CHAPTER 7

AVAILABLE TECHNIQUES FOR CONTROL OF POTENTIAL EMISSIONS

7.1 INTRODUCTION AND GENERAL POINTS

To reduce the emission from a pyroprocessing system to a certain controlled level, three basically different methods are available:

- Maintain the existing process while reducing the input of emission precursors into the system
- Modify the existing process (primary or integrated reduction measures)
- Maintain the existing process while adding a separate gas cleaning unit for the exhaust gas (secondary reduction measures)

A ***reduction of precursors*** can be very efficient at reducing emissions but is usually impracticable to achieve. (E.g. it may be realistic to replace a minor sulphur-rich component with a material having a low sulphur content to reduce SO_2 emissions. But if the larger part of the sulphur is contained in the main raw feed component it is almost impossible to reduce the SO_2 emission by raw material replacement.)

Typical for ***primary reduction measures*** is that:

☐ their emission reduction efficiency is very difficult to estimate for a specific application;

☐ they are usually less expensive compared to secondary reduction measures;

☐ they often are more ecological than secondary reduction measures because they have lower energy and material consumption;

☐ they often require a trial and error process to reach the envisaged goal (long implementation time).

Typical for ***secondary reduction measures*** is that:

☐ they usually have the highest emission reduction efficiency;

☐ they often are the most expensive measure.

All three methods do have one thing in common:

☐ they are not always applicable.

In the discussion about emission reduction measures one should also keep in mind that ***application of these measures in a new plant and in an existing plant are completely different issues***. The application of a low NO_x precalciner in a new cement kiln can be very efficient at a marginal additional investment cost whereas the application of a low NO_x calciner in an existing preheater kiln with satellite cooler would be less efficient and very expensive due mainly to replacement of the cooler. In a long wet kiln, a long dry kiln and a Lepol kiln the installation of a low NO_x precalciner is not even possible. **Also, if existing equipment is still efficiently operable, its remaining economic value has to be added to the cost of any replacement equipment.**

The costs that are attached to each reduction measure are estimated average costs, based on a certain plant capacity (see Tables in the summaries). The investment cost does not include additional cost for equipment or civil constructions that may be required for the implementation of the reduction measures (e.g. it is possible that because of an additional reduction measure with a high power consumption a replacement of the electrical power supply system is required).

The need for emissions reduction and the best suited measure to achieve the required environmental performance must be established for each plant respecting their specific situations. Only with this approach is it technically possible ***to achieve the highest possible environmental performance per ECU spent.***

As explained in Chapter 5.4, the selection of BAT for the prevention or reduction of emissions is necessarily very site specific in the assessment of the BAT criteria including benefits and costs. Therefore it is advisable to consider a wide range of techniques. In the BAT evaluation tables in this chapter the conclusions on Candidate BATs reflect the need to have such a wide range available but the conclusions are general and based on judgement. Therefore they cannot be considered prescriptive and final conclusions on BAT must be made on a case by case basis.

The BAT evaluations give separately conclusions on Candidate BATs for existing plants and new plants. This is because, for economic and technical reasons given in Chapter 5.4, a particular technique is less likely to be BAT in an existing plant. Existing plants undergoing major upgrades at high cost, such as increasing production capacity very significantly and/or making major process changes, are classified with new plants. Plants which are undergoing more restricted investment, such as replacing or modernising limited areas of equipment, are classified as rehabilitations and considered in the same category as existing plant.

7.2 CONTROL OF DUST EMISSIONS FROM MAJOR POINT SOURCES

7.2.1 INTRODUCTORY REMARKS

There are three main sources of potential dust emissions from cement production plants. These are kiln systems, clinker coolers and cement mills. In each of these sub-processes kiln exhaust gas or air is passing through pulverised material and no primary reduction methods are possible. Various dedusting devices have been used in the past for these three duties but for new plants only bag filters or electrostatic precipitators are installed.

The paragraphs below consider first the environmental significance of dust releases from cement production and then the general features of the abatement techniques available. Finally the applicability of the techniques which may be considered BAT for the different sub-processes is addressed and data relevant to the evaluation of Candidate BATs are given.

7.2.2 SIGNIFICANCE OF DUST RELEASES

Where national dust emission limits are set in EU countries for kilns, coolers and cement mills they are generally at 50 mg/Nm^3 for new installations. Significantly higher limits are often permitted for existing installations.

Because of the nature of the cement production process dust in the kiln exhaust gas consists of ground raw material. Dust in the vent air of clinker coolers consists of clinker fines and dust from cement mills consists of the final cement product.

With today’s technology it is technically possible to reduce the dust emission from most cement plant stacks to below 50 mg/Nm^3 dry. Nevertheless, replacement of existing equipment is often related to major cost in the order of several million ECU.

The environmental significance of dust is the maximum ground level concentration occurring after dispersion of the emission from the exhaust stack and how this concentration, together with any existing background concentration, compares with standards based on ambient health standards.

Modelling techniques have been used to calculate the air dispersion factors for a wide range of kiln exhausts. The factors are generally between 500,000 and 3,000,000. The dispersion factor is the ratio between the stack emission concentration and the maximum annual mean ground level concentration and is influenced by stack height, exhaust gas temperature and speed, atmospheric conditions, topography around the plant, etc.

If the stack emission concentration was 100 mg/Nm^3, the dispersion factors quoted would result in maximum ground level concentrations of between 0.2 and 0.03 µg/m^3. The present EU TSP limit (TSP = Total Suspended Particulate) is 150 µg/m^3. Therefore a further reduction of the dust emission limits is not needed. A further reduction of the dust emission may from an overall ecobalance stand-point have a negative impact on the environment because of the high additional power and material consumption that outweighs the benefit of the very small change in ground level dust concentration (0.02 – 0.1% of the EU TSP limit).

7.2.3 ABATEMENT TECHNIQUES

7.2.3.1 BAG FILTERS

Bag Filters (BFs) have been used in the cement industry well before Electrostatic Precipitators (EPs) were developed. BFs use a filtering medium, the bags, to separate the dust particles from the exhaust gas. While the exhaust gas can pass the bag tissue the dust particles are captured on the bag surface.

To further reduce pressure drop and dust emission of a BF, bags with special surface treatment or cleaning support (e.g. acoustic horns) can be installed.

The main disadvantage of bag filters is the high pressure drop over the whole filter (8 – 20 mbar) causing comparatively high power consumption at the filter fan.

Although BFs have a very high efficiency, their performance deteriorates for mechanical and process reasons. Bags have a limited life and will give high emissions through the development of pinholes, the occasional tearing of a bag or the failure or gradual deterioration of the seal at the fixing point of bags. It is important to prevent hot particles being carried in the gas stream into the filter, and to avoid severe temperature surges, which can cause disastrous failure.

Large modern BFs can be divided into separate compartments which can be separately isolated. This increases the size and cost of the filter but it allows on-line maintenance. For the operator the problem is that, if the emission monitor indicates an increase in emission, and this increase has occurred progressively through a multiplicity of small holes/leaks, it can be time consuming and expensive to find and rectify the faults.

The main advantage of bagfilters is that the dedusting efficiency is always very high even if the process parameters are changed (e.g. during start up or shut down of the kiln, clinker cooler or cement mill, during switching from compound to direct operation (raw mill on -> raw mill off), during occurrence of CO peaks or any other process disturbance).

The BFs can be subdivided into reverse gas BFs and pulse jet BFs. The dedusting efficiency of the two systems is very similar.

Reverse Gas BFs

The main difference between a reverse gas BF and a pulse jet BF is the cleaning method for the bags.

The reverse gas cleaned bag filters usually contain woven filter bags (usually glass fibre bags with special surface coating). The raw gas enters the bags from the bottom. It flows from the bag centre to the outside of the bag. The dust is deposited on the inner surface of the bag. Removal efficiency is improved and maintained by these particulate deposits (residual dust cake). With time more and more particulates are deposited on the bags and increase the system resistance to the gas flow (pressure loss).

To allow the filter fan to operate within the design parameters and to reduce the fan power consumption, this dust cake must be partly removed. Bag cleaning methods must be designed properly – not over-cleaning or under-cleaning. Otherwise increased dust emission or high pressure loss result.

The bag cleaning process is triggered either by a timer or, better, when the pressure drop over the bag filter reaches some predetermined level. A reverse air bag filter consists of several compartments, usually more than ten. When the bag cleaning process is started, the outlet valves of one of the compartments are closed (off-line cleaning). Then, an auxiliary fan forces a relatively gentle flow of filtered gas backwards through the compartment and bags to be cleaned. This causes the bags to partially collapse inward, dislodging the dust cake. This falls through the bags, the thimble and the tubesheet into the hopper. Metal anticollapse rings sewn into the bags along their length prevent complete bag collapse. One square meter of a bag can filter up to 45 m^3/h of exhaust gas.

Reverse gas bag filters are very well established in North and South America for kiln exhaust gas dedusting. The operating and investment costs of reverse gas BFs are usually higher compared to pulse jet BFs and EPs because of the filter size and the more expensive bags.

<u>Pulse Jet BFs</u>

The application of pulse jet BFs for dedusting of air from mills, coolers and transport systems is already standard. However, the dedusting of kiln exhaust gas with pulse jet BFs is very new and only started a few years ago. They have some advantages because of the reduced space requirement and reduced investment and operating cost compared to reverse air BFs. Pulse jet BFs for kiln exhaust gas dedusting are mainly used in Europe.

Pulse jet cleaned BFs normally employ felted fabrics of various types. The raw gas enters the bags from the outside. The cleaned gas flows through the centre of the bag to the clean gas plenum and from there to the stack. The dust is deposited on the outer surface of the bag. To prevent bag collapse during filtering, metal cages are inserted inside each bag. Just like the reverse-gas cleaned bag filter, periodic bag cleaning is required to remove excess residual dust cake. This is accomplished by pulsing compressed air down into each filter bag. Bag cleaning can be carried out either with the compartment isolated or **not** isolated (on-line or off-line cleaning). One square meter of a bag can filter up to 90 m^3/h of exhaust gas.

7.2.3.2 ELECTROSTATIC PRECIPITATORS

EPs were developed for use in cement production, initially on kilns, in the 50s and 60s. EPs use electrostatic forces to separate the dust from the gas. Discharge electrodes under high negative voltages (50 – 100 kV) emit electrons which settle on the dust particles. The now negatively charged particles are directed towards and separated on the collecting electrodes because of the electrical field between the discharge and the collecting electrodes. Then the dust particles accumulated on the collecting electrodes are discharged to the dust hoppers by electrode rapping.

The efficiency of EPs can be reduced during changes of the process parameters (e.g. during start up or shut down of the kiln, during switching from compound to direct operation and during occurrence of CO peaks). EPs are easy to maintain although on-line maintenance is not possible.

The main advantage of the EPs is the low pressure loss over the filter and therefore a reduced power consumption of the filter fan. The other advantages are the separation of coarse and fine particles in the filter for efficient evacuation of circulating elements and a constant pressure loss over the filter which allows constant high clinker production.

There are also means available to upgrade and optimise already existing EPs. Especially improved exhaust gas conditioning (e.g. conditioning tower) and modern control systems for EP energization have been shown to be very effective.

7.2.3.3 OTHER ABATEMENT TECHNIQUES

Cyclones and gravel bed filters are not installed any more for the final dedusting stage because of their reduced efficiency and high operating cost.

Cyclones

Cyclones have been used in the distant past to reduce material loss from kilns and more recently high efficiency designs have been installed on clinker coolers. They are not capable of achieving the emission levels now needed for final exhaust and they are not now installed.

Gravel Bed Filters

Gravel bed filters have given good service on clinker coolers but their maintenance costs are high and their efficiency is not comparable with that obtainable from EPs and BFs. They are no longer installed.

7.2.4 PROCESS DUTY

7.2.4.1 KILNS

7.2.4.1.1 SUMMARY

The first cement kilns were working with natural draft across the kiln. The exhaust gas was emitted to the atmosphere without any special treatment. At a later stage dust separators, mainly cyclones and electrostatic precipitators (EPs), were installed to reduce product loss. Today very efficient separators with a reduction efficiency of up to 99.99% are used which virtually eliminate dust emissions from cement plants.

Today two types of dust separators are used for kiln exhaust gas dedusting: Bag Filters (BFs) and EPs. Both types have a very high dedusting efficiency during normal operation. During special conditions like high CO concentration, kiln start up, kiln shut down or switching from compound operation (raw mill on) to direct operation (raw mill off) the efficiency of EPs can be significantly reduced while the efficiency of BFs is not affected. Therefore BFs have a higher overall efficiency if they are well maintained and filter bags are replaced periodically. It is a disadvantage of BFs that the replaced filter bags are waste and have to be disposed of according to national regulations.

Because of the maximum operating temperature of the bags in a BF and because of the electrical resistivity of the dust going to an EP the exhaust gas must be conditioned before it is directed to the dust separator. The gas is conditioned by water injection into the conditioning tower or the exhaust gas duct, or is cooled by air to air heat exchanger, or by fresh air dilution.

The total cost per tonne of clinker caused by the dedusting is usually in favour of EPs if clean gas dust contents above about 30 mg/Nm^3 are required. Below 20 mg/Nm^3 the cost for dust filters is often lowest for pulse jet bag filters. This is only a general statement and can be different for specific applications. The reasons for the lower costs of EPs above 30 mg/Nm^3 are mainly the low pressure drop over the filter and the reduced maintenance cost.

To reduce the clean gas dust content further to 20 mg/Nm^3 the collecting area and power input into the EP must be increased exponentially.

