NATIONAL POLICY ON HIGH TEMPERATURE THERMAL WASTE TREATMENT AND CEMENT KILN ALTERNATIVE FUEL USE

CEMENT PRODUCTION TECHNOLOGY IN SOUTH AFRICA AND AN EVALUATION OF THEIR ABILITY TO CO-PROCESS AFRs AND TREAT HAZARDOUS WASTES
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Acronyms and abbreviations - General

AFR  Alternative fuel and raw material
APCD  Air pollution control device
ATSDR  Agency for Toxic Substances and Disease Registry
AWFCO  Automatic waste feed cut-off
BAT  Best available techniques
BEP  Best environmental practise
BHF  Bag house filter
BIF  Boiler and industrial furnace
Btu  British thermal unit
°C  Degree Celsius
CAA  Clean Air Act
CEMBUREAU  European Cement Association
CEMS  Continuous emissions monitoring system
CEN  European Standardisation Organisation
CFR  Code of Federal Regulations
CKD  Cement kiln dust
Cl₂  Molecular chlorine
CSI  Cement Sustainability Initiative
DL  Detection limit
CO  Carbon monoxide
CO₂  Carbon dioxide
DE  Destruction efficiency
Dioxins  A term/abbreviation for polychlorinated dibenzodioxins and polychlorinated dibenzofurans (see also PCDD/Fs)
DRE  Destruction and removal efficiency
Dscm  Dry standard cubic meter
EC  European Commission
EF  Emission factor
e.g.  For example
EPA  Environmental Protection Agency
EPER  European Pollutant Emission Register
ESP  Electro static precipitator
EU  European Union
FF  Fabric filter
g  Gram
GC-ECD  Gas chromatography with electron capture detector
GC-MS  Gas chromatography with mass spectrometry
HAPs  Hazardous air pollutants
HCB  Hexachlorobenzene
HCl  Hydrogen chloride
HF  Hydrofluoric acid
i.e.  That is
IPPC  Integrated Pollution Prevention and Control
I-TEF  International Toxicity Equivalency Factor
I-TEQ  International Toxic Equivalent
IUPAC  International Union of Pure and Applied Chemistry
J  Joules
K  (Degree) Kelvin
kcal  Kilocalorie (1 kcal = 4.19 kJ)
kg  Kilogramme (1 kg = 1000 g)
kJ  Kilojoules (1 kJ = 0.24 kcal)
kPa  Kilo Pascal (= one thousand Pascal)
L  Litre
lb  Pound
LCA  Life cycle analysis
LOD  Limit of detection
LOI  Loss of ignition
LOQ  Limits of quantification
m$^3$  Cubic meter (typically under operating conditions without
normalization to, e.g., temperature, pressure, humidity)
MACT  Maximum Achievable Control Technology
MJ  Mega joule (1 MJ= 1000 kJ)
mg/kg  Milligrams per kilogram
MS  Mass spectrometry
mol  Mole (Unit of Substance)
Na  Sodium
NA  Not applicable
NAAQS  National Ambient Air Quality Standards
NATO  North Atlantic Treaty Organisation
ND  Not determined/no data (in other words: so far, no measurements available)
NESHAP  National Emission Standards for Hazardous Air Pollutants
ng  Nanogram (1 ng = 10^-9 gram)
Nm³  Normal cubic metre (101.3 kPa, 273 K)
NH₃  Ammonia
NOₓ  Nitrogen oxides (NO+NO₂)
NR  Not reported
N-TEQ  Toxic equivalent using the Nordic scheme (commonly used in the Scandinavian countries)
OECD  Organisation for Economic Co-operation and Development
O₂  Oxygen
PAH  Polycyclic aromatic hydrocarbons
PCA  Portland Cement Association (USA)
PCB  Polychlorinated biphenyls
PCDDs  Polychlorinated dibenzodioxins
PCDFs  Polychlorinated dibenzofurans
PCDD/Fs  Informal term used in this document for PCDDs and PCDFs
PIC  Product of incomplete combustion
pg  Picogram (1 pg = 10^-12 gram)
PM  Particulate matter
POHC  Principal organic hazardous constituent
POM  Polycyclic organic matter
POP  Persistent organic pollutants
ppb  Parts per billion
ppm  Parts per million
ppmv  Parts per million (volume basis)
ppq  Parts per quadrillion
ppt  Parts per trillion
ppt/v  Parts per trillion (volume basis)
ppm  Parts per million
QA/QC  Quality assurance/quality control  
QL  Quantification limit  
RACT  Reasonably Available Control Technology  
RCRA  Resource Conservation and Recovery Act  
RDF  Refuse derived fuel  
RT  Residence time  
sec  Second  
SINTEF  Foundation for Industrial and Scientific Research of Norway  
SNCR  Selective non catalytic reduction  
SiO₂  Silicon dioxide  
SCR  Selective catalytic reduction  
SO₂  Sulfur dioxide  
SO₃  Sulfur trioxide  
SOₓ  Sulfur oxides  
SQL  Sample quantification limit  
SRE  System removal efficiency  
t  Tonne (metric)  
TCDD  Abbreviation for 2,3,7,8-tetrachlorobidenzo-p-dioxin  
TCDF  Abbreviation for 2,3,7,8-tetrachlorobidenzofuran  
TEF  Toxicity Equivalency Factor  
TEQ  Toxic Equivalent (I-TEQ, N-TEQ or WHO-TEQ)  
TEQ/yr  Toxic Equivalents per year  
THC  Total hydrocarbons  
TOC  Total organic carbon  
tpa  Tonnes per annum (year)  
TRI  Toxics Release Inventory  
TSCA  Toxics Substances Control Act  
UK  United Kingdom  
US  United States of America  
US EPA  United States Environmental Protection Agency  
VDZ  Verein Deutsche Zementwerke  
VOC  Volatile organic compounds  
VSK  Vertical shaft kilns  
WBCSD  World Business Council for Sustainable Development

