT-AEL is 500 mg/Nm^3, where after primary measures/techniques the initial NO_x level is >1000 mg/Nm^3

[3] Existing kiln system design, fuel mix properties including waste, raw material burnability can influence the ability to be in the range. Levels below 350 mg/Nm^3 are achieved at kilns with favourable conditions. The lower value of 200 mg/Nm^3 has only been reported as monthly average for three plants (easy burning mix used)

Table 1.42: BAT associated emission levels for NO_x from the flue-gases of kiln firing and or preheating/precalcining processes in the cement industry

In this context, when co-incinerating waste, the requirements of the Waste Incineration Directive (WID) have to be met [59, European Commission, 2000].

18. **By applying SNCR, BAT is:**

- to apply an appropriate and sufficient NO_x reduction efficiency along with a stable operating process
- to apply a good stoichiometric distribution of ammonia in order to achieve the highest efficiency of NO_x reduction and to reduce the ammonia slip
- to keep the emissions of NH_3 slip from the flue-gases as low as possible, but below 30 mg/Nm^3, as the daily average value. The correlation between the NO_x abatement efficiency and the NH_3 slip has to be considered (see Sections 1.4.5.1.7). Depending on the initial NO_x level and on the NO_x abatement efficiency, the NH_3 slip may be higher up to 50 mg/Nm^3. For Lepol and long rotary kilns, the level may be even higher.

1.5.6.2 SO_x emissions

General considerations regarding SO_x emissions can be found in Sections 1.3.4.3 and 1.4.5.2.

19. BAT is to keep the emissions of SO_x low or to reduce the emissions of SO_x from the flue-gases of kiln firing and/or preheating/precalcining processes by applying one of the following measures/techniques (see Section 1.4.5.2):

- absorbent addition
- wet scrubber.

The following emission levels of SO_x are BAT-AELs:

Parameter	Unit	BAT-AEL[1] (daily average value)
SO_X expressed as SO_2	mg/Nm^3	<50 – <400
[1] The range takes into account the sulphur content in the raw materials		

Table 1.43: BAT associated emission levels for SO_X from the flue-gases of kiln firing and/or preheating/precalcining processes in the cement industry

In this context, when co-incinerating waste, the requirements of the Waste Incineration Directive (WID) have to be met [59, European Commission, 2000].

20. BAT is to optimise the raw milling processes (for the dry process) which act as SO_2 abatement for the kiln, as described in Section 1.3.4.3.

1.5.6.3 CO emissions and CO trips

1.5.6.3.1 Reduction of CO trips

General considerations regarding CO trips can be found in Sections 1.4.3.1, 1.4.4.3.1 and 1.4.5.3.

21. When applying electrostatic precipitators (ESPs) or hybrid filters, BAT is to minimise the frequency of CO trips and to keep their total duration to below 30 minutes annually, by applying the following measures/techniques in combination (see Section 1.4.5.3):

- reducing the ESP downtime. In this context, see Section 1.4.5.3, where several different measures/techniques are presented, which can be applied individually or in combination
- taking continuous automatic CO measurements
- using fast measuring and control equipment including a CO monitoring system with short response time and which is situated close to the CO source.

In this context, see Section 4.2.6, where a guideline regarding the control of CO trips is presented.

1.5.6.4 Total organic carbon emissions (TOC)

General considerations regarding TOC can be found in Sections 1.3.4.5 and 1.4.5.4.

22. **BAT is to keep the emissions of TOC from the flue-gases of the kiln firing processes low (see Section 1.4.5.4) by applying the following measure/technique:**

    - avoid feeding raw materials with a high content of volatile organic compounds into the kiln system via the raw material feeding route.

    In this context, when co-incinerating wastes, the requirements of the Waste Incineration Directive (WID) have to be met [59, European Commission, 2000].

1.5.6.5 Hydrogen chloride (HCl) and hydrogen fluoride (HF) emissions

General considerations regarding HCl and HF emissions can be found in Sections 1.3.4.8 and 1.4.5.5.