To compare one dedusting system with another one all components exhaust gas conditioning, filter and filter fan, must be included.

The tables below show two possibilities (BF and EP) to reduce dust emission with efficiencies of up to 99.99%. The described technologies refer to a preheater kiln (representing modern cement kiln technology) with a production rate of 3000 t/day. Exhaust gas from long wet kilns and long dry kilns can also be dedusted with BFs and EPs with very high efficiencies (up to 99.99%).

In the case of kiln exhaust gas dedusting with EPs process optimisation can also improve the EP efficiency.

To make the information in the tables below comparable a common base was used:

- Clinker production: 3000 t/d
- Kiln type: Preheater/Precalciner
- Dust input to filter: Up to 500 $gDust/Nm^3$
- Power cost: 0.04 ECU/kWh
- Amortisation: 10 years
- Interest rate: 10%

Most information is retrieved from literature (see Chapter 7.2.7) and cement industry specific experience. To fit it into the common base, conversion of the relevant data was required.

7.2.4.2 INDEX OF DESCRIBED DUST REDUCTION MEASURES

7.2.4.3 ELECTROSTATIC PRECIPITATORS FOR CEMENT KILNS (EP)

No.	BAT Evaluation Items		Comments	Remarks
1	**Consumables**			
1.1	Materials	[g_{steel}/t_{cli}]	5 - 20	1)
1.2	Air		None	
1.3	Water	[kg/t_{cli}]	25 - 75	2) Estimated
2	**Energy Consumption**			
2.1	Thermal		None	
2.2	Electrical	[kWh/t_{cli}]	1.5 - 2.0 [1]	3)
3	**Waste Generation**			
3.1	Solids	[g_{steel}/t_{cli}]	5 - 20	
3.2	Liquids		None	
4	**Emissions**			
4.1	To air		None	
4.2	To water		None	
4.3	Noise		None	
4.4	Odour		None	
4.5	Dust reduction	[%]	Up to 99.99	4)
5	**Impact on Product Quality**			
5.1	Cement		None	
6	**Experience**			
6.1	Duration	[years]	> 30	
6.2	Number of Applications		> 100	
7	**Costs**			
7.1	Investment cost	[10^6 ECU]	1.5 - 3.8 0.6 - 0.8	5) Estimated 6) Estimated
7.2	Operating cost	[ECU/t_{cli}]	0.1 - 0.2	7) Estimated

7.3	Total cost [ECU/t_{cli}]	0.4 - 0.8	
8	**Conclusion on Candidate BAT**		
8.1	For existing plants and plant rehabilitations	Yes	
8.2	For new plants and major upgrades	Yes	

1) Because of corrosion, erosion or deformation the internals of an EP are replaced every 8 to 20 years. The required collecting area of the electrodes depends, among other things, on the required clean gas dust content.
2) The water consumption depends on the gas temperature at the preheater exit, the relative duration of direct operation (mill off) and the raw material humidity.
3) Electrical power consumption for energization of the EP and operation of the filter fan and the conditioning tower.
4) The maximum dust reduction efficiency is not a guaranteed efficiency for applications on any kiln but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on an initial dust input into the filter of about 500 g/Nm^3. High efficiency is only guaranteed during normal operation. During situations like kiln upset, transition phase from compound to direct operation and start up and shut down of the kiln lower efficiencies can be expected.
5) The size and investment costs for EPs increase exponentially with the reduction of the clean gas dust content. The indicated investment cost does not include conditioning tower and filter fan (about 0.6 – 0.8 106 ECU). When EPs are designed to work without conditioning tower (some cases in dry weather countries), the oversizing of the filter increases investment above the level of a filter + tower system.
6) Cost for conditioning tower and filter fan.
7) The electrical power consumption for EPs increases exponentially with the reduction of the clean gas dust content.

7.2.4.4 BAG FILTERS FOR CEMENT KILNS (BF)

No.	BAT Evaluation Items	Comments	Remarks
1	**Consumables**		
1.1	Materials [$g_{textile}$/t_{cli}]	1.0 - 5.0	1)
1.2	Air	None	
1.3	Water [kg/t_{cli}]	0 - 75	2) Estimated
2	**Energy Consumption**		
2.1	Thermal [kJ/t_{cli}]	None	

2.2	Electrical [kWh/t_{cli}]	1.8 - 2.2	3)
3	**Waste Generation**		
3.1	Solids [$g_{textile}$/t_{cli}]	1.0 - 5.0	
3.2	Liquids	None	
4	**Emissions**		
4.1	To air	None	
4.2	To water	None	
4.3	Noise	None	
4.4	Odour	None	
4.5	Dust reduction [%]	Up to 99.99	4)
5	**Impact on Product Quality**		
5.1	Cement	None	
6	**Experience**		
6.1	Duration [years]	> 30	
6.2	Number of Applications	> 100	5)
7	**Costs**		
7.1	Investment cost [10^6 ECU]	1.5 - 3.5 0.6 - 0.8	6) 7)
7.2	Operating cost [ECU/t_{cli}]	0.15 - 0.35	
7.3	Total cost [ECU/t_{cli}]	0.5 - 0.9	
8	**Conclusion on Candidate BAT**		
8.1	For existing plants and plant rehabilitations	Yes	
8.2	For new plants and major upgrades	Yes	

1) The bags must be replaced every 2 to 4 years.

2) The water consumption depends on the gas temperature at the preheater exit, the relative duration of direct operation (mill off) and the raw material humidity. In the case of reverse gas filters it is possible to cool with fresh air only.

3) Electrical power consumption of filter fan conditioning tower and bag cleaning.

4) The maximum dust reduction efficiency is not a guaranteed efficiency for applications on any kiln but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on an initial dust input to the filters of about 500 g/Nm^3.

5) This applies for reverse air BFs. Pulse jet BFs have only recently been applied for cement kiln dedusting. Therefore their application number is still comparatively small.

6) Bag filter size is a function of the maximum gas flow through the filter. Bag filter price without conditioning tower and filter fan.

7) Cost for conditioning tower and filter fan. Conditioning towers are only needed for low temperature applications with e.g. polyacrylnitril bags.

7.2.5 CONTROL OF DUST EMISSION FROM CLINKER COOLERS

7.2.5.1 SUMMARY

The overall efficiency of the electrostatic precipitator (EP) is not much lower than the efficiency of a bag filter (pulse jet type) combined with an air to air heat exchanger (BFHE) but many new installations are of the BFHE type. Depending on the bag quality that is used for the pulse jet filter, the size of the air to air heat exchanger ahead of the pulse jet filter is designed to cool the clinker cooler vent air under all circumstances to below 120 to 180° C.

To make the information in the tables below comparable a common base was used:

- Clinker production: 3000 t/d
- Kiln type: Preheater/Precalciner
- Clinker cooler type Grate cooler
- Dust input into filter: Up to 20 gDust/Nm^3
- Power cost: 0.04 ECU/kWh
- Amortisation: 10 years
- Interest rate: 10%

Most information is retrieved from literature (see Chapter 7.2.7) and cement industry specific experience. To fit it into the common base, conversion of the relevant data was required.

7.2.5.2 INDEX OF DESCRIBED DUST REDUCTION MEASURES

7.2.5.3 Electrostatic Precipitators for Clinker Coolers (EP)

7.2.5.4 Pulse Jet Bag Filter with Air to Air Heat Exchanger for Clinker Coolers (BFHE)

7.2.5.3 ELECTROSTATIC PRECIPITATORS FOR CLINKER COOLERS (EP)

No.	BAT Evaluation Items		Comments	Remarks
1	**Consumables**			
1.1	Materials	[g_{steel}/t_{cli}]	5 - 20	1)
1.2	Air		None	
1.3	Water	[kg/t_{cli}]	None	
2	**Energy Consumption**			
2.1	Thermal		None	
2.2	Electrical	[kWh/t_{cli}]	1.0 - 1.6	2)
3	**Waste Generation**			
3.1	Solids	[g_{steel}/t_{cli}]	5 - 20	
3.2	Liquids		None	
4	**Emissions**			
4.1	To air		None	
4.2	To water		None	
4.3	Noise		None	
4.4	Odour		None	
4.5	Dust reduction	[%]	Up to 99.9	3)
5	**Impact on Product Quality**			
5.1	Cement		None	
6	**Experience**			
6.1	Duration	[years]	> 10	
6.2	Number of Applications		> 100	
7	**Costs**			
7.1	Investment cost	[10^6 ECU]	0.8 - 1.2	4)
7.2	Operating cost	[ECU/t_{cli}]	0.09 - 0.18	5)
7.3	Total cost	[ECU/t_{cli}]	0.22 - 0.38	
8	**Conclusion on Candidate BAT**			
8.1	For existing plants and plant rehabilitations		Yes	
8.2	For new plants and major upgrades		Yes	

1) Because of erosion or deformation the internals of an EP are replaced every 20 to 30 years. The required collecting area of the electrodes depends on the final clean gas dust content.
2) Electrical power consumption for energization of the EP and operation of the filter fan.
3) The maximum dust reduction efficiency is not a guaranteed efficiency for applications on any clinker cooler but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on a dust input to the filter of about 20 g/Nm^3. High efficiency is only guaranteed during normal operation. During situations like cooler upset and start up / shut down procedures of the kiln significantly lower efficiencies can be expected.
4) The size and investment costs for EPs increase exponentially with the reduction of the clean gas dust content.
5) The electrical power consumption for EPs increases exponentially with the reduction of the clean gas dust content.

7.2.5.4 PULSE JET BAG FILTER WITH AIR TO AIR HEAT EXCHANGER FOR CLINKER COOLERS (BFHE)

No.	BAT Evaluation Items		Comments	Remarks
1	**Consumables**			
1.1	Materials	[$g_{textile}/t_{cli}$]	0.5 - 0.8	1)
1.2	Air		None	
1.3	Water	[kg/t_{cli}]	None	
2	**Energy Consumption**			
2.1	Thermal	[kJ/t_{cli}]	None	
2.2	Electrical	[kWh/t_{cli}]	1.8 - 2.2	2)
3	**Waste Generation**			
3.1	Solids	[$g_{textile}/t_{cli}$]	0.5 - 0.8	
3.2	Liquids		None	
4	**Emissions**			
4.1	To air		None	
4.2	To water		None	
4.3	Noise		Low	3)
4.4	Odour		None	
4.5	Dust reduction	[%]	Up to 99.9	4)

5	**Impact on Product Quality**			
5.1	Cement		None	
6	**Experience**			
6.1	Duration	[years]	> 10	
6.2	Number of Applications		> 50	
7	**Costs**			
7.1	Investment cost	[10^6 ECU]	1.0 - 1.4	5)
7.2	Operating cost	[ECU/t_{cli}]	0.10 - 0.15	6)
7.3	Total cost	[ECU/t_{cli}]	0.26 - 0.38	
8	**Conclusion on Candidate BAT**			
8.1	For existing plants and plant rehabilitations		Yes	
8.2	For new plants and major upgrades		Yes	

1) The bags must be replaced every 2 to 3 years.

2) Electrical power consumption of filter fan, heat exchanger and bag cleaning.

3) Fans of air to air heat exchanger can cause additional noise. Several countermeasures to limit the additional noise are available.

4) The maximum dust reduction efficiency is not a guaranteed efficiency for applications on any clinker cooler but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on a dust input into the filter of about 20 g/Nm^3.

5) Bag filter size is a function of the maximum gas flow through the filter. Price includes air to air heat exchanger, filter and fan.

6) The operating cost is mainly a function of the cost for bag replacement (bag quality) and the power cost for the filter fan.

7.2.6 CONTROL OF DUST EMISSION FROM CEMENT MILLS

7.2.6.1 SUMMARY

Most plants use pulse jet BF's for dedusting of cement mill vent air. Electrostatic precipitators (EP) were also installed in the past and are still in operation. EPs are not installed any more for cement mill dedusting. Because of the low vent air temperature no vent air conditioning is required for the pulse jet BFs.

To make the information in the tables below comparable a common base was used:

• Clinker production:	3000 t/d
• Cement mill production:	160 t/h
• Cement mill type:	Ball mill
• Initial emission:	Up to 300 gDust/Nm^3
• Power cost:	0.04 ECU/kWh
• Amortisation:	10 years
• Interest rate:	10%

Most information is retrieved from literature (see Chapter 7.2.7) and cement industry specific experience. To fit them into the common base, conversion of the relevant data was required.

7.2.6.2 INDEX OF DESCRIBED DUST REDUCTION MEASURES

7.2.6.3 PULSE JET BAG FILTER FOR CEMENT MILLS (BF)

No.	BAT Evaluation Items		Comments	Remarks
1	**Consumables**			
1.1	Materials	[$g_{textile}/t_{cli}$]	0.3 - 0.4	1)
1.2	Air		None	
1.3	Water	[kg/t_{cli}]	None	
2	**Energy Consumption**			
2.1	Thermal	[kJ/t_{cli}]	None	
2.2	Electrical	[kWh/t_{cli}]	0.4 - 0.6	2)
3	**Waste Generation**			
3.1	Solids	[$g_{textile}/t_{cli}$]	0.3 - 0.4	
3.2	Liquids		None	
4	**Emissions**			
4.1	To air		None	
4.2	To water		None	
4.3	Noise		None	
4.4	Odour		None	
4.5	Dust reduction	[%]	Up to 99.99	

5	**Impact on Product Quality**			
5.1	Cement		None	
6	**Experience**			
6.1	Duration	[years]	> 30	
6.2	Number of Applications		> 100	
7	**Costs**			
7.1	Investment cost	[10^6 ECU]	0.3 - 0.5	4)
7.2	Operating cost	[ECU/t_{cli}]	0.03 - 0.04	5)
7.3	Total cost	[ECU/t_{cli}]	0.08 - 0.12	
8	**Conclusion on Candidate BAT**			
8.1	For existing plants and plant rehabilitations		Yes	6)
8.2	For new plants and major upgrades		Yes	

1) The bags must be replaced every 2 to 4 years.
2) Electrical power consumption of filter fan, conditioning tower and bag cleaning.
3) The maximum dust reduction efficiency is not a guaranteed efficiency for applications on any cement mill but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on a dust input into the filter of about 300 g/Nm^3.
4) Bag filter size is a function of the maximum gas flow through the filter. Price includes filter and fan.
5) The operating cost is mainly a function of the cost for bag replacement (bag quality) and the power cost for the filter fan.
6) If the existing plant is equipped with an efficient electostatic precipitator (EP) then the potential advantage of a bag filter would not justify the replacement of the EP.