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<table>
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<th>Abbreviation</th>
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<tr>
<td>WHO</td>
<td>World Health Organization</td>
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<tr>
<td>y</td>
<td>Year</td>
</tr>
<tr>
<td>% v/v</td>
<td>Percentage by volume</td>
</tr>
<tr>
<td>µg/m³</td>
<td>Micrograms per cubic meter</td>
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<td>µg</td>
<td>Microgram</td>
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## Glossary

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<td>AFR</td>
<td>Alternative fuel and raw materials, often wastes or secondary products from other industries, used to substitute conventional fossil fuel and conventional raw materials.</td>
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<td>Cementitious</td>
<td>Materials behaving like cement, i.e. reactive in the presence of water; also compatible with cement.</td>
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<tr>
<td>Co-processing</td>
<td>Utilisation of alternative fuel and raw materials in the purpose of energy and resource recovery.</td>
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<tr>
<td>Dioxins</td>
<td>Together with PCDD/Fs used as term/abbreviation for Polychlorinated dibenzodioxins and Polychlorinated dibenzofurans in this document</td>
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<tr>
<td>Kiln inlet/outlet</td>
<td>Were the raw meal enters the kiln system and the clinker leaves the kiln system.</td>
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<tr>
<td>Pozzolana</td>
<td>Pozzolanas are materials that, though not cementitious in themselves, contain silica (and alumina) in a reactive form able to combine with lime in the presence of water to form compounds with cementitious properties. Natural pozzolana is composed mainly of a fine, reddish volcanic earth. An artificial pozzolana has been developed that combines a fly ash and water-quenched boiler slag.</td>
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1. **Cement kiln technology – an introduction**

Cement clinker is the intermediate product in the manufacture of the hydraulic binding agent Portland cement. By means of a single thermal treatment, a mixture of non-hydraulic naturally occurring minerals – limestone/chalk, quartz, clays and feldspars – is transformed into an intimate mixture of hydraulically active minerals alite, belite, aluminate and ferrite.

This thermal treatment of heating and cooling which is responsible for this transformation is called clinkering and involves peak material temperatures of 1450° C. The thermal process contains the following major process steps:

- 20 to 900° C, with removal of all kinds of H₂O, heating up of material;
- 600 to 900° C, with the calcination (CO₂ driven out);
- 800 to 1450° C, with the completion of reactions, recrystallisation of alite and belite.

Ever since the rotary kiln was introduced around 1895, it became the central part of all modern clinker producing installations. The previously used vertical shaft kiln is still used for production of hydraulic lime, but only in few countries for cement clinker in small scale plants.

The first rotary kilns were long wet kilns, where all of the heat consuming thermal process takes place in a rotary kiln with a length to diameter (L/D) ratio of around 30 to 38, with several support stations.

With the introduction of the dry process, optimisation led to technologies which allowed drying, preheating and calcining to take place in a stationary installation instead of the rotary kiln.
The principle of the rotary kiln, invented by Frederick Ransome in England (patented in 1895), is still the central part for all industrial cement clinker production lines. No other type of equipment has been found to suit the needs of the sintering process better, where the kiln charge is partially liquid and sticky.

The rotary kiln consists of a steel tube with a length to diameter (L/D) ratio between 10 and 38, supported by two to seven or more support stations. The inclination of 2.5 to 4.5% together with a drive to rotate the kiln about its axis at 0.5 to 4.5 revolutions per minute, allows for a slow internal material transport.

In order to withstand the very high peak temperatures (gas: 2000° C, material: 1450° C), the entire rotary kiln is lined with different types of heat resistant bricks (refractories). Most long and some short kilns are equipped with internals (chains, crosses, lifters) to improve heat transfer.

Major cost items of kiln operation are consumption of refractories and internals (mainly chains) as well as general maintenance such as alignment of support stations and girth drives. Other critical areas are the seals between the rotary kiln and the stationary installation at both ends.

One common property of all rotary kiln systems is the long retention time in the high temperature zone of gas and material.

The major environmental impact of cement kiln systems can be summarised as follows:

- emission of combustion gas, CO₂, vapour, dust, air pollutants and noise;
- generation of dust (in some cases);
- consumption primarily of combustibles, but also of power, refractories and steel;
- the inherent potential for environmentally sustainable elimination of a large variety of wastes.
1.1 Long rotary kilns

Long rotary kilns can be fed with slurry, crushed filter cakes, nodules or dry meal and are thus suitable for all process types.

The largest long kilns have L/D of 38, diameter of 7.5 m and length of 230 m. Such huge units produce around 3600 t/d using the wet process (Belgium, US, former Soviet Union).

Long rotary kilns are designed for drying, preheating, calcining and sintering, so that only the feed system and cooler have to be added.

1.1.1 Long wet kilns

Wet process kilns, used since 1895, are the oldest type of rotary kilns for producing cement clinker. Because homogenisation was easier to perform with liquid material, wet raw material preparation was initially applied. Wet kiln feed contains typically 30 to 40% of water which is required to maintain liquid properties of the feed. This water must then be evaporated in the specially designed drying zone at the inlet section of the kiln where a significant portion of the heat from fuel combustion is used.

This technology has high heat consumption with the resulting emission of high quantities of combustion gas and water vapour.