23. **BAT is to keep the emissions of HCl below 10 mg/Nm^3 (BAT-AEL), as the daily average value or average over the sampling period (spot measurements, for at least half an hour), by applying the following primary measures/techniques individually or in combination:**

    - using raw materials and fuels containing a low chlorine content (see also Sections 1.4.3.2 and 1.4.3.3)
    - limiting the amount of chlorine content for any waste that is to be used as raw material and/or fuel in a cement kiln (see Section 1.2.4, 1.4.3.2 and 1.4.3.3).

24. **BAT is to keep the emissions of HF below 1 mg/Nm^3 (BAT-AEL) expressed as HF, as the daily average value or average over the sampling period (spot measurements, for at least half an hour), by applying the following primary measure/technique individually or in combination:**

    - using raw materials and fuels containing low fluorine (see also Sections 1.4.3.2 and 1.4.3.3)
    - limiting the amount of fluorine content for any waste that is to be used as raw material and/or fuel in a cement kiln (see Section 1.2.4, 1.4.3.2 and 1.4.3.3).

    In this context, see Section 4.2.2.1.1, where examples of concentration ranges for substances in waste/waste input criteria are presented. Furthermore in this context, when co-incinerating waste, the requirements of the Waste Incineration Directive (WID) have to be met [59, European Commission, 2000].

1.5.7 PCDD/F emissions

General considerations regarding PCDD/F emissions can be found in Sections 1.3.4.6 and 1.4.6.

25. **BAT is to avoid emissions of PCDD/F or to keep the emissions of PCDD/F from the flue-gases of the kiln firing processes low by applying the following measures/techniques individually or in combination:**

    - carefully selecting and controlling of kiln inputs (raw materials), i.e. chlorine, copper and volatile organic compounds
    - carefully selecting and controlling of kiln inputs (fuels), i.e. chlorine and copper
    - limiting/avoiding the use of wastes which contain chlorinated organic materials

- avoid feeding fuels with a high content of halogens (e.g. chlorine) in secondary firing
- quick cooling of kiln exhaust gases to lower than 200 °C and minimising residence time of flue-gases and oxygen content in zones where the temperatures range between 300 and 450 °C
- stop co-incinerating waste for operations such as start-ups and/or shutdowns

The BAT-AELs are <0.05 – 0.1 ng PCDD/F I-TEQ/Nm^3, as the average over the sampling period (6 – 8 hours).

In this context, see Section 1.4.6, where different measures/techniques are presented, which can be applied individually or in combination. Furthermore in this context, when co-incinerating waste, the requirements of the Waste Incineration Directive (WID) have to be met [59, European Commission, 2000].

1.5.8 Metal emissions

General considerations regarding metal emissions can be found in Sections 1.3.4.7, 1.3.4.7.1 and 1.4.7.

26. BAT is to minimise the emissions of metals from the flue-gases of the kiln firing processes by applying the following measures/techniques individually or in combination:

- selecting materials with a low content of relevant metals and limiting the content of relevant metals in materials, especially mercury
- using a quality assurance system to guarantee the characteristics of the waste materials used (see Sections 1.4.3.2 and 1.4.3.3).
- using effective dust removal measures/techniques. In this context, see Section 1.4.4.3, where different measures/techniques for dust removal are presented, which can be applied individually or in combination.

The following emission levels of metals are BAT-AELs:

Metals	**Unit**	**BAT-AEL (average over the sampling period (spot measurements, for at least half an hour))**
Hg	mg/Nm^3	<0.05[2]
∑ (Cd, Tl)	mg/Nm^3	<0.05[1]
∑ (As, Sb, Pb, Cr, Co, Cu, Mn, Ni, V)	mg/Nm^3	<0.5[1]

[1] Low levels have been reported, see Sections 1.3.4.7, 1.3.4.7.1 and 1.4.7

[2] Low levels have been reported (see Sections 1.3.4.7, 1.3.4.7.1and 1.4.7). Values higher than 0.03 mg/Nm^3 have to be further investigated. Values close to 0.05 mg/Nm^3 require consideration of additional measures/techniques such as those described in Sections 1.3.4.13, 1.3.9.1 and 1.4.7

Table 1.44: BAT associated emission levels for metals from the flue-gases of the kiln firing processes

In this context, when using wastes, the requirements of the Waste Incineration Directive (WID) have to be considered [59, European Commission, 2000].