7.2.6.4 ELECTROSTATIC PRECIPITATORS FOR CEMENT MILLS (EP)

No.	BAT Evaluation Items		Comments	Remarks
1	**Consumables**			
1.1	Materials	[g_{steel}/t_{cli}]	5 - 20	1)
1.2	Air		None	
1.3	Water	[kg/t_{cli}]	None	

2	**Energy Consumption**		
2.1	Thermal	None	
2.2	Electrical [kWh/t_{cli}]	1.0 - 1.6	2)
3	**Waste Generation**		
3.1	Solids [g_{steel}/t_{cli}]	5 - 20	
3.2	Liquids	None	
4	**Emissions**		
4.1	To air	None	
4.2	To water	None	
4.3	Noise	None	
4.4	Odour	None	
4.5	Dust reduction [%]	Up to 99.99	3)
5	**Impact on Product Quality**		
5.1	Cement	None	
6	**Experience**		
6.1	Duration [years]	> 10	
6.2	Number of Applications	> 100	
7	**Costs**		
7.1	Investment cost [10^6 ECU]	0.8 - 1.2	4)
7.2	Operating cost [ECU/t_{cli}]	0.09 - 0.18	5)
7.3	Total cost [ECU/t_{cli}]	0.22 - 0.38	
8	**Conclusion on Candidate BAT**		
8.1	For existing plants and plant rehabilitations	Yes	
8.2	For new plants and major upgrades	No	

1) Because of erosion or deformation the internals of an EP are replaced every 20 to 30 years. The required collecting area of the electrodes depends on the final clean gas dust content.

2) Electrical power consumption for energization of the EP and operation of the filter fan.

3) The maximum dust reduction efficiency is not a guaranteed efficiency for applications on any cement mill but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on a dust input to the filter of about 20 g/Nm^3. High efficiency is only

guaranteed during normal operation. During situations like cooler upset and start up / shut down procedures of the kiln significantly lower efficiencies can be expected.

4) The size and investment costs for EPs increase exponentially with the reduction of the clean gas dust content.
5) The electrical power consumption for EPs increases exponentially with the reduction of the clean gas dust content.

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7.3 CONTROL OF NO_x-EMISSIONS

7.3.1 SUMMARY

Nitrogen oxide, NO, is formed during fuel combustion by oxidation of the molecular nitrogen of the combustion air as well as the nitrogen compounds in the fuels and raw materials. Significant oxidation of the molecular nitrogen of the combustion air takes place in oxidizing flames with temperatures above 1200° C (thermal NO). Since the flame temperature in the rotary kiln is well above 1400° C considerable amounts of thermal NO are produced, but also in zones with lower temperatures such as in precalciners, at any kiln inlet burner and in the preheater significant amounts of NO can be produced (fuel NO). Less than 10% of NO produced in a kiln system is converted to NO_2 prior to leaving the system. The sum of NO and NO_2 emission expressed as NO_2 is called NO_x emission.

The NO_x emissions of cement kilns expressed as NO_2 vary generally between 500 and 2000 mg/Nm^3.

To reduce the NO_x emission from a pyroprocessing system to a certain controlled level, two basically different methods are available:

- Modify the existing process (primary or integrated reduction measures, Chapters 7.3.3 to 7.3.7)
- Maintain the existing process while adding a separate gas cleaning unit for the exhaust gas (secondary reduction measures, Chapters 7.3.8 and 9.1.1)

The tables below show a number of possibilities to reduce NO_x emission with efficiencies between 0 and 65%. Each reduction measure needs certain preconditions before it can be applied. The SNCR (Selective Non-Catalytic Reduction) for example needs a temperature window (900 to 1000° C) with a reasonable residence time of the exhaust gas in the active zone. Many kilns do not provide these conditions because they use secondary firing at the kiln inlet, have a very short riser duct, etc. In some cases it is possible to modify the existing kiln system to allow the application of the required reduction measure. This, however, usually causes major additional investment cost.

The reduction efficiencies described hereafter are based on the reduction of NO_x concentration in the exhaust gas. Most European countries use concentration limits for the pollutants in the exhaust gas from cement plants to limit the emission impact to an acceptable degree. Because of the nature of the cement production process the normal NO_x concentration in the kiln exhaust gas varies over a wide range within short periods of time.

To comply with short term (½ hour, 1 day) emission limits without secondary reduction measures major adjustments to the kiln control may be required. This can result in the overall output of NO_x in terms of t/year being higher than for kiln operation without such adjustments. Since NO_x from the cement kiln stack contributes very little to ground level NO_x and O_3 [37] concentration which can vary from one day or one hour to the other, it would be wise to focus more on long term average emission concentration (mg/m^3).

The primary reduction measures (Chapters 7.3.3 to 7.3.7) have a limited reduction efficiency regarding peak emissions. It is widely agreed today that with the most sophisticated equipment and procedures, the NO_x emission from most new preheater/precalciner kilns can be kept below 500 mg/Nm^3 if long term (e.g. one year) averages are considered. For existing kilns it is much more difficult to determine the lowest achievable NO_x emission because of the large variety of different kiln systems. Many of the existing dry kilns probably would emit less than 1200 mg/Nm^3 (long term average).

When applicable, the only available secondary reduction measure, selective non-catalytic reduction (SNCR) (see Chapter 7.3.8), could in some cases reduce the NO_x emission to as low as 500 mg/Nm^3. At high ammonia injection rates the molar utilisation of the injected ammonia is very low and the ammonia slip can become significant. This may further increase the ammonia emission and pollute the filter dust and thereby prevent dust recycling. In other words a very high reduction efficiency (> 65%) with SNCR is ecologically and economically not recommendable. Further investigation into this matter will be carried out by VDZ [36].

Selective catalytic reduction (SCR) is not yet available as a full scale installation in cement plants. SCR is presently being tested in pilot plants in different locations. First full scale applications are not expected before the year 2000 [36]. See Chapter 9 – Emerging Techniques.

Secondary emissions that are emitted either during the production and transportation of agents (ammonia, etc.) or in power generation that are used to reduce emissions are not included in this investigation.

The reduction efficiencies of the NO_x reduction measures reported below can of course not be summed up to calculate the final NO_x reduction capacity. Some measures cannot even be combined with others. Furthermore the reduction efficiency is always highest at highest emissions. This means that the lower the emissions the harder and more costly it is to reduce them further. Especially for the primary reduction measures it is often very difficult to predict the NO_x reduction efficiency for a specific kiln. The reduction efficiency can be anywhere between the maximum efficiency listed below and zero.

To make the information in the tables below comparable a common base was used:

• Clinker production:	3000 t/d
• Kiln type:	Preheater/Precalciner (if not indicated differently)
• Initial emission:	Up to 2000 mg/Nm^3 (NO_x expressed as NO_2)
• Coal cost:	60 ECU/t
• Power cost:	0.04 ECU/kWh
• Ammonia costs:	100 ECU/t NH_3 25%(costs between 80 and 120 are known)
• Amortization:	10 years
• Interest rate:	10%

Most information is retrieved from **literature** (see Chapter 7.3.9) and cement industry specific experience. To fit them into the common base, conversion of the relevant data was required.

7.3.2 INDEX OF DESCRIBED NOX REDUCTION MEASURES

7.3.3 OPTIMISATION OF CLINKER BURNING PROCESS (OCBP)

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 through the stabilization of process parameters. NO_x reduction is a side effect of the optimisation. The reduction is usually caused by the reduced flame and burning temperatures and the reduced heat consumption.

The application of a high level control system is a special case of kiln optimisation and is described in the next Section.

The addition of mineralisers to the raw material is a technology to improve the clinker quality and to reduce the sintering zone temperature. Its contribution to NO_x reduction is not yet known quantitatively but it was found that during test runs with mineralisers that NO_x was reduced. Mineralisers are not further considered in this report.

No.	BAT Evaluation Items	Comments	Remarks
1	**Consumables**		
1.1	Materials	None	
1.2	Air	None	
1.3	Water	None	
2	**Energy Consumption**		
2.1	Thermal	Reduced	
2.2	Electrical	Reduced	
3	**Waste Generation**		
3.1	Solids	None	
3.2	Liquids	None	

4	**Emissions**		
4.1	To air	None	
4.2	To water	None	
4.3	Noise	None	
4.4	Odour	None	
4.5	NO_x reduction [%]	0 - 20 [5,6]	1) Estimated
5	**Impact on Product Quality**		
5.1	Cement	Less fluctuation in product quality	
6	**Experience**		
6.1	Duration	Years	
6.2	Number of applications	Numerous	
7	**Costs**		
7.1	Investment cost [10^6 ECU]	0 - 5 [6]	2)
7.2	Operating cost [ECU/t cli]	-	3)
7.3	Total cost [ECU/t cli]	-	4)
8	**Conclusion on Candidate BAT**		
8.1	For existing plants and plant rehabilitations	Yes	
8.2	For new plants and major upgrades	Yes	

1) The maximum NO_x reduction efficiency is not a guaranteed efficiency for applications on any kiln but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on an initial NO_x emission of about 2000 mg/Nm^3. Most kiln optimisations are executed to reduce operating cost and improve product quality. The effect of kiln optimisation on NO_x emission is known qualitatively but not quantitatively.

2) Kiln optimisation can include many elements ranging from instruction/training of the kiln operators up to installation of new equipment such as dosing systems, homogenization silos, preblending beds, new clinker coolers, etc.

3) Most kiln optimisations were executed to reduce operating cost, 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 cost, higher productivity and other factors. The cost reduction cannot be indicated generally because kiln optimisation is a very individual step by step process extending for each kiln often over a long period of time.

4) Partially offset by lower energy consumption.

7.3.4 COMPUTER BASED EXPERT SYSTEM FOR KILN OPERATION (ES)

Expert systems allow emission data to be monitored and process parameters to be kept much closer to the set points, in particular also those parameters which are decisive for NO formation.

No.	BAT Evaluation Items	Comments	Remarks
1	**Consumables**		
1.1	Materials		
1.2	Air	None	
1.3	Water	None	
2	**Energy Consumption**		
2.1	Thermal	Reduced	
2.2	Electrical	Reduced	
3	**Waste Generation**		
3.1	Solids		
3.2	Liquids	None	
4	**Emissions**		
4.1	To air	None	
4.2	To water	None	
4.3	Noise	None	
4.4	Odour	None	
4.5	NO_x reduction [%]	Up to 30 [1,2,3,4,5,6,7]	1)
5	**Impact on Product Quality**		
5.1	Cement	Less fluctuation in product quality	
6	**Experience**		
6.1	Duration [years]	> 10	
6.2	Number of applications	> 50	
7	**Costs**		
7.1	Investment cost [10^6 ECU]	0.3 - 2.5 [6]	2)

7.2	Operating cost [ECU/t cli]	< 0.1	
7.3	Total cost [ECU/t cli]	0.14 - 0.51	3)
8	**Conclusion on Candidate BAT**		
8.1	For existing plants and plant rehabilitations	Yes	
8.2	For new plants and major upgrades	Yes	

1) The maximum NO_x reduction efficiency is not a guaranteed efficiency for applications on any kiln but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on an initial NO_x emission of about 2000 mg/Nm^3.

2) The investment cost for the high level control system only is about 300,000 ECU. Additional investment may be necessary to install the required measuring and dosing systems in the plant.

3) Partially compensated by lower energy consumption.

7.3.5 OPTIMIZATION OF MAIN BURNER (LOW-NOX BURNER, LNB)

The reduced NO_x formation with low-NO_x burners is partly caused by a more uniform flame flow pattern without high temperature peaks and partly caused by the flame flow pattern also creating a flame internal reducing atmosphere. It is very difficult if not impossible to predict the NO reduction efficiency of low-NO_x burners for individual applications.

No.	BAT Evaluation Items	Comments	Remarks
1	**Consumables**		
1.1	Materials	None	
1.2	Air	None	
1.3	Water	None	
2	**Energy Consumption**		
2.1	Thermal [kJ/kg cli]	Reduced by 0 - 80 [17]	
2.2	Electrical	Slightly reduced	
3	**Waste Generation**		
3.1	Solids	None	
3.2	Liquids	None	

4	**Emissions**		
4.1	To air	None	
4.2	To water	None	
4.3	Noise	None	
4.4	Odour	None	
4.5	NO_x reduction [%]	0 - 30 [1,2,5,6,7,8,9,11, 12,13,14,15,16, 17,18,27,28]	1)
5	**Impact on Product Quality**		
5.1	Cement		5)
6	**Experience**		
6.1	Duration [years]	> 10	
6.2	Number of applications	> 100	
7	**Costs**		
7.1	Investment cost [10^6 ECU]	0.2 - 0.35 0.6 - 0.8 [6,9]	2) 3)
7.2	Operating cost [ECU/t cli]	0	
7.3	Total cost [ECU/t cli]	0.03 - 0.19	4)
8	**Conclusion on Candidate BAT**		
8.1	For existing plants and plant rehabilitations	Yes	
8.2	For new plants and major upgrades	Yes	

1) The maximum NO_x reduction efficiency is not a guaranteed efficiency for application on any kiln but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on an initial NO_x emission of about 2000 mg/Nm^3. The application of low-NO_x burners is not always followed by a reduction of the NO_x emission. An investigation by VDZ [17] shows that 50% of the tested kilns with low-NO_x burners did not show a significant NO_x reduction.