1.1.2 Long dry kilns with chains

Long dry kilns were developed in the US based on batch type dry homogenising systems for raw material preparation. Due to their simplicity, they became popular and were used for about 50% of the installed capacity. Because of the high fuel consumption, particularly without heat exchanging internals, only few of them have been installed in Europe.
High heat consumption leads also to high kiln exit gas temperature requiring water injection before the ID fan. Therefore numerous long dry kilns have been equipped with dedusting cyclones making them actually into one-stage suspension preheaters.

Unlike with the wet kiln, dust return is technically easy to arrange, but often results in high external dust cycles.

Units of up to 5000 t/d with kiln dimensions of LxD = 7.5x260m were projected, however only up to 2000 t/d kilns were actually built.

1.2 Grate preheater kilns

Grate preheater technology, perhaps better known as Lepol kilns, was invented in 1928 and represented the first approach to let part of the clinkering process take place in an innovative piece of equipment allowing the reduction of the rotary kiln to a L/D ratio of 11 to 16.

Nodules made from dry meal on a nodulizer disc (semi-dry process) or from wet slurry filter cakes in an extruder (semi-wet process) are fed onto a horizontal travelling grate where mainly preheating takes place.

In order to achieve optimum thermal efficiency, the semi-wet grate preheaters can be equipped with triple pass gas systems and cooler waste air is used for raw material drying.

Maximum unit size built is 3300 t/d for a semi-wet kiln system.

1.3 Suspension preheater kilns

A significant development was the invention of the suspension preheater in the early 1930s. Preheating and even partial calcination of the dry raw meal takes place by maintaining the
meal in suspension with hot gas from the rotary kiln. Considerably larger contact surface allows almost complete heat exchange, at least theoretically. Following different philosophies, a variety of solutions were initially installed by the cement kiln suppliers.

1.4 Shaft preheater kilns

Shaft preheaters were built in numerous cases when suspension preheater technology was introduced. Due to its theoretically superior heat exchange (according to the counter current principle), several suppliers applied that technology. However, due to the difficulty of even distribution of meal to gas, actual performance was far worse than expected, and the technology using only shaft stages was eventually abandoned in favour of hybrid systems with cyclone stages or pure multi-stage cyclone preheaters.

Other than the pure shaft preheaters, which were usually equipped with dedusting cyclones, there was also a variety of hybrids with both shaft and cyclone stages. Many of those hybrids are still in operation, however most of them have been converted to pure cyclone preheaters.

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

Typical capacities of shaft preheater kilns were up to 1500 t/d, whereas hybrid systems can produce 3000 t/d and more.

1.5 Two stage cyclone preheater kilns

The cyclone preheater with 2 stages was often applied to convert wet kilns to dry process, or for new plants with high inputs of circulating elements (sulfur, chloride, alkalis) before kiln gas bypass technology was developed.
The 450 to 500° C hot exhaust gas must be cooled with air before entering the kiln ID fan and can then be used for raw material drying.

1.6 Four stage cyclone preheater kilns

The four stage cyclone preheater kiln system was standard technology in the 1970s. Many plants were built in the 1000 to 3000 t/d range, some of them equipped with planetary coolers.

The exhaust gas with a temperature of around 330° C is normally used for raw material drying.

Pressure drop across the preheater is about the same as for a modern 5-stage preheater with precalciner because of the older cyclone design used in earlier years.

When the meal enters the rotary kiln, calcination is already about 30% completed.

In earlier years, insurmountable problems were encountered with four stage preheaters where excessive inputs of circulating elements (chlorides, sulfur, alkalies) from feed and/or fuel occurred. Highly enriched cycles of those elements lead to build-ups in cyclone and duct walls frequently causing blockages and kiln stops of several days duration. Only the kiln gas bypass solved the problem later on, however at cost of higher heat and material consumption as well as the need for dust disposal.

Almost all four stage suspension preheaters have a rotary kiln with three supports, which has been the standard concept after about 1970. Sizes from 3.5 to 6 m diameter have been built with L/D ratios being in the range of 13 to 16.

Mechanically simpler than the long wet and dry kilns, it is probably the most widely applied kiln type today.
1.7 Four to six stage cyclone preheater kilns with precalciner

Kiln systems with 5 cyclone preheater stages and precalciner (PC) are considered standard and BAT technology for ordinary new plants.

The size of a new plant is primarily determined by predicted market developments, but also by economy of scale. Typical unit capacity for new plants in Europe today is 3000 to 5000 t/d. Technically, larger units with up to 15,000 t/d are possible, and three 10,000 t/d kilns are currently in operation in fast growing Asian markets.

A 5-stage preheater-precalciner kiln with 3000 t/d is used as basis for the relative performance figures.

Earlier precalciner systems had only 4 preheater stages with accordingly higher exhaust gas temperature and fuel consumption.

Where natural raw material moisture is low, 6 stage preheaters can be the preferred choice, particularly in combination with bag filter dedusting.

Where excessive inputs of circulating elements exist, a kiln gas bypass is required to maintain continuous kiln operation. However, due to the different gas flow characteristics, a bypass has a much higher efficiency than a straight preheater kiln.

In spite of the fact that the meal enters the kiln 75 to 95% calcined, most precalciner kilns are still equipped with a rotary kiln with a calcining zone, i.e. with a L/D of 13 to 16 like the straight preheater. Largest preheater/precalciner kilns with three supports are in operation for 10,000 t/d in Thailand, with DxL of 6.0 x 96 to 100m.
2. **Consumption of energy and best available techniques for production – a summary**

Cement manufacturing is an energy intensive process. The specific thermal energy consumption of a cement kiln varies between 3000 and 7500 MJ per ton of clinker, depending on the basic process design of the plant.