1.5.9 Process losses/waste

General considerations regarding process losses/waste can be found in Sections 1.3.5 and 1.4.9.

27. **BAT is to re-use collected particulate matter in the process, wherever practicable, or to utilise these dusts in other commercial products, when possible.**

1.5.10 Noise

General considerations regarding noise can be found in Sections 1.3.7 and 1.4.10.

28. **BAT is to reduce/minimise noise emissions during the cement manufacturing processes by applying a combination of the following measures/techniques (see Section 1.4.10):**

- enclosing the noisy operations/units
- vibration insulation of operations/units
- using internal and external lining made of impact absorbent material
- soundproofing buildings to shelter any noisy operations involving material transformation equipment
- building up noise protection walls, e.g. construction of buildings or natural barriers, such as growing trees and bushes between the protected area and the noisy activity
- applying outlet silencers to exhaust stacks
- lagging ducts and final blowers which are situated in soundproofed buildings
- closing doors and windows of covered areas.

1.6 Emerging techniques in the cement industry

1.6.1 Fluidised bed cement manufacturing technique

The cement sintering technique by means of the fluidised bed cement kiln system has been a project subsidised by the Ministry of International Trade and Industry in Japan since 1986. A pilot plant with the capacity of 20 tonnes clinker/day was operational for six years, between 1989 and 1995, by Sumitomo Osaka Cement Co. Ltd at Toshigi Factory in Japan. A 200 tonnes clinker/day large scale pilot plant was constructed at the end of 1995.

The configuration of the 20 tonnes clinker/day fluidised bed cement kiln system is shown in Figure 1.71. The system consists of a suspension preheater (SP), a spouted bed granulating kiln (SBK), a fluidised bed sintering kiln (FBK), a fluidised bed quenching cooler (FBK) and a packed bed cooler.