2) New burner.

3) If the existing firing system is direct firing it must be changed to an indirect firing system to allow combustion with low primary air flow.

4) Partially compensated by lower energy consumption.

5) May result in a slightly increased free lime content.

7.3.6 ADDITION OF WATER TO THE FLAME OR FUEL OF THE MAIN BURNER (AWFF)

Addition of water to the fuel or directly to the flame (e.g. in the form of organically polluted water) reduces the temperature and increases the concentration of hydroxyl radicals. This has a positive effect on NO_x reduction in the burning zone. Optimum results were achieved with alternative fuels containing a certain amount of water.

No.	BAT Evaluation Items		Comments	Remarks
1	**Consumables**			
1.1	Materials		None	
1.2	Air		None	
1.3	Water	[kg/t cli]	3 - 20 [10]	1)
2	**Energy Consumption**			
2.1	Thermal	[MJ/t cli]	10 - 65 [8,12]	
2.2	Electrical	[kW/ t cli]	0.02 - 0.15	2)
3	**Waste Generation**			
3.1	Solids		None	
3.2	Liquids		None	
4	**Emissions**			
4.1	To air		H_2O, CO_2	3)
4.2	To water		None	
4.3	Noise		None	
4.4	Odour		None	
4.5	NO_x reduction	[%]	up to 50 [8,10,11,12,27, 28]	4)
5	**Impact on Product Quality**			
5.1	Cement		None	
6	**Experience**			
6.1	Duration	[years]	> 5	
6.2	Number of known applications		> 3	
7	**Costs**			
7.1	Investment cost	[10^6 ECU]	0 - 0.2	Estimated

7.2	Operating cost [ECU/t cli]	0.03 - 0.25 [8] plus 0.0 - 0.25	5)
7.3	Total cost [ECU/t cli]	0.03 - 0.52	
8	**Conclusion on Candidate BAT**		
8.1	For existing plants and plant rehabilitations	Yes	1)
8.2	For new plants and major upgrades	Yes	1)

1) Can cause kiln operating problems.
2) Additional power consumption of kiln ID fan and filter.
3) The additional CO_2 emission is caused by the additional heat requirement for water evaporation. This causes a small additional CO_2 emission (approx. 0.1 – 1.5%) compared to the total CO_2 emission of the kiln. Additional CO_2 emission will be reduced if waste water is used.
4) The maximum NO_x reduction efficiency is not a guaranteed efficiency for applications on any kiln but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on an initial NO_x emission of about 2000 mg/Nm^3.
5) If the kiln, fan or filter gas handling capacity is limited (which is often the case) the maximum clinker production may be reduced while injecting water. This cost is very specific for the situation of each kiln and is difficult to estimate.

7.3.7 MULTI-STAGE COMBUSTION FOR IN-LINE PRECALCINERS (MSCI)

By introducing fuel through a burner in the kiln inlet zone or the riser duct a reducing environment is set up in this second combustion stage. The resulting intermediate products from the consecutive reactions of combustion act as reducing agents for NO created in the sintering zone and at the same time prevent the formation of more NO. After this second combustion stage, in the direction of the gas flow, tertiary air and more fuel (third combustion stage) are added to complete the combustion of the fuel from the second combustion stage. The use of multi-stage combustion is mainly suited to new kilns or an upgrade of kiln production rate.

Lump fuel firing can be a variant of the staged combustion. In case of a preheater kiln lump fuel can be introduced at the kiln inlet or at the precalciner (e.g. tyres). In the case of a wet kiln the lump fuel can be added via a mid-kiln valve (see below). Lump fuel firing is reported to have a positive effect on NO_x reduction. It is however very difficult to produce a controlled reducing atmosphere with lump fuel firing.

Long wet and long dry kilns usually have no access to a temperature zone of about 900 to 1000° C (kiln inlet in preheater kilns). For the sake of firing alternative fuels that cannot pass the main burner, mid-kiln firing systems were installed in a few plants. NO_x reduction can be a side effect of mid-kiln firing. It is however very difficult to produce a controlled reducing atmosphere with a mid-kiln firing system and very high operating and investment cost are associated with it.

No.	BAT Evaluation Items	Comments	Remarks
1	**Consumables**		
1.1	Materials	None	
1.2	Air	None	
1.3	Water	None	
2	**Energy Consumption**		
2.1	Thermal	None	
2.2	Electrical	None	
3	**Waste Generation**		
3.1	Solids	None	
3.2	Liquids	None	
4	**Emissions**		
4.1	To air	CO, SO_2 [13,19,20,24,26]	1)
4.2	To water	None	
4.3	Noise	None	
4.4	Odour	None	
4.5	NO_x reduction [%]	10 - 50 [2,6,13,19,20,21,22, 23,24,24,26]	2)
5	**Impact on Product Quality**		
5.1	Cement	None	
6	**Experience**		
6.1	Duration [years]	> 5	
6.2	Number of applications	> 20	
7	**Costs**		
7.1	Investment cost [10^6 ECU]	1 - 4 [6,9,19] 15 - 20 [6]	3) 4)
7.2	Operating cost [ECU/t cli]	0	

7.3	Total cost [ECU/t cli]	0.16 - 0.65 2.4 - 3.3	3) 4)
8	**Conclusion on Candidate BAT**		
8.1	For existing plants and plant rehabilitations	No	4), 5)
8.2	For new plants and major upgrades	Yes	

1) CO and SO_2 emission can be increased if the combustion process is not completed in the precalciner.
2) The maximum NO_x reduction efficiency is not a guaranteed efficiency for application on any kiln but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on an initial NO_x emission of about 2000 mg/Nm^3. Only a limited number of in-line precalciners with staged combustion are presently in operation. Therefore only limited information based on long term experience is available for the time being
3) Cost for precalciner and tertiary air duct for a preheater kiln that is suitable for transformation into a precalciner kiln.
4) Cost of the transformation of a preheater kiln with a satellite cooler into a precalciner kiln with a grate cooler.
5) MSCI is candidate BAT for existing kilns only if they are already equipped with a precalciner or an increase in the production rate is foreseen and the clinker cooler is of the grate cooler type.

7.3.8 SELECTIVE NON-CATALYTIC REDUCTION (SNCR) FOR PREHEATER/ PRECALCINER KILNS

Selective Non-Catalytic Reduction is the only available secondary reduction measure at the moment. NH_2-X compounds are injected into the exhaust gas at a temperature of about 950 to 1000° C to reduce NO to N_2. The required temperature window must provide sufficient retention time for the injected agents to react with NO. Experience shows that for most applications ammonia water is the best agent for SNCR at preheater/precalciner kilns. The transport and storage of ammonia water is a potential danger for the environment.

No.	BAT Evaluation Items	Comments	Remarks
1	**Consumables**		
1.1	Materials [gNH_3/t cli]	ca. 500 [29]	1)
	[gNH_3/t cli]	ca. 250 [30]	2)
		1700	3)

	[g urea/t cli]	[32]	
1.2	Air	None	
1.3	Water [kg/t cli]	1.5 140 1.5	1) 2) 3)
2	**Energy Consumption**		
2.1	Thermal [kJ/kg cli]	5 500 0	1), Estimated 2), Estimated 3), Estimated
2.2	Electrical [kW/t cli]	Negligible ca. 2 [30]	1),3), Estimated 2),4)
3	**Waste Generation**		
3.1	Solids	Ammonia aerosols	5)
3.2	Liquids	None	
4	**Emissions**		
4.1	To air	Ammonia, N_2O, CO_2, aerosols, dust [6,9,18] CO [32]	1),2),3),9) 3)
4.2	To water	None	
4.3	Noise	None	
4.4	Odour	None	
4.5	NO_x reduction [%]	Up to 65 [7,9,18,28,29,31] Up to 50 [30] Up to 65 [16,18,32]	1),6),12),16) 2),12),16) 3),6),12),16)
5	**Impact on Product Quality**		
5.1	Cement	Higher NH_3 concentration [9]	11)

6	**Experience**		
6.1	Duration [years]	> 5	1)
		Short time test	2)
		Short time test	3)
6.2	Number of known applications	> 3	1)
		1	2)
		1	3)
7	**Costs**		
7.1	Investment cost [10^6 ECU]	0.5 - 1.5 [6,9,29]	1),7)
		0.4 - 0.6 [30]	2)
		0.5 - 1.0 [8,32]	3)
7.2	Operating cost [ECU/t cli]	0.3 - 0.5 [6,9,29]	1),8)
		1.9 - 2.7 [30]	2),10)
		plus	
		0 - 2.8	2), 13)
		1.0 - 1.5 [8,9,18]	3)
7.3	Total cost [ECU/t cli]	0.38 - 0.74	1)
		2.0 - 5.6	2)
		1.1 - 1.7	3)
8	**Conclusion on Candidate BAT**		
8.1	For existing plants and plant rehabilitations	Yes	1),14)
		No	2)
		No	3)
8.2	For new plants and major upgrades	Yes	1),15)
		No	2)
		No	3)

1) Injection of ammonia water.
2) Injection of bio solids.

3) Injection of urea.

4) Additional power consumption relative to the normal power consumption of the kiln ID fan, mill fan and filter fan (if present), estimated on the basis of the additional exhaust gas volume.

5) If an ammonia slip occurs the released ammonia can react with SO_2 and other compounds in the exhaust gas to form fine particulates also called aerosols.

6) Higher reduction efficiencies can be achieved by injecting higher NH_3 quantities. Experience shows that after a reduction of 55 to 65% of NO_x a significant NH_3 slip occurs. Therefore the ecological and economical limit for SNCR NO_x reduction is at about 65%.

7) The investment costs are very much influenced by local regulations for storing ammonia water.

8) The operating costs are mainly determined by the cost for the injected ammonia.

9) If ammonia is injected at high molar ratios an ammonia slip is likely to occur. If urea is used for NO_x reduction the risk for additional N_2O and ammonia emission is increased. The additional CO_2 emission is caused by the additional heat consumption of 5 – 500 kJ/kg cli. (water evaporation). This corresponds to an additional CO_2 emission of about 0.1 – 10%.

10) The operating costs are mainly determined by the cost for the injected bio solids and by additional fuel cost.

11) Released ammonia can partially be adsorbed in the filter dust which later may be added to the cement. This would increase the ammonia content of the cement.

12) Only NO_x produced in the kiln is reduced. NO_x from precalciner and preheater cannot be influenced.

13) If the kiln, fan or filter gas handling capacity is limited the maximum clinker production may be reduced while adding bio solids. This cost is very specific for the situation of each kiln and is difficult to estimate.

14) Candidate BAT only for suspension preheater/precalciner kilns where temperature window and residence time are available.

15) Only if required emission target cannot be reached with primary reduction measures.

16) The maximum NO_x reduction efficiency is not a guaranteed efficiency for applications on any kiln but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on an initial NO_x emission of about 2000 mg/Nm^3.

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7.4 CONTROL OF SO_2-EMISSIONS

7.4.1 SUMMARY

Sulfur dioxide, SO_2, is formed during fuel combustion (fuel sulfur), releases of SO_2 in the burning zone of the kiln (from sulfates, e.g. $CaSO_4$) and oxidation of pyrite/marcasite (sulfide) and organic sulfur in the preheater or in the kiln inlet of long wet or long dry kilns. The behaviour of sulfur in preheater kilns and long wet or long dry kilns is significantly different.

Summarized it can be said that under normal conditions any sulfur introduced into the rotary kiln or the secondary firing/precalciner part of a preheater/precalciner kiln system only marginally contributes to the kiln's SO_2-emissions. This is different with sulfur in the form of sulfides and organic sulfur contained in the raw meal and fed in the usual way to the preheater top cyclone. About 30% of this sulfide and organic sulfur input leave the preheater as SO_2. During direct operation most of it is emitted to the atmosphere while during compound operation (that is when the kiln exhaust gases are passing through the raw mill, typically 60 – 85% of the operation time) 30 to 90% of the SO_2 is absorbed in the raw mill. In long wet and long dry kiln systems as well as in preheater bypass systems(very rare in EU) all types of sulfur input can contribute to SO_2 emissions, although in some cases the absorbtion of fuel sulfur can reach up to 90%.

The SO_2 emissions of cement kilns vary between 10 and 3,500 mg/Nm^3.

To reduce the SO_2 emission from a pyroprocessing system to a certain controlled level, three basically different methods are available:

- Maintain the existing process while reducing the sulfur input into the system (Chapter 7.4.3)
- Modify the existing process (primary or integrated reduction measure, Chapter 7.4.4)
- Maintain the existing process while adding a separate gas cleaning unit for the exhaust gas (secondary reduction measures, Chapters 7.4.5 to 7.4.8)

The tables below show a number of possibilities to reduce SO_2 emissions with efficiencies between 0 and 95%. Each reduction measure needs certain preconditions before it can be applied. In some cases it is possible to adjust the existing kiln system to allow the application of the required reduction measure. This, however, usually causes major additional investment cost.