The dominant use of energy in cement manufacture is as fuel for the kiln. The main users of electricity are the mills (raw grinding, finish grinding, cement mills and coal mills) and the exhaust fans (kiln/raw mill and cement mill) which together account for more than 80% of electrical energy usage. On average, energy costs, in the form of fuel and electricity, represent 50% of the total production cost involved in producing a tonne of cement. Electrical energy represents approximately 20% of this overall energy requirement.

The theoretical energy use for the burning process (chemical reactions) is about 1700 to 1800 MJ/tonne clinker. The actual fuel energy use for different kiln systems is in the following ranges (MJ/tonne clinker):

- about 3000 for dry process, multi-stage cyclone preheater and precalciner kilns;
- 3100-4200 for dry process rotary kilns equipped with cyclone preheaters;
- 3300-4500 for semi-dry/semi-wet processes;
- up to 5000 for dry process long kilns;
- 5000-6000 for wet process long kilns;
- 3100-4200 for vertical shaft kilns.
The actual use of energy for the production of one ton of clinker is from 70 to 250 percent higher than the theoretical energy need. This clearly shows the potential for improvement of energy use through upgrades and process optimisation.

The specific electrical energy consumption ranges typically between 90 and 130 kWh per ton of cement.

2.1 Options for resource reduction

A technique to reduce energy use and emissions from the cement industry, expressed per unit mass of cement product, is to reduce the clinker content of cement products. This can be done by adding fillers, for example sand, slag, limestone, fly-ash and pozzolana, in the grinding step. In Europe the average clinker content in cement is 80-85 %. Many manufacturers of cement are working on techniques to further lower the clinker content. One reported technique claims to exchange 50% of the clinker with maintained product quality/performance and without increased production cost. Cement standards define some types of cement with less than 20 % clinker, the balance being made of blast furnace slag.

Ordinary Portland cement is composed of 95-100 % of Clinker. Portland pozzolana cement II B-P however contains only 65-79 % of clinker, i.e. to produce 1 ton of II/B-P you need 650 kg of clinker compared to 950 kg of clinker for the ordinary Portland cement. This is not only saving raw materials but also reduces the CO₂ emission which will related to the same ratio, i.e. 950/650 = 1.46 times more CO₂ emission for the production of ordinary Portland cement compared to the II/B-P cement.

Recycling of collected dust to the production processes lowers the total consumption of raw materials. This recycling may take place directly into the kiln or kiln feed (alkali metal content being the limiting factor) or by blending with finished cement products.

The use of suitable wastes as raw materials can reduce the input of natural resources, but should always be done with satisfactory control on the substances introduced to the kiln process.
Kiln systems with 5 cyclone preheater stages and precalciner are considered standard technology for ordinary new plants, such a configuration will use 2900-3200 MJ/tonne clinker. To optimise the input of energy in other kiln systems it is a possibility to change the configuration of the kiln to a short dry process kiln with multi stage preheating and precalcination. This is usually not feasible unless done as part of a major upgrade with an increase in production. The application of the latest generation of clinker coolers and recovering waste heat as far as possible, utilising it for drying and preheating processes, are examples of methods which cut primary energy consumption.

Electrical energy use can be minimised through the installation of power management systems and the utilisation of energy efficient equipment such as high-pressure grinding rolls for clinker comminution and variable speed drives for fans.

Energy use will be increased by most type of end-of-pipe abatement. Some reduction techniques will also have a positive effect on energy use, for example process control optimisation.

2.2 Best available techniques for cement production

Technological advancement of the cement industry will concentrate on the further development of new technology, on the utilization of secondary materials and other supplementary cementitious materials. In recent years, improvement of cement production lines with precalcining systems includes the new homogenization technology, new preheating and precalcining systems with the capacity of up to ten thousand tons of cement per day, various new types of crushing and grinding systems, new operation and management systems, new environmental protection measures such as the use of new bag dust collector and low NOₓ burner. The utilization of secondary materials and supplementary cementitious materials may save huge amounts of natural resources.

Dry preheater/precalciner kilns are regarded to be the best available techniques (BAT) and to constitute the Best Environmental Practise (BEP). These technologies are also the most
economically feasible option, which constitutes a competitive advantage and thereby contributes to gradually phase out older, polluting and less competitive technologies.

For new plants and major upgrades the best available techniques for the production of cement clinker is a dry process kiln with multi-stage preheating and precalcination. A smooth and stable kiln process, operating close to the process parameter set points, is beneficial for all kiln emissions as well as the energy use. This can be obtained by applying:

- Process control optimisation, including computer-based automatic control systems.

- The use of modern fuel feed systems.

• Minimising fuel energy use by means of:

  - Preheating and precalcination to the extent possible, considering the existing kiln system configuration.

• Careful selection and control of substances entering the kiln can reduce emissions and when practicable, homogenous raw materials and fuels with low contents of sulfur, nitrogen, chlorine, metals and volatile organic compounds should be selected.
3. Fuels storage, preparation and firing

Three different types of conventional or fossil fuels are used in cement kiln firing in decreasing order of importance:

- pulverized coal and petcoke;
- (heavy) fuel oil;
- natural gas.

Conventional fuels are today increasingly substituted by non-conventional, non-fossil (gaseous, liquid, pulverized, coarse crushed) alternative (or secondary) fuels for resource efficiency and economical reasons.