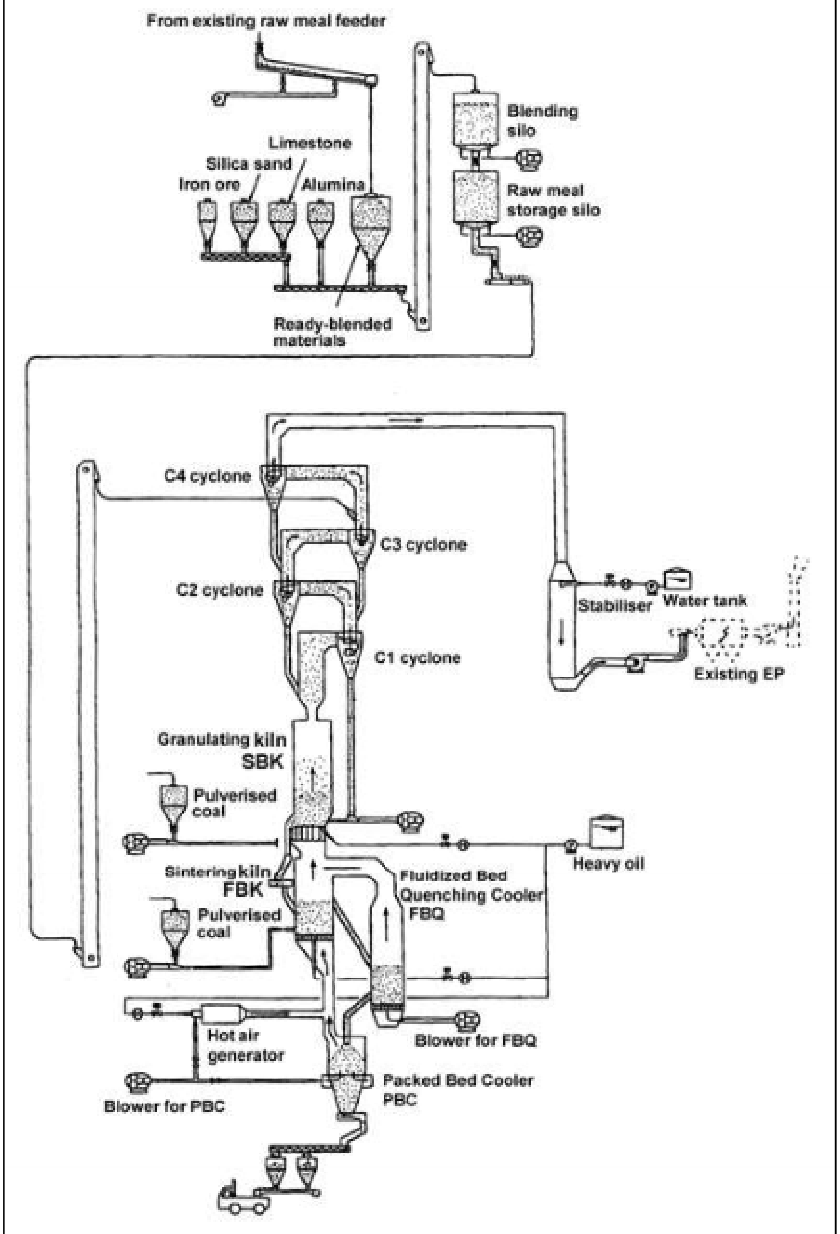

Figure 1.71: Fluidised bed cement kiln
[22, Japan, 1996]

The suspension preheater is a conventional four stage cyclone preheater which preheats and calcines the raw meal. The granulating kiln granulates the raw meal into granules of about 1.5 – 2.5 mm diameter at a temperature of 1300 °C. In the sintering kiln, the sintering of the granules is completed at a temperature of 1400 °C. The fluidised bed quenching cooler quickly cools the cement clinker from 1400 to 1000 °C. Finally, the cement clinker is cooled down to about 100 °C in the packed bed cooler.

The cement clinker produced in the fluidised bed kiln is of the same or better quality as the clinker from a commercial plant. The NO_x emissions are 115 – 190 mg/Nm^3 when heavy oil is used and 440 – 515 mg/Nm^3 when pulverised coal is used as fuel (converted to 10 % O_2). According to a feasibility study of a 3000 tonne clinker/day plant, the heat use can be reduced by 10 – 12 % compared with a suspension preheater rotary kiln with grate cooler, it is therefore expected that the CO_2 emissions can be reduced by 10 – 12 %.

The final targets of the technical development of the fluidised bed cement kiln system are (in accordance with the feasibility study on a 3000 tonne clinker/day plant and based on the results from the 20 tonnes/day pilot plant):

1. Reduction of heat use by 10 – 12 %
2. Reduction of CO_2 emissions by 10 – 12 %
3. A NO_x emission level of 380 mg/Nm^3 or less (converted to 10 % O_2)
4. To maintain the current SO_x emission level
5. Reduction of construction costs by 30 %
6. Reduction of installation area by 30 %.

1.6.2 Staged combustion combined with SNCR

In theory, a combination of staged combustion and SNCR could be comparable to SCR. This combination is considered very promising by suppliers. Some results regarding the use of SCR are described in Section 1.4.5.1.8.

1.6.3 Cement kiln flue-gas treatment with dry sodium bicarbonate and chemical re-use

Description

This measure/technique is considered for the desulphurisation of the flue-gases from cement kilns, typically in situations where waste materials are used as fuels. To achieve a high abatement rate on SO_2 along with high abatement efficiencies, dry sodium bicarbonate is used and, depending on the characteristics and the composition, sodium-based wastes can often be re-used in the cement production process. However, in some cases these wastes cannot be used because it may lead to a too high sodium content in the cement composition.