The reduction efficiencies described are based on the reduction of the SO_2 concentration in the exhaust gas. Most European countries use concentration limits for the pollutants in the exhaust gas from cement plants to limit the emission impact to an acceptable degree. Because of the nature of the cement production process, the fuels and the raw materials, the observed SO_2 concentrations in the kiln exhaust gas vary in a wide range within short periods of time. To comply with limits over short term periodes (½ hour, 1 day) very strong corrective actions with secondary reduction measures may be required. It should be investigated from case to case if emission limits based on averages of longer time periods would improve the efficiency of environmental protection (e.g. with the same amount of slaked lime added to a kiln feed, lower total SO_2 emission can be achieved if the time intervals for the calculation of the SO_2 emission are extended).

The primary reduction measures (Chapters 7.4.3 and 7.4.4) have a limited reduction efficiency regarding peak emissions. Even if all possible primary measures are taken the SO_2 emission can still be anywhere between 10 and 3,500 mg/Nm^3. Prediction of reduction efficiencies of primary reduction measures can be very difficult. The presently existing secondary reduction measures (Chapters 7.4.5 to 7.4.8) can reduce the SO_2 emissions below 500 mg/Nm^3. The only economical secondary reduction measure (0.1 – 0.4 ECU/t_{cli}), the addition of slaked lime to the kiln feed, is limited to a maximum raw gas SO_2 content of about 1,200 mg/Nm^3 if an emission level of 400 mg/Nm^3 is to be achieved. All other secondary reduction measures significantly increase the production cost of clinker (2.7 – 3.1 ECU/t_{cli}).

The reduction efficiencies of the SO_2 reduction measures reported below can of course not be summed up to calculate the final SO_2 reduction capacity. Some measures cannot even be combined with others. Furthermore the reduction efficiency is usually highest at highest emissions. This means that the lower the emissions the harder and more costly it is to reduce them further.

Secondary emissions that are emitted during the production and transportation of agents (slaked lime, activated carbon...), and power used for emission reduction, are not included in this investigation.

To make the information in the tables below comparable a common base was used:

- Clinker production: 3000 t/d
- Kiln type: Preheater/Precalciner (if not indicated differently)
- Initial emission: Up to 3000 mgSO_2/Nm^3
- Coal cost: 60 ECU/t
- Activated coke cost: 240 ECU/t
- Slaked lime cost: 85 ECU/t
- Power cost: 0.04 ECU/kWh
- Amortization: 10 years
- Interest rate: 10%

Most information is retrieved from literature (see Chapter 7.4.9) and cement industry specific experience. To fit them into the common base, conversion of the relevant data was required.

7.4.2 INDEX OF DESCRIBED SO_2 REDUCTION MEASURES

7.4.3 REDUCTION OF SULFUR CONTENTS IN FUELS AND KILN FEED (RSC)

The sulfur behaviour in cement kiln systems and the emissions resulting therefrom can be summarized as follows:

	Lepol, Preheater/ precalciner kilns	**Other kilns**
Fuel sulfur	O	√
Volatile sulfur in raw materials (pyrites, marcasite, organic sulfur)	√	√
Non-volatile sulfur in raw materials (sulfates)	O	√

O = No effect on sulfur emissions

√ = May increase sulfur emissions

Fuel sulfur in preheater/precalciner kilns practically does not leave the kiln system as SO_2 emission because of the very efficient scrubbing by the hot meal in the preheater or/and in the precalciner. In preheater kilns all fuel sulfur must leave the system as a well defined compound like K_2SO_4 and $Ca_2K_2(SO_4)_3$ or in solid solution in the clinker minerals (e.g. belite). Therefore fuel sulfur does not contribute significantly to SO_2 emissions from preheater/precalciner kilns.

Fuel sulfur in other kilns than cyclone and grate preheater kilns, however, can have a significant impact on the SO_2 emission. This is due to a somewhat less intensive contact between the raw meal and the exhaust gas (reduced scrubbing effect). An average of 10 to 50% of the fuel sulfur leaves the kiln as SO_2.

Raw material sulfur in form of sulfides (pyrite, marcasite) or organic sulfur can increase the SO_2 emission of preheater/precalciner kilns. An average of 30 to 50% of the kiln feed sulfides leave the preheater kilns as SO_2. Raw material sulfur in the form of sulfates does not contribute to the SO_2 emissions but leaves the kiln in the same way as the fuel sulfur, i.e. integrated in the clinker.

Raw material sulfur in other kilns than preheater/precalciner kilns can contribute to the SO_2 emission in a similar manner as the fuel SO_2. Sulfides are oxidised to SO_2 at the kiln feed end and the sulfates are dissociated and SO_2 is released in the burning zone. 10 to 50% of the sulfur input may leave the kiln as SO_2.

Therefore a reduction of the sulfide input can reduce the SO_2 emission from preheater/precalciner kilns. Fuel sulfur and sulfate reduction has no influence on preheater/precalciner kilns SO_2 emission.

In other kilns than preheater kilns all sulfur input can contribute to SO_2 emissions. The costs for the reduction of sulfur inputs into such kiln systems cover a wide range. A solution could be a reduction of the fuel sulfur by replacing a normal fuel like a sulfur rich coal, with an alternative fuel with low sulfur content, provided this is economically feasible.

7.4.4 OPTIMIZATION OF THE CLINKER BURNING PROCESS (OCBP)

Optimization 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 (e.g. refractory). SO_2 reduction is a side effect of the optimization. The reduction is usually caused by the reduced SO_2 volatility (lower flame and burning temperatures and oxidizing instead of reducing atmosphere in the kiln) as well as stable kiln operation. The effect of kiln optimization on SO_2 emission is very strong for long wet and long dry kilns and marginal for preheater kilns.

The application of a high level control system is a special case of kiln optimization.

No.	BAT Evaluation Items	Comments	Remarks
1	**Consumables**		
1.1	Materials	None	
1.2	Air	None	
1.3	Water	None	
2	**Energy Consumption**		
2.1	Thermal	Reduced	
2.2	Electrical	Reduced	
3	**Waste Generation**		
3.1	Solids	None	
3.2	Liquids	None	
4	**Emissions**		
4.1	To air	NO_x	1)
4.2	To water	None	
4.3	Noise	None	

4.4	Odour	None	
4.5	SO_2 reduction [%]	0 - 50 [19]	2)
5	**Impact on Product Quality**		
5.1	Cement	Less fluctuation in product quality	
6	**Experience**		
6.1	Duration	Years	
6.2	Number of applications	Numerous	
7	**Costs**		
7.1	Investment cost [10^6 ECU]	0 - 5 [6]	3)
7.2	Operating cost [ECU/t cli]	0	4)
7.3	Total cost [ECU/t cli]	0 - 0.81	
8	**Conclusion on Candidate BAT**		
8.1	For existing plants and plant rehabilitations	Yes	
8.2	For new plants and major upgrades	Yes	

1) If the oxygen concentration in the kiln is increased to avoid reducing atmosphere the NO_x production rate can be higher.

2) The maximum SO_2 reduction efficiency is not a guaranteed efficiency for applications on any non-cyclone preheater kiln but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on an initial SO_2 emission of about 3000 mg/Nm^3. Influence of kiln optimisation on SO_2 from preheater kilns is usually negligible.

3) Kiln optimisation can include many elements ranging from instruction/training of the kiln operators up to installation of new equipment such as new burner, dosing systems, homogenisation silos, preblending beds, new clinker coolers, etc.

4) Most kiln optimisations have been executed to reduce operating cost, increase capacity and improve product quality. The operating cost of an optimized kiln is usually lower if compared to the non optimised state. The savings result from reduced fuel and refractory consumption, lower maintenance cost, higher productivity and other effects. No general cost reduction can be indicated because kiln optimisation is a very individual step by step process extending for each kiln often over a long period of time.

7.4.5 ADDITION OF SLAKED LIME ($Ca(OH)_2$) TO THE KILN FEED OF PREHEATER KILNS (SLKF)

The addition of slaked lime to the exhaust gas of the kiln can absorb some of the SO_2. It has been found that the best method of introducing the slaked lime is to add it to the kiln feed (it was found that direct injection of slaked lime into the exhaust gas is less efficient compared to the addition of slaked lime to the kiln feed). Once injected into the exhaust gas it absorbs SO_2 in the top cyclones:

$$Ca(OH)_2 + SO_2 \text{-->} CaSO_3 + H_2O$$

The $CaSO_3$ then moves into the kiln together with the raw material. The $CaSO_3$ reacts with the exhaust gas to form $CaSO_4$ which becomes incorporated in the clinker. The reactivity of the slaked lime is not very high. Therefore molar ratios between $Ca(OH)_2$ and SO_2 of 3 to 6 have to be applied. If an emission level of 400 mg/Nm^3 is to be achieved, the SO_2 concentration in the raw gas should not be above 1,200 mg/Nm^3. For higher initial SO_2 emissions, the addition of slaked lime to the kiln feed is economically and ecologically not feasible.

No.	BAT Evaluation Items		Comments	Remarks
1	**Consumables**			
1.1	Materials	[kgCa(OH)$_2$/t$_{cli}$]	2 - 8 [5,8,11,12,15,18]	1)
1.2	Air		None	
1.3	Water		None	
2	**Energy Consumption**			
2.1	Thermal		None	
2.2	Electrical	[kWh/ t$_{cli}$]	0.2 - 0.5 [11]	
3	**Waste Generation**			
3.1	Solids		None	
3.2	Liquids		None	
4	**Emissions**			
4.1	To air		None	
4.2	To water		None	
4.3	Noise		None	
4.4	Odour		None	
4.5	SO_2 reduction	[%]	Up to 65 [5,8,9,12,15,18]	2)

5	**Impact on Product Quality**			
5.1	Cement		None	
6	**Experience**			
6.1	Duration	[years]	> 5	
6.2	Number of known applications		> 4	
7	**Costs**			
7.1	Investment cost	[10^6 ECU]	0.2 - 0.3	Estimated
7.2	Operating cost	[ECU/t_{cli}]	0.1 - 0.4 [5,11]	
7.3	Total cost	[ECU/t_{cli}]	0.13 - 0.45	
8	**Conclusion on Candidate BAT**			
8.1	For existing plants and plant rehabilitations		Yes	
8.2	For new plants and major upgrades		Yes	

1) The required $Ca(OH)_2$ input is a function of the average SO_2 raw gas emission, the required clean gas SO_2 concentration and the situation in the top stage cyclones (temperature, retention time). 2 to 8 kg/t_{cli} are average figures. Maximum input can be up to 20 kg/t_{cli}.

2) The maximum SO_2 reduction efficiency is not a guaranteed efficiency for applications on preheater kilns but the maximum efficiency that may be achieved under optimum conditions. The maximum lime utilisation efficiency is obtained with an initial SO_2 emission of about 3000 mg/Nm^3.

7.4.6 CIRCULATING FLUIDIZED BED ABSORBER (CFBA)

To reduce very high SO_2 emissions (more than 1500 mg/Nm^3) to 500 or 400 mg/Nm^3 a separate scrubber is required if the primary reduction measures remain insufficient. The CFBA uses a Venturi reactor column to produce a fluidised bed consisting of a blend of slaked lime and raw meal. The intensive contact between gas and absorbent, the long residence time and the low operating temperature close to the dew point allow a very efficient absorption of SO_2. The gas leaving the Venturi is loaded with absorbent which is collected in the downstream electrostatic precipitator. A portion of the extracted absorbent is returned to the CFBA and the other portion is added to the kiln inlet where the absorbent is converted into clinker.

No.	BAT Evaluation Items		Comments	Remarks
1	**Consumables**			
1.1	Materials	kgCa(OH)$_2$/t$_{cli}$ kgRawMeal/t$_{cli}$	13 30	1)
1.2	Air		None	
1.3	Water		Yes	
2	**Energy Consumption**			
2.1	Thermal		None	
2.2	Electrical	kWh/t$_{cli}$	8.5	
3	**Waste Generation**			
3.1	Solids		None	
3.2	Liquids		None	
4	**Emissions**			
4.1	To air		None	
4.2	To water		None	
4.3	Noise		None	
4.4	Odour		None	
4.5	SO_2 reduction	[%]	Up to 90 [3,5,12,17]	2)
5	**Impact on Product Quality**			
5.1	Cement		None	3)
6	**Experience**			
6.1	Duration	[years]	> 9	
6.2	Number of applications		> 1	
7	**Costs**			
7.1	Investment cost	[10^6 ECU]	11 [5]	
7.2	Operating cost	[ECU/t$_{cli}$]	1.6 (1.4)	4)
7.3	Total cost	[ECU/t$_{cli}$]	3.4 (3.2)	4)

8	**Conclusion on Candidate BAT**		
8.1	For existing plants and plant rehabilitations	No	5)
8.2	For new plants and major upgrades	No	5)

1) The absorbent of the CFBA is fully recovered in the cement production process. Therefore the CFBA is neutral regarding the mass balance of the cement production.
2) The maximum SO_2 reduction efficiency is not a guaranteed efficiency for applications on any kiln but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on an initial SO_2 emission of about 3000 mg/Nm^3. It was found that also compounds of the exhaust gas, other than SO_2, are adsorbed in the CFBA.
3) The additional sulfur content of the clinker reduces the required addition of gypsum to the cement mill.
4) If the contribution from gypsum replacement is also included in the cost evaluation the values in brackets are valid. The contributions are subject to strong variations from one plant to another.
5) Yes only in case very high SO_2 emissions have to be reduced.