In order to keep heat losses at minimum, cement kilns are operated at lowest reasonable excess oxygen factors. This requires highly uniform and reliable fuel metering as well as the fuel being present in a form which allows for easy and complete combustion (fuel preparation process and fuel storage).

These conditions are fulfilled by all pulverized, liquid and gaseous fuels, be it conventional or alternative fuels. The main fuel input (65 – 85%) has therefore to be of this type whereas the remaining 15 – 35% may be fed in coarse crushed or lumpy form.

Fuel feed points to the kiln system are:

- via the main burner at the rotary kiln outlet end;
- via a feed chute at the transition chamber at the rotary kiln inlet end (for lump fuel);
- via fuel burners to the riser pipe;
• via precalciner burners to the precalciner;

• via a feed chute to the precalciner (for lump fuel);

• via a mid-kiln valve to long wet and dry kilns (for lump fuel).

The fuel introduced via the main burner to the hot zone of the rotary kiln therein produces the main flame with flame temperatures around 2000° C. For process optimisation reasons the flame has to be adjustable within limits.

The flame is shaped and adjusted by the so called primary air (10 – 15% of total combustion air) through interaction of the outer axial air ring channel as well as of the conical inner air ring channel of the (main) burner

3.1 Alternative fuels storage, preparation and firing

Alternative fuels can be subdivided into five classes:

• Gaseous alternative fuels, for example coke oven gases, refinery waste gas, pyrolysis gas, landfill gas, etc.

• Liquid alternative fuels, for example low chlorine spent solvents, lubricating as well as vegetable oils and fats, distillation residues, hydraulic oils, insulating oils, etc.

• Pulverized, granulated or fine crushed solid alternative fuels, for example ground waste wood, sawdust, planer shavings, dried sewage sludge, granulated plastic, animal flours, agricultural residues, residues from food production, fine crushed tyres, etc.

• Coarse crushed solid alternative fuels, for example crushed tyres, rubber/plastic waste, waste wood, reagglomerated organic matter, etc.
• Lump alternative fuels, for example whole tyres, plastic bales, material in bags and drums, etc. Gaseous, liquid, and finely pulverized alternative fuels can be fed to the kiln system via any of the feed points mentioned in the previous chapter. Coarse crushed and lump fuels can (with some exceptions) be fed to the transition chamber or to the mid-kiln valve only.

Alternative fuels preparation is usually performed outside the cement plant by the supplier or by specialist organizations. The preparation processes are therefore not dealt with here.

So alternative fuels only need to be stored at the cement plant and then proportioned for feeding them to the cement kiln.

Since alternative fuel supplies tend to be variable in rapidly developing “waste” material markets it is often recommended to design alternative fuel plants as multi-purpose plants from the very beginning.

**Figure 1** Multi purpose plant for liquid AFRs
Figure 2  Multi purpose plant for granulated AFRs

Figure 3  Multi purpose plant for lump AF

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Figure 4 Tyre handling concept
4. Normal emission levels and BAT for emission prevention

Average emission data (long term average values) from European rotary cement kilns in operation are summarised in the table below. The figures given are representative of the ranges within which kilns normally operate. Due to the age and design of the plant, the nature of the raw materials, etc., individual kilns may operate outside these ranges.

Table 1 Long term average emission values from European cement kilns

<table>
<thead>
<tr>
<th>Emission</th>
<th>mg per standard cubic meter [mg/Nm³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust</td>
<td>20 – 200</td>
</tr>
<tr>
<td>NOₓ</td>
<td>500 – 2000</td>
</tr>
<tr>
<td>SO₂</td>
<td>10 – 2500</td>
</tr>
<tr>
<td>Total organic carbon (TOC)</td>
<td>10 – 100</td>
</tr>
<tr>
<td>CO</td>
<td>500 – 2000</td>
</tr>
<tr>
<td>Fluorides</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>Chlorides</td>
<td>&lt; 25</td>
</tr>
<tr>
<td>PCDD/F</td>
<td>&lt; 0.1 [ng/Nm3]</td>
</tr>
<tr>
<td>Heavy metals:</td>
<td></td>
</tr>
<tr>
<td>- class 1 (Hg, Cd, Tl)</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>- class 2 (As, Co, Ni, Se, Te)</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>- class 3 (Sb, Pb, Cr, Cu, Mn, V, Sn) incl. Zn</td>
<td>&lt; 0.3</td>
</tr>
</tbody>
</table>

4.1 Pollution reduction

Major emissions from cement manufacturing plants traditionally are airborne pollutants and powered dust from the kiln and its emissions. Pollutants are mainly particulates from a number of solid processing and handling operations, CO₂, SO₂ and NO₂.
Relatively speaking, SO\textsubscript{2} and NO\textsubscript{2} emissions from cement industries are small, and they represent less than 2\% of the total emitted of these compounds in USA and Europe. In recent years, as a result of advanced control technology and equipment design, such as electrostatic precipitator and bag filter facilities, significant progress has been reached in reducing air emissions from the cement industrial sector. For a new plant today, air pollution emissions are significantly lower than those from typical facilities built 30-40 years ago.

Worldwide, the cement industry produces about 5\% of global manmade CO\textsubscript{2} (Worrell et al, 2001). As the industry produces an equal weight of CO\textsubscript{2} and clinker, any cost imposed on the reduction of CO\textsubscript{2} emission to the atmosphere and any management plan can have a significant impact on the industry’s financial performance. At the present rate of many CO\textsubscript{2} management expenses on the market - in the range of $10 to $25/ton and expected to rise as the public demand its treatment - many cement enterprises will not be able to foot the bill, unless their production capacities are increased and are big enough to bear the cost.