In order to allow a high SO_2 abatement with a low quantity of reagent, and, at the same time, to allow the re-use of waste materials from flue-gas treatment, emerging techniques on double step filtration of the flue-gas can be used.

Double step filtration

A first dust filter collects the process dust which can be re-used in the process as it is not charged with sodium. The dry sodium bicarbonate injection appears downstream of this first filter. Dry ground sodium bicarbonate is injected and reacts with SO_x to sodium salts, mainly sodium sulphate (Na_2SO_4). These wastes from the flue-gas treatment are collected by a second filter, typically a fabric filter.

Achieved environmental benefits

This measure/technique allows high and efficient SO_x abatements in the flue-gases to be obtained while not compromising the integral re-use of wastes from flue-gas treatment as follows:

- no excessive sodium in cement
- no added SO_x into the flue-gas.

Furthermore, no waste is produced additionally and additional natural resources are not used.

Cross-media effects

Sodium-based waste could only be re-used to a limited extent. Up until 2008, this was not done because re-use of sodium based waste has impacts on the quality on cement and clinker.

To a certain extent, additional SO_x emissions may occur which are caused by the recycled calcium or sodium sulphates.

No additional natural resources are used because the reagent $CaCl_2$ is available in the soda ash plant.

Additional transportation costs may occur because wastes from the flue-gas treatment process have to be transported from the cement plant to the treatment plant. However, the amount of wastes concerned is relatively small in comparison with the total amount of dust and the dust not containing sulphate which is directly re-used in the cement plant.

Operational data

This measure/technique is undergoing tests at the pre-industrial level. In 2008, no operational data were available.

Applicability

Only a few trials have been carried out on wet process using this technique. The double step filtration technique is especially well adapted for plants where ESPs are used for reducing dust emissions. In these cases, the addition of a second filter (fabric filter) may be less expensive than the replacement of the existing one. However, in combination with sodium bicarbonate, there is not any full scale application in the industry.

Regarding double filtration, there is no operational cement plant yet (2008) in combination with sodium bicarbonate, but trials are being carried out.

Regarding the treatment of wastes resulting from flue-gas treatment, this technique is being tested on sulphate-based wastes at pre-industrial scales in France and other specific treatment plants are being studied/planned. This technique is industrially operational and is applied in France and Italy for municipal waste incineration plants treating flue-gas wastes. Information regarding waste incineration can also be found in the Reference Document on Best Available Techniques for Waste Incineration [87, European Commission, 2001].

Economics

Treatment of sodium wastes as such, in order to be used by the chemical industry – as already done in the municipal waste incineration industry – is economically difficult to justify, because of the high dust content available in waste materials used.

Driving force for implementation

High abatement rate or high abatement efficiency requirement for SO_x in the kiln flue-gas.

Example plants and reference literature

Test plants in France. [168, TWG CLM, 2007], [176, France, 2008], [182, TWG CLM, 2008]

1.7 Conclusions and recommendations

Timing of the work process

The kick-off meeting for the review of the cement and lime BREF document was held in September 2005. The TWG agreed to extend the scope of this document and to add an additional industrial sector on magnesium oxide (MgO/magnesia) production using the dry process route to the cement and lime BREF. After the period for collecting information and data, a second TWG meeting was held in February 2007 in order to verify and agree on information and data that should be used for the revision of the BREF document. Furthermore, the TWG asked for a procedural exception for the review process of this document in order to split the discussions on Sections 1 – 4 and the BAT sections for the three chapters on cement, lime and magnesium oxide.

Based on the TWG request and taking into account the generic schedule for the review of BREFs (December 2005), the IEF agreed to split the discussions on Sections 1 – 4 and the BAT sections for the three chapters on cement, lime and magnesium oxide.