7.4.7 WET SCRUBBER (WS)

An alternative to the CFBA (dry scrubbing) is wet scrubbing. A system presently in operation [16] works as follows. The exhaust gas from the kiln passes first a gas/water heat exchanger before it enters the SO_2 scrubber at a temperature of about 115° C. In the scrubber SO_2 is absorbed in a slurry loaded with 6 – 10% solids consisting of 98% $CaSO_4.2H_2O$ and 2% $CaCO_3$. The slurry is sprayed in counter current to the exhaust gas and collected in the recycle tank at the bottom of the scrubber where it is oxidised with air ($CaSO_3 + 0.5O_2 \text{--->} CaSO_4$). A part of the slurry is pumped to a centrifuge where water and gypsum are separated. The rest is reinjected through a circulation line into the scrubber. A chalk slurry of 30% moisture is injected into the circulation line before the spray nozzles to replace the used and extracted absorbent ($CaCO_3+SO_2 \text{--->} CaSO_3 + CO_2$). The exhaust gas leaves the scrubber with a temperature of about 70° C.

No.	BAT Evaluation Items		Comments	Remarks
1	**Consumables**			
1.1	Materials	[kg$CaCO_3$/t$_{cli}$]	35 [25]	
1.2	Air	[m3/t$_{cli}$]	63 [25]	
1.3	Water	[kg/t$_{cli}$]	None	

2	**Energy Consumption**			
2.1	Thermal		None	
2.2	Electrical	[kW/t_{cli}]	24 [25]	
3	**Waste Generation**			
3.1	Solids		None	1)
3.2	Liquids			
4	**Emissions**			
4.1	To air		None	
4.2	To water	[m3/h]	0.5 [25]	
4.3	Noise		None	
4.4	Odour		None	
4.5	SO_2 reduction	[%]	75 - 90 [16]	2)
5	**Impact on Product Quality**			
5.1	Cement		None	
6	**Experience**			
6.1	Duration	[years]	6	
6.2	Number of known applications		1 [16]	
7	**Costs**			
7.1	Investment cost	[10^6 ECU]	10 - 14 [25]	3)
7.2	Operating cost	[ECU/t_{cli}]	2.7 [25]	4)
7.3	Total cost	[ECU/t_{cli}]	4.3 - 5.0	4)
8	**Conclusion on Candidate BAT**			
8.1	For existing plants and plant rehabilitations		No	1), 4)
8.2	For new plants and major upgrades		No	1), 4)

1) The scrubber produces gypsum that is used in the cement production.

2) The maximum SO_2 reduction efficiency is not a guaranteed efficiency for applications on any kiln but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on an initial SO_2 emission of about 3000 mg/Nm^3.

3) The reported investment cost from a wet scrubber for cement kiln exhaust gas is 12.2 Million ECU (including heat recovery system). The kilns that are equipped with this wet scrubber only produce about half of the BAT reference kiln (3000 t_{cli}/day) but are wet kilns with a high specific heat consumption and a high specific exhaust gas quantity. The total exhaust gas that is treated in the wet scrubber is about twice the exhaust gas from a modern preheater kiln for 3000 t/d. The estimation of the cost for a 3000 t/d kiln is very difficult.
4) 2.7 ECU/$_{tcli}$ is the operating cost in the reference plant including material and power consumption as well as maintenance cost. This cost is offset by the plant generating a benefit: 3.5 ECU/t_{cli} for the heat sold to the community and 0.18 ECU/t_{cli} for the gypsum. If these revenues are included in the cost calculation the total cost amounts to 0.3 – 0.8 ECU/t_{cli} . The high revenues from the heat recovery are however very specific for this unique application, mainly because of the very high heat output of the kilns which is significantly higher than that of most other kilns in Europe built more recently.

7.4.8 ADSORPTION ON ACTIVATED COKE, POLVITEC (AAC)

The POLVITEC consists of several packed beds of activated coke. The dedusted kiln exhaust gas is passed across the activated coke where compounds like SO_2 and NH_3 are efficiently adsorbed. The cleaned gas is then released to the atmosphere. The used activated coke is periodically extracted to a separate silo and replaced with fresh adsorbent. From the used coke silo the coke is fed to the kiln together with other fuels. The adsorbed SO_2 is thereby subsequently embedded in the clinker.

No.	BAT Evaluation Items		Comments	Remarks
1	**Consumables**			
1.1	Materials	[kgCarbon/t_{cli}]	4.5 [22]	
1.2	Air		None	
1.3	Water		None	
2	**Energy Consumption**			
2.1	Thermal		None	
2.2	Electrical	[kWh/t_{cli}]	6 [22]	
3	**Waste Generation**			
3.1	Solids		None	
3.2	Liquids		None	
4	**Emissions**			
4.1	To air		None	

4.2	To water	None	
4.3	Noise	None	
4.4	Odour	None	
4.5	SO_2 reduction [%]	Up to 95 [7,22]	1)
5	**Impact on Product Quality**		
5.1	Cement	None	
6	**Experience**		
6.1	Duration [years]	3	
6.2	Number of known applications	1	
7	**Costs**		
7.1	Investment cost [10^6 ECU]	21 [7,22]	
7.2	Operating cost [ECU/t_{cli}]	0.9 (0.5) [7,22]	2)
7.3	Total cost [ECU/t_{cli}]	4.3 (3.9)	2)
8	**Conclusion on Candidate BAT**		
8.1	For existing plants and plant rehabilitations	No	3)
8.2	For new plants and major upgrades	No	3)

1) The maximum SO_2 reduction efficiency is not a guaranteed efficiency for applications on any kiln but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on an initial SO_2 emission of about 3,000 mg/Nm^3.

2) If the contributions from gypsum and coal replacement are also included in the cost evaluation the values in brackets are valid. The contributions are subject to strong variations from one plant to another.

3) Adsorption on activated carbon is too expensive. In the case of the Polvitec installed in a Swiss cement plant only the financial contribution of the communities burning their sewage sludge in the kiln, the fees for burning other alternative fuels in the kiln and the complex problem with different emission components made the project ecologically and economically feasible.

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7.5 CONTROL OF VOC-EMISSIONS

7.5.1 SUMMARY

The main source of VOC emissions (VOC means Volatile Organic Compounds) from cement kiln stacks is organic matter present in or attached to the raw material. A portion of this organic matter is expelled when the raw material is exposed to the heat in the kiln system. Some of the expelled organic compounds are oxidised but others leave the kiln as organic emissions. The lower the organic content of the raw material and the higher the required temperature for expulsion of the organic compounds the lower is the VOC emission from the kiln. The conditions for formation of dioxins and furans (D/F) are different from those for VOC formation. Formation (de novo synthesis) is considered to be able to occur by reactions in the gaseous phase at a temperature between 350 and 450° C in the exhaust gas system provided precursors and other components are available. D/F are never caused by the combustion process. D/F, which might be present in the fuel, are completely destroyed at the high temperatures in the kiln.

Especially in the USA, it is assumed that unfavourable raw materials (high content of organic matter in natural raw materials or in alternative materials) in combination with high chlorine content in the exhaust gas can increase the D/F emission in some kiln systems. In such cases emission concentrations above 0.1ng TE/Nm^3 (most stringent emission limit for D/F) have been observed. In contrast this kind of formation is low in European kilns, probably due to lower concentrations of precursors.

The expulsion behaviour of the organic matter in the raw materials depends, among other things, on the kiln type. The oxygen concentration in the exhaust gas of preheater kilns has only a marginal effect on the VOC emission while the oxygen concentration in long wet and long dry kilns has a very high VOC reduction potential. With increased oxygen content the VOC emissions from wet kilns are lower for the same raw material compared to preheater kilns. This finding can be explained by the higher temperature difference between raw meal and exhaust gas in the long wet and long dry kilns compared to preheater kilns.

The combustion in the burning zone produces flame temperatures of up to 2,000° C. Therefore all organic compounds that are injected through the main burner are completely oxidised (burned) and cannot contribute to VOC emissions. Secondary and precalciner firing produce temperatures between 900 and 1,100° C. Therefore, careful choice, preparation and injection of the fuels completely prevent VOC emission from secondary and precalciner firing. Since VOC emissions result from raw materials VOC emission cannot be used as an indicator for good combustion conditions in the kiln.

The VOC emission is the sum of the concentrations of all volatile organic compounds in the exhaust gas. Flame ionisation detectors (FID) are used to measure the VOC emissions. They are expressed as ppm or mg/Nm^3 methane or propane equivalents depending on which of the two gases were used for calibration of the FID.

The VOC emissions of cement kilns are typically between 10 and 100 mg/Nm^3. There are a few cases known where the VOC emission can reach as much as 500 mg/Nm^3 because of the raw material characteristics.

The emission of CO is also very strongly related to the content of organic matter in the raw material. VOCs that are expelled from the raw materials can be oxidised to CO_2 or CO. Especially in areas of the kiln where only very little O_2 and/or not very high temperatures are available the incomplete oxidation of VOC can produce CO. Due to the contribution of the organic matter in the raw materials to the CO emissions, CO emissions are not suitable as an indicator for good combustion conditions in the kiln.

To reduce the VOC emission from a pyroprocessing system to a certain controlled level, three basically different methods are available:

- Maintain the existing process while reducing the input of organic matter into the system (Chapter 7.5.3)
- Modify the existing process (primary or integrated reduction measures, Chapters 7.5.4 and 7.5.5)
- Maintain the existing process while adding a separate gas cleaning unit for the exhaust gas (secondary reduction measures, Chapter 7.5.6)

The tables below show a number of possibilities to reduce VOC emissions with efficiencies between 0 and 95%. Each reduction measure needs certain preconditions before it can be applied. In some cases it is possible to adjust the existing kiln system to allow the application of the required reduction measure. This, however, usually causes major additional investment cost.

The reduction efficiencies described hereafter are based on the reduction of VOC concentrations in the exhaust gas. Most European countries use concentration limits for the pollutants in the exhaust gas from cement plants to limit the emission impact to an acceptable degree.

The application of the primary reduction measures (Chapters 7.5.4 and 7.5.5) is limited to specific cases and very often connected to very high investment and operating cost. No compliance with any VOC emission limit can be guaranteed with primary reduction measures without exceeding reasonable investment and operating cost. Maximum VOC emissions of a specific raw material can be estimated with the help of an Expulsion Test. [10]

The only presently available secondary reduction measure, POLVITEC (see Chapter 7.5.6), can reduce VOC emissions of organic compounds larger than C_6 (C_6 = hydrocarbons with 6 carbon atoms) to below all known emission limits. Compounds smaller or equal to C_5 are not very efficiently removed. It must be mentioned that up to 80% of cement kiln VOC emission can consist of compounds equal or smaller than C_5 compounds.

Secondary emissions that are emitted during the production and transportation of adsorbents, or in generation of power used to reduce emissions are not included in this investigation.

The reduction efficiencies of the VOC reduction measures reported below can of course not be summed up to calculate the final VOC reduction capacity. Some measures cannot even be combined with others. Furthermore the reduction efficiency is always highest at highest emissions. This means that the lower the emissions the harder and more costly it is to reduce them further.

To make the information in the tables below comparable a common base was used:

• Clinker production:	3000 t/d
• Kiln type:	Preheater/Precalciner (if not indicated differently)
• Initial emission:	10 – 100 (normal) up to 500 (exceptional) mgC_3H_8eq/Nm^3
• Coal cost:	60 ECU/t
• Activated coke cost:	240 ECU/t
• Power cost:	0.04 ECU/kWh
• Amortization:	10 years
• Interest rate:	10%

Most information is retrieved from literature (see Chapter 7.5.7) and cement industry specific experience. To fit them into the common base, conversion of the relevant data was required.

7.5.2 INDEX OF DESCRIBED VOC REDUCTION MEASURES

7.5.3 REDUCTION OF ORGANIC MATTER CONTAINED IN THE RAW MATERIALS (ROC)

Depending on the geological history of the rock that is used as a raw material more or less organic matter is included in it. A portion of this organic matter is expelled after being introduced into the kiln. Some of the expelled organic compounds are oxidised, others leave the kiln as organic emissions. The lower the organic content of the raw material and the higher the required temperature for expulsion of the organic compounds the lower is the organic emission from the kiln.

A reduction of the organic matter in the natural raw material is virtually impossible.

7.5.4 ADDITION OF ORGANIC MATTER CONTAINING RAW MATERIAL COMPONENTS TO THE HOT ZONE OF THE KILN (AHZ)

If a component of the raw material that is responsible for the high emission of VOC is added directly to the hot zone of the kiln (e.g. kiln inlet) the organic compounds are burned before they can escape to the atmosphere. This is, however, only reasonable for components that represent a small portion of the raw material. The disadvantages of this addition are an increased heat consumption of the kiln, possibly additional build ups at the injection point and a less homogeneous and constant kiln feed which can lead to reduced clinker quality.

If the main portion of the raw material is responsible for the VOC emission it would be possible to add the whole raw material to a flash calciner where the sharp temperature increase destroys almost all organic compounds. To install such a flash calciner with all the additionally required equipment major investment is necessary. The heat consumption for a kiln with flash calciner is significantly higher compared to a preheater kiln.