Increasing the use of alternative fuels and raw materials can reduce the use of virgin materials including limestone and petroleum products, and can reduce CO\textsubscript{2} emission and production costs. Alternative and substituted materials as fly ash from power plants, steel mill slugs, and pozzolanic substances can be used in cement to replace some of the limestone, and the quality of the product is not affected in applications.

The following measures are recommended with regards to achieve emission reduction:

1. A well defined emission inventory and reporting process with emission reduction cost estimates;

2. A program for effective communication with the local stakeholders including regulatory personnel;

3. A program to define the emission reduction targets and timetable;

4. In order to win confidence, the industry needs an effective way of monitoring and reporting emissions which can address the safety concerns of the public and product quality concerns of the users.
4.2 Selection of BATs for controlling emissions

Best available techniques can be selected which may be of broadly equal applicability on a new installation for the abatement of the different potential pollutants. For this purpose a new installation is assumed to be a modern dry process kiln of large capacity. Selection of a particular BAT from the clusters of BATs will require evaluation of the factors relevant to a particular case.

Many BATs are only suitable for dry preheater process plants and, where appropriate, references are made to long dry or wet kilns.

High dust emissions, before abatement, are inherent in the process. So too are NO\textsubscript{x} emissions but these can also be influenced by the plant equipment used and the way the plant is operated. The potential for emissions of SO\textsubscript{2}, VOC and dust is primarily dependent on the nature of the raw materials.

Assessment of BAT for existing plants is more complex than for new plants because of the greater variety in the processes and equipment designs in use, space and layout restrictions, etc., as well as the nature of the raw materials. These factors can have a very marked effect on the costs of applying abatement techniques and so the ‘availability’ of a BAT is affected. This means that a wider range of BATs needs to be available and evaluated for each case. It also means that it will often not be economically viable to achieve the emission standards that can be achieved with a new plant.

When evaluating alternative investments at an existing plant, it is important that the remaining economic value of existing pollution equipment is added to the investment cost, if the existing pollution control equipment to be replaced is still efficiently operable.

Emissions from cement manufacture essentially have no cross-media impact as there are rarely significant emissions to land or water. Abatement techniques for emissions to air can be interlinked in two main respects. Control of kiln burning to minimise SO\textsubscript{2} emission can
increase NOx formation, and vice versa, so an operating balance has to be struck. Secondly some techniques may abate more than one type of emission.

The degree of abatement achievable, particularly for primary reduction measures, is not accurately predictable.

Electrostatic precipitators (EPs) and bag filters (BFs) are BAT for dust emissions from both kilns and clinker coolers. For cement mills, efficiently operable EPs continue to be used. When they have to be replaced, as when new abatement equipment has to be built, bag filters are BAT. Costs preclude bag filters from being installed for kilns and coolers of existing installations if electrostatic precipitators are already fitted.

For new kilns, one cluster of BATs for NOx control may be identified as:

- optimisation of clinker burning process;
- expert system for kiln operation;
- low NOx burner;
- multi-stage combustion in pre-calciners (dry kilns only);
- add water to flame or fuel to kiln;
- selective non-catalytic reduction (dry process) (SNCR).

SNCR is distinguished by relatively limited operational experience but abatement efficiency can be quite high. Add water to flame or fuel to kiln may enable the use of alternative fuels to reduce NOx. Optimisation of clinker burning process can also contribute to SO2 reduction. For new kilns an emission level of 500 mg/Nm3 (long term average) should be achievable.
4.3 BAT and BEP for controlling and minimising PCDD/PCDF emission

The following primary measures are considered to be most critical in avoiding the formation and emission of PCDD/F from modern cement kilns and seems in most cases to be sufficient to comply with an emission level of 0.1 ng PCDD/F I-TEQ/Nm³:

✓ Quick cooling of kiln exhaust gases to lower than 200 °C in long wet and long dry kilns without preheating. In modern preheater and precalciner kilns this feature is already inherent in the process design.

✓ Limit or avoid alternative raw material feed as part of raw-material-mix if it includes organics.

✓ No alternative fuel feed during start-up and shut down.

✓ Monitoring and stabilisation of critical process parameters, i.e. homogenous raw mix and fuel feed, regular dosage and excess oxygen.
5. Utilisation of alternative fuels and raw materials in modern cement production – an introduction

In the burning of cement clinker it is necessary to maintain material temperatures of up to 1450 °C in order to ensure the sintering reactions required. This is achieved by applying peak combustion temperatures of about 2000 °C with the main burner flame. The combustion gases from the main burner remain at a temperature above 1200 °C for at least 5-10 seconds. An excess of oxygen – typically 2-3 % – is also required in the combustion gases of the rotary kiln as the clinker needs to be burned under oxidising conditions. These conditions are essential for the formation of the clinker phases and the quality of the finished cement.

The retention time of the kiln charge in the rotary kiln is 20-30 and up to 60 minutes depending on the length of the kiln. The figure below illustrates the temperature profiles for the combustion gases and the material for a preheater/precalciner rotary kiln system. While the temperature profiles may be different for the various kiln types, the peak gas and material temperatures described above have to be maintained in any case. The burning conditions in kilns with precalciner firing depend on the precalciner design. Gas temperatures from a precalciner burner are typically around 1100 °C, and the gas retention time in the precalciner is approximately 3 seconds.