The first draft covering the revised Sections 1 – 4 and 6 of the three chapters cement, lime and magnesium oxide was issued for consultation in September 2007. The second part of the first draft covering the sections on techniques to consider in the determination of BAT (Sections 1.4, 2.4 and 3.4) and the BAT sections (Sections 1.5, 2.5 and 3.5) of the three chapters were issued for consultation in May 2008. The final TWG meeting was held in September 2008.

The project on the first revision of this BREF document, which was the pioneer for the review of the first series of BREFs, generated huge interest throughout. At the time of the final plenary meeting, there were more than 110 TWG members.

Based on the generic schedule for the review of BREFs (December 2005), the revision of the cement and lime BREF document did not entail a complete redraft of the first document adopted in December 2001 but updated the existing, and included additional information which was reviewed (for instance regarding techniques) as it could have had impact on BAT conclusions. The information exchange and data gathering was based on the wishes of the TWG and on the conclusions agreed at the second TWG meeting (January 2007). The guidance document on data collection agreed upon by the IEF in April 2008 was not used for this process.

Sources of information, development of this cement chapter and information gaps

The revised cement chapter is based on a large number of documents and on over 50 sources of information from both industry and Member States. The reports were submitted by CEMBUREAU, the industry association representing the majority of European cement manufacturers and the Member States Germany, Austria, Sweden, France, the United Kingdom, Ireland, the Netherlands, Italy, Hungary, Estonia, Spain, Portugal, Finland and the Czech Republic. Furthermore, information was provided by EURITS, the industry association representing the majority of the EU's hazardous waste incineration sector and by a supplier from Norway. These documents can be considered as the building blocks of the revised parts of this cement chapter.

Additional useful information was obtained by visiting cement manufacturing sites in the UK, Austria, Germany, Belgium, Spain, Finland and Hungary.

Based on the information and data provided, and the comments received after the consultation periods, this cement chapter was revised by updating information and data. Furthermore, additional sections were developed, e.g. on the use of waste as fuels and/or raw materials as well as their consumption during the cement making process, cogeneration, several types of emissions to air, examples of costs data for flue-gas abatement measures/techniques and primary measures/techniques used for emissions reduction, impacts on emissions behaviour and energy efficiency by using waste materials and environmental management tools.

Despite much very useful information and many comments regarding several different issues, some data problems and their consequences for this cement chapter have to be pointed out:

- there is a lack of information regarding the frequency of measurements, i.e. in the case of periodic measurements
- there is a lack of information on the issue of mercury emissions and the link between mercury emissions and the technical options which are available for reducing mercury
- to a certain extent, there is a lack of consistent information regarding monitoring techniques and measurement systems for emissions, e.g. mercury emissions
- regarding the use of activated carbon, information and data were provided only for SO_x emissions reduction rather than being considered as a multi pollutant reduction technique for several other emissions to air
- input data were provided regarding the use of waste which are different in the EU-27 in terms of, e.g. characteristics and parameters because of plant specific data. The data which were submitted in this context show many specific details, but lead to the conclusion that it is difficult to make general quantitative statements regarding this issue and the corresponding BAT conclusion is based on a qualitative approach
- as an emerging technique, fluidised bed technique for cement manufacturing is described (see Section 1.6.1); however, there was no information provided by the TWG as to how this technique should be/can be further developed.

During the final CLM TWG meeting, a detailed discussion regarding the source and possible reduction techniques of mercury emissions took place. The discussion showed the following:

- the level of mercury emissions is mainly influenced by the raw material composition. Regarding the emissions data provided showed that levels of below 0.05 mg/Nm^3 can be achieved; however, there was no evidence available as to where these lower levels came from. CEMBUREAU agreed to do research on this issue in order to get a better understanding of these mercury emissions and how this issue relates to all plants. CEMBUREAU will try to come up with a full set of data related to this issue for the next review of this CLM BREF document
- continuous monitoring of mercury emissions is carried out in Germany and Austria due to legally binding requirements to monitor mercury continuously (in Germany since 2000). In 2008 in the German cement industry, 34 mercury CEMs (Continuous Emissions Monitors) were in operation. The monitoring devices were under research and in general until 2008, the performance of CEMs were improved in order to work properly and to deliver reliable results. It was generally found that in some cases additional maintenance had to be carried out. In some other cases, it was necessary to modify the commercially available devices to make them suitable for individual application. There are only rare cases (10 %) where CEMs cannot be used properly. Experiences on a long term stability of these devices are not yet available. Intervals for a periodical maintenance of CEMs are based on future experiences. In October 2007, the German UBA asked suppliers and providers of these mercury measurement devices about their experiences. As a result, guidelines for quality assurance are now available which also set requirements for the maintenance procedure for most of the CEMs. Furthermore, proper calibration of CEMs according to the European standard EN 14181 would be a challenge. In the case of mercury CEMs, this calibration procedure needs greater effort than for CEMs for other emissions, e.g. dust or NO_x). Periodic quality assurance procedures should be carried out by experienced personnel only.

The ongoing research process should be followed and investigations should be made in terms of improvements and further developments. The outcome should be taken into consideration for the next review of this CLM BREF document and information and data regarding this issue should be collected in order to make general quantitative statements on the continuous measurement of mercury emissions.

Level of consensus at the final TWG meeting

The conclusions of the work regarding the cement chapter were agreed at the final TWG meeting in September 2008. The main discussion items at this final TWG meeting were the BAT conclusions. The BAT proposals for the cement industry were discussed case by case.

At this final TWG meeting, a high level of consensus was achieved on BAT (best available techniques) for the cement industry and no split views were recorded. Therefore – as also seen retrospectively over the whole information exchange period – the information exchange process can be considered successful.

Recommendations for future work

The information exchange and its result for the cement industry, i.e. the cement chapter of this document, present an important step forward in achieving the integrated prevention and control of pollution for cement manufacturing. Further work on the following issues could continue the process:

- collect data by taking into account the guidance set out in the IEF guidance document issued in April 2008 to allow an assessment of the performance of certain measures/techniques at the plant level, especially potential BAT
- collect information regarding the relationship between process type, waste (type, amounts) used and emissions
- collect costs data (e.g. investment, operational costs) regarding all measures/techniques to consider in the determination of BAT
- collect costs data along with the reduction efficiencies of abatement measures/techniques
- collect information and data regarding options for minimising energy consumption or for increasing energy efficiency
- collect data on energy consumption along with best performance data related to kiln types used
- collect information and data regarding the reduction of NO_x emissions especially regarding the SCR and SNCR technique
- collect information regarding NH_3 emissions
- collect more information regarding activated carbon considered as a multi pollutant reduction measure/technique, e.g. for SO_x emissions reduction
- collect information regarding monitoring and monitoring frequencies, e.g. for periodic measurements, so that authorities are able to check permit obligations/conditions
- investigate the revision of the Reference Document on the General Principles of Monitoring
- collect information and data regarding TOC emissions
- collect data and research measures/techniques which could be used for the reduction of metals (mercury)
- collect information and data about all process input, specifically on mercury
- collect information and data regarding input criteria for waste
- collect information regarding continuous mercury emissions monitoring measures/techniques used in the cement industry
- collect information regarding fluidised bed cement manufacturing technique.

Suggested topics for future R&D work

For the use of SCR for NO_x reduction in the cement industry, there is still some further work necessary regarding the development of appropriate catalysts and the further development of the process (see BAT 17 d in Section 1.5.6.1).

In particular regarding the techniques described in the Emerging Techniques section (Section 1.6), some future R&D work will still be necessary and useful, so that these techniques can be considered in future in the determination of BAT for the cement industry.

Besides that, the EC is launching and supporting, through its RTD programmes, a series of projects dealing with clean technologies, emerging effluent treatment and recycling technologies and management strategies. Potentially these projects could provide a useful contribution to future BREF reviews. Readers are therefore invited to inform the EIPPCB of any research results which are relevant to the scope of this document (see also the preface of this document).