No.	BAT Evaluation Items		Comments	Remarks
1	**Consumables**			
1.1	Materials		None	
1.2	Air		None	
1.3	Water		None	
2	**Energy Consumption**			
2.1	Thermal	[kJ/t_{cli}]	0 - 3300	1)
2.2	Electrical	[kWh/t_{cli}]	0 - 2.5	
3	**Waste Generation**			
3.1	Solids		None	
3.2	Liquids		None	
4	**Emissions**			
4.1	To air	[kg CO_2/t_{cli}] [NO_x]	200 Yes	
4.2	To water		None	
4.3	Noise		None	
4.4	Odour		None	
4.5	VOC reduction	[%]	Up to 95%	4)
5	**Impact on Product Quality**			
5.1	Cement		Reduced quality possible	See above

6	**Experience**		
6.1	Duration [years]	5	
6.2	Number of Applications	> 1	
7	**Costs**		
7.1	Investment cost [10^6 ECU]	Up to 25	2)
7.2	Operating cost [ECU/t_{cli}]	Up to 8.9	1)
7.3	Total cost [ECU/t_{cli}]	Up to 13	
8	**Conclusion on Candidate BAT**		
8.1	For existing plants and plant rehabilitations	No	1),2),3)
8.2	For new plants and major upgrades	No	1),2),3)

1) If small portions of the raw material are directly added to the hot zone the additional heat consumption will be small to negligible. If all raw material is added to a flash calciner a very high additional heat input is required which increases the operating cost.

2) If only a very small portion of the raw material has to be added directly to the hot zone of the kiln the additional investment cost may be low. If a flash calciner must be built the costs are very high.

3) AHZ is considered candidate BAT if only small portions of the raw materials would have to be added to the hot zone.

4) The maximum VOC reduction efficiency is not a guaranteed efficiency for applications on any kiln but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on an initial VOC emission of about 100 mg/Nm^3.

7.5.5 INCREASED OXYGEN CONCENTRATION AT THE KILN INLET OF LONG WET OR LONG DRY KILNS (IOC)

An increase of the oxygen concentration can significantly reduce the organic emission from the raw materials in long wet and long dry kilns. It is assumed that the large temperature difference between raw meal and exhaust gas at the point of release of the organic compounds is responsible for the emission reduction. An increase of the oxygen concentration always causes an increase of the heat consumption and the CO_2 and NO_x emission, and a reduction of the maximum production capacity.

No.	BAT Evaluation Items		Comments	Remarks
1	**Consumables**			
1.1	Materials		None	
1.2	Air		Yes	
1.3	Water		None	
2	**Energy Consumption**			
2.1	Thermal	[MJ/t_{cli}]	50 - 60	
2.2	Electrical	[kW/t_{cli}]	0.1 - 0.2	
3	**Waste Generation**			
3.1	Solids		None	
3.2	Liquids		None	
4	**Emissions**			
4.1	To air		CO_2, NO_x	
4.2	To water		None	
4.3	Noise		None	
4.4	Odour		None	
4.5	VOC reduction	[%]	Up to 40 [1]	1)
5	**Impact on Product Quality**			
5.1	Cement		None	
6	**Experience**			
6.1	Duration	[years]	> 10	
6.2	Number of applications		> 10	
7	**Costs**			
7.1	Investment cost	[10^6 ECU]	0	2)
7.2	Operating cost	[ECU/t_{cli}]	0.13 - 0.15 0 - 1.2	3),4) 5)
7.3	Total cost	[ECU/t_{cli}]	0.13 - 1.4	
8	**Conclusion on Candidate BAT**			
8.1	For existing plants and plant rehabilitations		Yes	
8.2	For new plants and major upgrades		N.A.	

1) The maximum VOC reduction efficiency is not a guaranteed efficiency for applications on any kiln but the maximum efficiency that may be achieved under optimum conditions. The maximum reduction efficiency is based on an initial VOC emission of about 100 mg/Nm^3.
2) Additional equipment is not required.
3) Example for an increase of the oxygen concentration from 1.2 to 2.3%.
4) Cost of additional heat consumption.
5) Because of the additional excess air (excess oxygen) the production rate is reduced. If the market is such that all cement can be sold, the production loss is estimated to be 0.2 ECU/t_{cli} per % production reduction.

7.5.6 ADSORPTION ON ACTIVATED COKE, POLVITEC (AAC)

The POLVITEC consists of several packed beds of activated coke. The dedusted kiln exhaust gas is passed across the activated coke where compounds like VOC, SO_2 and NH_3 are adsorbed. The cleaned gas is then released to the atmosphere. The used activated coke is periodically extracted to a separate silo and replaced with fresh adsorbent. From the used coke silo the coke is fed to the kiln together with other fuels where the adsorbed VOCs are burned. Due to the character of the activated coke only organic compounds larger than C_5 are adsorbed with a high efficiency.

Adsorption on activated coke is too expensive. In the case of the Polvitec installed in a Swiss cement plant only the financial contribution of the communities burning their sewage sludge in the kiln, the fees for burning other alternative fuels in the kiln and the complex problem with different emission components made the project ecologically and economically feasible.

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7.6 CONTROL OF HEAVY METAL EMISSIONS

7.6.1 INTRODUCTORY REMARKS

All metals heavier than Titanium (4.51 g/cm^3) are considered as heavy metals(HM).The heavy metals make up a small but definite proportion of the materials in the Earth's crust like soil, rock, fuels (e.g. carbon) etc. Not all heavy metals are toxic and not all toxic heavy metals have the same toxicity. Therefore some countries differentiate between different toxicity classes: (e.g. TA-Luft, Germany)

- Class I: Cd, Hg, Tl
- Class II: As, Co, Ni, Se, Te
- Class III: Pb, Cr, Cu, Pt, V, Sn, Pd, Sb, Mn, Rh

The HM in class I are the most, the HM in class III the least toxic heavy metals.

The main sources of heavy metal (HM) emissions from cement kiln stacks are raw materials and fuels containing heavy metals. Regarding the behaviour of the HM in the kiln system three classes can be distinguished.

The *non or low volatile HM* (As, Be, Co, Cr, Cu, Mn, Mo, Sb, Se, Te, V, Zn) are incorporated in the clinker to almost 100% and therefore do practically not appear as emissions. As a general rule the sum of the emissions of all non-volatile HM of a preheater kiln is always much below 0.1% of the corresponding metal input.

The semi-volatile HM such as Tl, Pb, and Cd are not completely (Pb, Cd) to very little (Tl) incorporated directly in the clinker. The remaining part which is not incorporated in the clinker is almost completely adsorbed on the surface of the dust particles in the kiln exhaust gas system. Kiln filters like electrostatic precipitators and bag filters can therefore efficiently remove the semi-volatile HM from the exhaust gas. The dust collected in the filter is usually reintroduced into the kiln which leads to an internal accumulation of these HM in the kiln system. To eliminate the semi-volatile elements from the kiln system a portion of the dust collected in the kiln filter is extracted and fed to the cement mills.

Volatile HM cannot be efficiently controlled by dedusting of the kiln exhaust gas because a portion of the volatile HM always remains volatile (not attached to dust particles). The most prominent and only example of relevance to the cement industry is mercury (Hg). Hg is suspected to be emitted to a large degree in vaporous form. The lower the exhaust gas temperature is at the filter inlet the higher is the proportion of Hg attached to dust particles that can be removed from the exhaust gas.

Unlike preheater kilns, long wet and long dry kilns have been studied less in their heavy metal emission behaviour. From the basic principle and from the higher stack gas temperatures one could expect a less favourable situation but the practical evidence is incomplete. In fact the only data that are available contradict the assumption that long wet kilns are less favourable regarding HM scrubbing compared to preheater kilns.

The HM emissions of cement kilns are usually significantly below a total of 0.5 mg/Nm^3 and therefore in compliance with most regulations.

To reduce the HM emission from a pyroprocessing system to a certain controlled level, three basically different methods are available:

- Maintain the existing process while reducing the input of HM into the system
- Modify the existing process (primary or integrated reduction measures)
- Maintain the existing process while adding a separate gas cleaning unit for the exhaust gas (secondary reduction measures)

Each reduction measure needs certain preconditions before it can be applied. In some cases it is possible to adjust the existing kiln system to allow the application of the required reduction measure. This, however, usually causes major additional investment cost.

The most common HM emission reduction measures are reduction of HM input and efficient dedusting. To avoid accumulation of HM in the kiln system a portion of the filter dust should continuously or periodically be extracted from the dedusting system. Additional secondary reduction measures like the adsorption on activated coke are only required if the content of the volatile HM (e.g. Hg) is very high.

The reduction efficiencies of the HM reduction measures reported below can of course not be summed up to calculate the final HM reduction capacity. Some measures cannot even be combined with others. Furthermore the reduction efficiency is always highest at highest emissions. This means that the lower the emission are the harder and more costly is it to reduce them further.

Most information is retrieved from literature (see Chapter 7.6.6) and cement industry specific experience. To fit them into the common base, conversion of the relevant data was required.

7.6.2 INDEX OF DESCRIBED HM REDUCTION MEASURES

7.6.3 REDUCTION OF HEAVY METALS IN THE RAW MATERIALS AND FUELS (RMR)

Heavy metals (HM) are naturally contained in the cement raw materials. The non-volatile heavy metals reach the dedusting unit incorporated in natural concentrations in the dust particles. The semi-volatile and volatile HM can reach the dedusting equipment either in the same form as above, bound to the dust (e.g.Tl) or as vapour (e.g. Hg). The higher the content of the volatile HM in the raw material and the fuels the higher is usually the emission of these HM but at a generally low level.

A reduction of the semi-volatile and volatile HM in the raw materials and fuels is virtually impossible. However, the use of waste materials or alternative fuels excessively enriched in HM to replace regular raw materials and fuels should be avoided.

7.6.4 HIGH EFFICIENCY DEDUSTING (HED)

Portions of some of the semi-volatile heavy metals (HM) and much of the volatile HM mercury leave the kiln attached to the surface of the emitted dust particles. The dust emission reduction efficiency is therefore very important for the HM emission reduction. High dedusting efficiencies can be achieved with electrostatic precipitators (EP) and bag filters (BF). Especially existing EPs can be optimised with various measures starting with exhaust gas conditioning and ending with enlargement or replacement of the filter. (See also Chapter 7.2)

7.6.5 ADSORPTION ON ACTIVATED COKE, POLVITEC (AAC)

The POLVITEC consists of several packed beds of activated coke. The dedusted kiln exhaust gas is passed across the activated coke where compounds like HM, VOC, SO_2 and NH_3 are adsorbed. The cleaned gas is then released to the atmosphere. The used activated coke is periodically extracted to a separate silo and replaced with fresh adsorbent. From the used coke silo the coke is fed to the kiln together with other fuels where the adsorbed HM are integrated in the clinker or again emitted from the kiln system. If volatile or semi-volatile compounds are enriched in the system between kiln and adsorber the HM should be removed from the system by extracting a small portion of the dust collected in the kiln dust filter and by feeding it to the cement mill.

Since volatile and semi-volatile HM are effectively adsorbed on activated coke and since the clean gas dust content downstream of the AAC device is down to a few mg/Nm^3 the emission of HM is practically zero.

Adsorption on activated coke is too expensive. In the case of the Polvitec installed in a Swiss cement plant only the financial contribution of the communities burning their sewage sludge in the kiln, the fees for burning other alternative fuels in the kiln and the complex problem with different emission components made the project ecologically and economically feasible.

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7.7 CONTROL OF FUGITIVE DUST EMISSIONS

7.7.1 INTRODUCTORY REMARKS

Fugitive emission sources are mainly related to:

- storage of raw materials and clinker;
- handling of raw materials and clinker;
- vehicle traffic at the manufacturing site.

For new installations the prevention of fugitive dusts emissions is an essential element of the project, which has to be built with the aim of minimising any possible source of fugitive dust. From this point of view simple and linear lay-out is the best. For existing installations the reduction of fugitive dust is not always possible or easy to achieve through simple methods and major modifications of plant lay-out are often required. Proper and complete maintenance of the installation has always the indirect result of reducing fugitive dust, through the reduction of air leakage and spillage points. The use of automatic devices and control systems also helps in fugitive dust reduction, as well as continuous trouble-free operations.

7.7.2 AVAILABLE TECHNIQUES FOR FUGITIVE DUST ABATEMENT

According to the different dust generation mechanisms we consider the following control measures:

- open piles wind protection;
- water spray and chemical dust suppressors;
- paving, road wetting and housekeeping;
- mobile and stationary vacuum cleaning equipment;
- ventilation and collection in fabric filters;
- closed storage with automatic handling system.

Open Piles and Wind Protection

Granted that storage piles of dusty materials placed in a temporary outdoor location should be avoided, it is possible to reduce fugitive dust emissions from open piles using properly designed wind barriers.

These are essentially natural or artificial obstacles behind which the storage pile can be hidden to reduce the force of wind and its erosion effect. The barrier can be completed with rows of evergreen trees.

This control measure can be improved if it is coupled with particular precautions taken during pile formation, such as lowering the height of pile, compressing the surface, using wetting agents.

Water Spray and Chemical Dust Suppressors

Some operations such as truck dumping, or material transfer from a conveying system to another one or to a pile in a store may produce fugitive dust to varying extent. When the point where the dust comes from is well localised a water spray injection system can be installed.

The humidification of dust particles through the contact with fine water droplets aids agglomeration and so helps dust to settle.

A wide variety of chemical agents is also available to improve the overall efficiency of the water spray, with production of dilute solutions or foams.

The positive effect of water spray is strongly affected by good positioning of spray nozzles, to be placed as close as possible to dust source; liquid flow rate should also be controlled at minimum level.

Paving, Road Wetting and Housekeeping

The aim is evidently to prevent settled dust being transformed to suspended particulate matter. Areas likely to be used by lorries should be paved when possible and the surface should be maintained as clean as possible. Specific lanes must be indicated and vehicle speed limited. Wetting the roads can be considered to reduce dust emissions especially in dry season.