Under the conditions prevailing in a cement kiln – i.e. flame temperatures of up to 2000 °C, material temperatures of up to 1450 °C and gas retention times of up to 10 seconds at temperatures between 1200 and 2000 °C – all kinds of organic compounds fed to the main burner with the fuels are reliably destroyed. The combustion process in the main flame of the rotary kiln is therefore complete. No (hydrocarbon type) products of incomplete combustion can be identified in the combustion gases of the main burner at steady-state conditions.

The cement manufacturing process is an industrial process where large material volumes are turned into commercial products, i.e. clinker and cement. Cement kilns operate continuously all through the year – 24 hours a day – with only minor interruptions for maintenance and repair. A smooth kiln operation is necessary in a cement plant in order to meet production targets and to meet the quality requirements of the products. Consequently, to achieve these
goals, all relevant process parameters are permanently monitored and recorded including the analytical control of all raw materials, fuels, intermediate and finished products as well as environmental monitoring.

With these prerequisites – i.e. large material flow, continuous operation and comprehensive process and product control, the cement manufacturing process seems to be well suited for co-processing by-products and residues from industrial sources, both as raw materials and fuels substitutes and as mineral additions. The selection of appropriate feed points is essential for environmentally sound co-processing of alternative materials, i.e.:

- **Raw materials**: mineral waste free of organic compounds can be added to the raw meal or raw slurry preparation system. Mineral wastes containing significantly quantities of organic components are introduced via the solid fuels handling system, i.e. directly to the main burner, to the secondary firing or, rarely, to the calcining zone of a long wet kiln ("mid-kiln").

- **Fuels**: alternative fuels are fed to the main burner, to the secondary firing in the preheater/precalciner section, or to the mid-kiln zone of a long wet kiln.

- **Mineral additions**: mineral additions such as granulated blast furnace slag, fly ash from thermal power plants or industrial gypsum are fed to the cement mill. In Europe, the type of mineral additions permitted is regulated by the cement standards.

In addition to regulatory requirements, the cement producers have set up self-limitations such as

- To prevent potential abuse of the cement kiln system in waste recovery operations
- To assure the required product quality
- To protect the manufacturing process from operational problems
- To avoid negative impacts to the environment, and
- To ensure workers’ health and safety.
The cement manufacturing process is a large materials throughput process with continuous operation and comprehensive operational control. Therefore, it has a large potential for co-processing a variety of materials from industrial sources.

Wastes and hazardous wastes in the environment represent a challenge for many countries, but cement kiln co-processing can constitute a sound and affordable recovery option. Cement kilns can destroy organic hazardous wastes in a safe and sound manner when properly operated and will be mutually beneficial to both industry, which generates such wastes, and to the society who want to dispose properly of such wastes in a safe and environmentally acceptable manner. The added benefit of non-renewable fossil energy conservation is important, since large quantities of valuable natural fuel can be saved in the manufacture of cement when such techniques are employed.

Since the early 70s, and particularly since the mid 80s, alternative – i.e. non-fossil – raw materials and fuels derived mainly from industrial sources have been beneficially utilised in
the cement industry for economic reasons. Since that time, it has been demonstrated both in daily operations and in numerous tests that the overall environmental performance of a cement plant is not impaired by this practice in an appropriately managed plant operation.

Cement kilns make full use of both the calorific and the mineral content of alternative materials. Fossil fuels such as coal or crude oil can be substituted by combustible materials which otherwise would often be landfilled or incinerated in specialised facilities.

The mineral part of alternative fuels (ashes) as well as non-combustible industrial residues or by-products can substitute for part of the natural raw materials (limestone’s, clay, etc.). All components are effectively incorporated into the product, and – with few exceptions – no residues are left for disposal. The use of mineral additions from industrial sources substituting clinker saves both raw material resources and energy resources as the energy intensive clinker production can be reduced.

With the substitution of fossil fuels by (renewable) alternative fuels, the overall output of thermal CO₂ is reduced. A thermal substitution rate of 40% in a cement plant with an annual production of 1 million tons of clinker reduces the net CO₂ generation by about 100,000 tons. Substitution of clinker by mineral additions may be more important as both thermal CO₂ from fossil fuels and CO₂ from the decarbonation of raw materials is reduced.

Since only moderate investments are needed, cement plants can recover adequate wastes at lower costs than would be required for landfilling or treatment in specialised incinerators. In addition, public investment required for the installation of new specialised incinerators would also be reduced. Substitute materials derived from waste streams usually reduce the production cost in cement manufacturing, thus strengthening the position of the industry particularly with regard to imports from countries with less stringent environmental legislation. It will also facilitate the industry’s development of technologies to further clean up atmospheric emissions.
6. Evaluation of South African cement plants

The objective of this study has been to compare the cement kiln technology used internationally and that currently used in South Africa and to evaluate their ability to co-process AFRs and treat hazardous wastes in these kilns.

6.1 Introduction

Ten out of eleven South African cement plants was visited in the period August to October 2007. Most South African cement plants have expressed interest in replacing fossil fuel and virgin raw materials with alternative fuels and raw materials (AFR) and developed subsequent environmental impact assessments (EIAs). Some plants are not going to use AFRs.

The South African cement industry is characterized by cement plants that vary in age from “recently” commissioned plants (some are under construction) to plants built in the early 1930’s, all of which incorporate old and new technologies. All South African cement plants produce Portland cement and blended cement products such as CEM I, and more recently CEM II and CEM III products, which are also the most common manufactured cement products in South Africa. Portland cement is a fine, typically grey powder comprised of dicalcium silicate, tricalcium silicate, tricalcium aluminate, and tetracalcium alumino-ferrite, with the addition of 2-5% calcium sulphate (gypsum). Different types of Portland cements can be created depending on the application, as well as the chemical and physical properties desired.