In conjunction with these measures good housekeeping practices should be used in order to avoid fugitive dust emissions as far as possible.

Mobile and Stationary Vacuum Cleaning

During maintenance operations or in the case of trouble with conveying systems, spillage of materials can take place. To prevent the formation of fugitive dust during removal operations, vacuum systems should be used. A high pressure fan, connected with a bag filter, maintains high negative pressure in a pipe network, with inlets to branch pipes being fitted with valves. By opening the appropriate valve it is possible to suck up dust and even aggregates, which are finally collected in a bag filter.

New buildings can be easily equipped with this kind of system, while existing buildings are normally better fitted with mobile systems and flexible connections.

The material recovered during a cleaning operation can be recycled in the process.

This equipment reduces a lot of heavy manual operations.

Ventilation and Collection in Fabric Filters

To keep in closed conveying systems, or bins or silos, all the materials handled within the process is a primary measure to be coupled with systems able to maintain them under negative pressure.

The suction air for this purpose must be then dedusted by a fabric filter before being emitted into the atmosphere.

Best practical engineering design should be applied to optimise the efficiency of this control technique, common to many industrial sectors, in order to reduce air leakage, energy loss and the volume of air to be dedusted.

A fabric filter of the jet pulse cleaning type fits this kind of application very well due to its flexibility in flow rate (0.5 to 10 m^3/s or more); in dust burden (few mg/m^3 to hundreds g/m^3), in quality of available fabric and in its geometrical arrangement and dimensions. These characteristics make this kind of filter suitable even for mobile installations, such as stacker and reclaimer systems. For normal operation at ambient temperature polyester or acrylic fabric should be used; when wet materials are handled specific humidity resistant fabrics are available, as well as heat resistant fabrics when hot materials, such as clinker, are treated.

Care must be given to the collected dust discharge design or conveying systems. The dust has to be returned to a point just after the dedusted zone along the conveying system, to avoid dust recycling.

Closed Storage with Automatic Handling System

Clinker silos and fully automated raw material storage are considered today the most efficient solution to solve the problem of fugitive dust generated by high volume stocks.

Plenty of different technical solutions have been developed to deal with specific characteristics of almost every kind of material, from very wet and sticky clays to dry and dusty sands.

Closed fully automated stores for raw material are more complex because, generally, they must handle many different raw materials, possibly providing for prehomogeneisation of them or between them.

While clinker silos can be fitted in existing plants when enough room is available, the same is not generally possible for automated raw material storage, because the whole lay-out of the plant may need to be greatly modified.

These types of storage are equipped with one or more fabric filters to prevent fugitive dust formation in loading and unloading operations.

7.8 CONTROL OF NOISE EMISSIONS

7.8.1 INTRODUCTORY REMARKS

Any operations concerning cement production must be performed having regard to the relevant objectives of any prevailing regulations which include noise control.

Noise reduction is claimed to be a growing challenge for cement manufacturing in the future, maybe not because of the hi-tech demands for existing plants but certainly because of the high investment costs and difficulties faced in carrying out major modifications.

Differently from airborne emissions the evaluation of the noise to the environment depends very much on the immediate neighbourhood of a plant. Thus noise reduction measures have to be discussed site specifically taking into account e.g. the noise impacts to the nearest residential area.

In practice, the best noise reduction techniques, in the majority of cases, can be adopted only in new plants. This points out the relevancy of good acoustic design, starting from the preliminary study of plant lay-out, and the right choice of machinery: the most effective noise reduction is made at source.

In existing plants, solutions depend on space availability, conditions of previous structures and even architectural considerations.

BAT listed below should be adopted to attain the above mentioned objectives. Efficiency is based on the reduction of noise in dB.

Air-flow generated noise, machine generated noise and residual noise escaping from buildings are outlined as the three major types of noise source.

7.8.2 AIR-FLOW GENERATED NOISE

This applies to stack, fan inlet/outlet or air intake and ventilation units. Generally, air flowing in a duct, pipe or stack generates noise whose sound power level depends on cross section, flow contours and speed. Flow speed higher than 15-20 m/s generates itself a noise which has to be reduced. If a fan or compressor adds its mechanical contribution the sound power level get louder and is characterised with the typical frequency spectrum of the machine, depending on its performance in pressure and flow.

Primary measures to control noise at source, such as good sizing of inlet/outlet ducts to reduce speed, or modification of existing machines (e.g. fan with aerofoil blades and low rpm), can be only moderately effective. Installation of silencers may be the only available technology for the reduction of air-flow generated noise. Silencers must be installed as close as possible to the noise source and as far as possible from the noise outlet, having regard to maintaining air speed after the reduction device.

Silencers can be mainly of three types: simple **lining of ducts** with deadening materials as rockwool or glasswool, **parallel baffles silencers and "plenum" silencers**. **Mufflers** used for the inlet/outlet of compressors are normally designed specifically by machine suppliers. Simple linings with deadening materials are suitable for many purposes and cause very low pressure drop, but require, with an average reduction efficiency of 1 – 2 dB/m, installation over a considerable length. Parallel baffles silencers are suitable for ducts with flow rates up to 250,000 m^3/h with an average reduction efficiency of 10 – 15 dB/m, but for high flow rate could cause rather high pressure drop (40 – 60 mmWG). In any case for very high flow rate "plenum" silencers (a series of expansion chambers lined with deadening materials) are preferable, because of high noise reduction efficiency and very low pressure drop (max. 20 mmWG), but they have higher investment costs.

7.8.3 MACHINE GENERATED NOISE

This regards mainly process machines (crushers, grinding mills), fan casings, motors/couplings and compressors. Compressors are normally coupled with an insulating box designed specifically by machine suppliers.

Otherwise noise can, in some cases, be reduced primarily by choosing a less noisy machine. In some other cases noise can be reduced by **insulating the machine** with soundproof materials or enclosing the machine inside a **soundproof box**. In any case it is necessary to provide a proper cooling device, which must be sound-insulated too, in order to dissipate heat.

Insulating materials used are multilayer rockwool (up to 120 kg/m^3) or glasswool (up to 80 kg/m^3) boards (up to 120 mm) combined, for heavy duty fans, with a lead plate (1 – 2 mm).

7.8.4 NOISE ESCAPING FROM BUILDINGS

When the above mentioned insulation measures are not possible, because of space availability or plant lay-out, or do not work well enough, the only solution is to enclose the machine in a building or to create curtain walls to reduce sound propagation. Also in this case it may be necessary to install a cooling device, which must be sound-insulated too, in order to dissipate heat. For these cooling devices, the same precautions adopted for air inlet/outlet should be utilised.

Many kind of materials can be used to build curtain walls, with a common recommendation being to avoid solid transmission of vibrations from machinery to the floor or to the structure of the building. If this happens, the whole façade could be made to vibrate as a loudspeaker membrane, generating rather low frequency sound levels but very high sound power levels taking into account the total vibrating surface.

The sound-proofing efficiency of a curtain depends proportionally on its specific mass (kg/m^3) and sound frequency. Thus efficiency seems to be higher for high frequency, but every material has its own critical frequency, where efficiency drops because of its intrinsic rigidity.

Concrete blocks or hollow bricks, because of their rigidity, give best noise reduction beyond an overall thickness of 200 mm (150 kg/m^2).

Prefab concrete, for the same reason, must preferably be thicker than 80 mm (175 kg/m^2).

Windows must be made of 30 kg/m^2 laminated glass, two glass sheets (7 and 3 mm) joined by a plastic layer (1 mm).

“**Sandwich boards**” made of metal plates/rockwool (glasswool), dimensioned depending on required noise reduction, can be sound proofing (25 – 50 kg/m^2) and deadening (25 kg/m^2 with an internal 40% perforated iron plate).

Main doors and gates must be considered as “sandwich boards”, taking care of sealing.

7.9 REDUCTION OF ODOURS

7.9.1 INTRODUCTORY REMARKS

To eliminate misunderstanding, odour should be used to define either the perception of smell or that which is smelled and odorant should be defined as any odorous substances. Odour intensity, then, is the magnitude of the olfactory sensation produced on exposure to an odorant. Odour control is a term that can be used to describe any process that makes olfactory experiences more acceptable to people. The perceptual route to this objective is usually, but not always, the reduction of odour intensity.

When, referring to a cement plant operation, the reduction of odour intensity is accomplished by removal of odorants from the atmosphere, the process is equivalent to gas, vapour and even particles abatement, but with some special considerations. These include problems related to the need to attain very low concentration, often approaching threshold levels, uncertainties with regard to the reliability of sensory or chemical analysis and difficulties associated with diffuse or sporadic sources.

The olfactory identification of an odorant is based on two parameters: the odour detection threshold and the odour index.

Odour detection threshold is defined as the odorant concentration which is detected as often as not over a series of presentations. 50% and 100% occurrence of recognition of an odorant give respectively the 50% and 100% detection threshold, which are the two parameters normally available in literature.

Odour index takes into account also the evaporation as a ratio between vapour pressure and 100% detection threshold of odorant.

In general gases and vapours are odorous. The relatively few odourless or practically odourless exceptions include 0_2, N_2, H_2, H_2O, H_2O_2, CO, CO_2, CH_4, NO and the noble gases. Odours can be also associated with airborne particulate matter, as some particles can stimulate the sense of smell because the particles themselves are volatile or because they are desorbing a volatile odorant.

7.9.2 STACK EMISSIONS

Odorous chemicals released by a cement plant are mainly SO_2 and, at a lower level, NH_3 and organics, all with a 50 – 100% detection threshold window ranging from 100 ppt to 10 ppm.

7.9.3 DIFFUSE EMISSIONS

The problem of diffuse odorous emissions is related mainly to fuel unloading and stocking facilities.

Good management of unloading operations and storage purging is required. Careful maintenance of fuel distribution network helps to avoid spillage and related odours.

7.10 REDUCTION OF VIBRATION

7.10.1 INTRODUCTORY REMARKS

Recent years have seen the rise of vibration problems associated with structures which are more delicate and intricate, and machines which are faster and more complex. The problems have been coupled with demands for lower running costs and increased efficiency. Moreover vibrations now stand out as potential source of nuisance outside as well as inside the industrial site.

Vibration intensity is measured as speed (m/s) or acceleration (m/s^2).

Actually few national regulations set up standards for vibration of structures or for maximum vibrations nuisance to people. Solid transmission of vibrations from machinery to the floor or to the structure of industrial building is rather seen as a potential source of noise as shown in Chapter 7.8. Examples of potential causes of vibration are roller mill vibration or clinker silo vibration.

7.10.2 ROLLER MILLS VIBRATIONS

All machines characterised by high rotation speed and mechanical stress of structure potentially generate vibrations. Good practice is to install them on vibration-dampening mounts and a concrete foundation. If this measure does not work correctly it may be necessary, involving great investment, to isolate the foundation of the machine in order to avoid transmission of vibration to the rest of structure and to let it vibrate independently. These are actually the available technologies.

7.10.3 CLINKER SILOS VIBRATIONS

Clinker silo vibration, a very rare event, is avoidable or at least reducible through correct sizing of structure, control of clinker constancy of quality and temperature, good distribution and a number of extraction hoppers.

7.11 CONTROL OF RELEASES TO SURFACE WATERS

7.11.1 INTRODUCTORY REMARKS

Cement production does not normally involve significant quantities of liquid wastes, surplus water usually being limited to surface run off and process/cooling water only. However process waters, site drainage waters, emergency fire water and chemically contaminated waters should, where appropriate, be contained and where necessary treated before release to controlled waters or sewer.

7.11.2 PROCESS WATERS

Waters used in the process to make up slurry or granulated meal and to operate spray conditioning towers are completely evaporated and then emitted at the stack.

7.11.3 COOLING WATERS

Mechanical cooling waters are recycled after use and, if necessary, restored. This closed system, if not yet operating, is quite easy to set up also in existing plants. However cooling water should be recycled within the process from which it issues. Where that is not practicable, it should be recycled to another part of the process which has a lower water quality requirement.

7.11.4 LABORATORY WATER RELEASE

Water released from the site chemical laboratory may be contaminated by chemicals such as acids or alkalis. It should be treated at least in a neutralisation tank, in order to control the resultant pH. It is to be said that the water consumption of a chemical laboratory is more or less 10 – 20 m^3/day and is continuously being reduced because of substitution of the traditional chemical analysis methods with physical methods.

7.11.5. STORM WATER

Rainwater should be collected and subsequently treated every time it does not fall directly on the soil. These waters may be, because of spillage of fuels, motor oils and because of vehicle traffic which generates fugitive dust, contaminated by oils, greases, fuels or simply suspended particles. Good housekeeping of pavements is the first method to control pollution.

Moreover, settling and/or oil removal tanks may be installed before the release to water. The size of these devices should be specified carefully in order to handle the most likely emergencies.

Also areas where spillages are most likely, such as storage tanks, should be bunded. Rainwater collected should not be disposed of via surface water drains or soakaways and the composition of any wastes collected should be checked prior to treatment or disposal. Bunds should:

- be impermeable;
- have no outlet;
- drain to a sump;
- be designed to catch leaks from any likely failure of tank or its fittings;
- be hydraulically tested on initial construction and subsequently where there is any doubt about their integrity;
- have a suitable capacity related to the tank;
- where not frequently inspected, fitted with a high level probe and appropriate alarm;
- have the fill points within the bund where possible.

7.11.6 SEWER DISCHARGE

Sewer discharge from office or industrial facilities activities should be treated as any other sewer discharge from residential buildings.