The exacting nature of Portland cement manufacture requires some 80 separate and continuous operations, the use of large-scale heavy machinery and equipment, and large amounts of heat and energy. Large volumes of fossil fuels (in solid and liquid form) are required to maintain high combustion levels in kilns. Coal, hard coal, coke, and pet coke are used in this process. The capital investment per worker in the cement industry is among the
highest in all industries. All local cement produces have to comply with the European Norm Standards for cementitious products.

**Milling / Blending Units**
1. Polokwane – Lafarge SA
2. Potgietersrus – Alpha
3. Roodepoort – Alpha
4. Brakpan – Alpha
5. Kaalfontein – Lafarge SA
6. Jupiter – PPC Cement
7. Middelburg – Alpha
8. Nelspruit – Lafarge SA
10. Richards Bay – Lafarge SA
11. Bloemfontein – Alpha
12. Durban – Natal Portland Cement
13. Matsapha (Swaziland) – Alpha
14. Gaborone (Botswana) – PPC Cement

**Production units**
1. Slurry – PPC Cement
2. Lichtenburg – Lafarge SA
3. Dudfield – Alpha
4. Dwaalboom – PPC Cement
5. Hercules – PPC Cement
6. Ulco – Alpha
7. Simuma – Natal Portland Cement
8. Port Elizabeth – PPC Cement
9. De Hoek – PPC Cement
10. Riebeeck – PPC Cement

**Figure 6**  South Africa’s cement industry facilities (derived from CNCI report)
The figure is from Vincenzo, 2004 (source unknown to the author).
6.2 Main findings

The main findings of the visits can be summarized as follows:

- The South African cement industry consists of four main companies, Pretoria Portland Cement (PPC), Natal Portland Cement (NPC-Cimpor), Lafarge, & Holcim-Afrisam. They have 11 plants and 20 kilns, distributed all over the country. At least two new kilns are under construction and some are planned.

Figure 7 Nathal Portland Cement, Port Shepstone. A new modern kiln is soon ready for operation (preheater tower on the right).
Current production in the kilns planning to use AFR is approximately 8 million tons of clinker per year and the production capacity may increase by as much as 60% by 2014.

Current coal use in the kilns planning to use AFR is approximately 1.3 mill t/y.

Current electricity use of the kilns planning to use AFR is approximately 1 mill MWh/y.

Figure 8  Pretoria Portland Cement, Port Elizabeth

The South African cement industry uses a mix of older long dry kilns (with and without limited preheating) and modern short dry kilns with preheating (some with
precalciner). The best available technique for the production of cement clinker today is a dry process kiln with multi-stage preheating and precalcination.

- Kilns without preheating of the raw material require more energy.

- All the visited plants are either using electrostatic precipitator or bag filters for dust removal and seem to be in compliance with local regulation. The Provincial emission limits vary widely; the emission limits for dust is generally higher in South Africa than in Europe.
• The environmental performance of the plants visited is variable, especially on the dust and NO$_x$ emissions. It can be expected that the plants will be within normal emissions levels when it comes to the major air pollutants (see table 1).

![Figure 10 Lafarge Licthenburg](image)

Figure 10  Lafarge Licthenburg

• Most of the cement companies have implemented an environmental management system and are certified according to ISO 14001.
Some of the long dry kilns have no exit gas conditioning or cooling before the gas enters to the air pollution control device (electro static precipitator), implying that the temperature will be in the range of 200-400 °C, which under unfavorable conditions may contribute to the formation and release of dioxins; this should be checked.

Figure 11  Pretoria Portland Cement Slurry

- All the plants receive electricity from the grid, i.e. Escom. Most of the plants said they experience dips in power with subsequent process and air pollution control instability.

- The water supply seems to be limited in some plants but may only be a concern for future expansions.
• The plants seem to have variable or inconsistent monitoring and reporting requirements (varies with and within the province).

• Some plants only measure the main air pollutants, as dust, SO$_2$ and NO$_x$, which is often more for process than environmental control.

• Some plants have implemented a comprehensive measurement surveillance of their stack emissions, consisting of the latest continuous emission monitors (CEMs) installed in the stacks for on-line measurements of the main air pollutants. These companies also do independent sampling and analysis of trace pollutants like acid gases, heavy metals and dioxins on a regular basis.

Figure 12  Holcim Dudfield
Some kilns have already used alternative fuels and raw materials (AFR) for some years (started 2001-2002), specifically spent pot lining (SPL) from the Aluminum Industry. They generally use both fractions, i.e. the carbon fraction which can contain 6-14 MJ/kg of energy, and the refractory fraction, which contains alternative raw materials components as aluminium and silica. Both fractions contain however cyanide, fluoride and sodium; the last two elements can cause problems in the process and the quality if not properly controlled.

Figure 13 Pretoria Portland Cement Dwaalboom. A new line and preheater tower is under construction.

Some kilns use boiler and fly ash as an alternative raw material or mineral substitute, but these are often blended with cement and needs not to be processed.
• All the cement companies have a dedicated AFR-organisation in place but will need to develop necessary laboratory capacity for input control.

Figure 14  Control room at PPC Hercules, Pretoria.

• Most of the plants lack equipment for receiving, preparation/pre-treating and feeding AFR and eventually hazardous wastes. Most of the cement companies have enough space in their premises to allow AFR-activities, but safety and environmental protection must follow high standards.

• There seems to be no regulation in place for storage and pre-treatment of AFRs (and hazardous wastes).
Figure 15  PPC Riebeck, Western Cape. Long dry kiln without exit gas conditioning/cooling. No plans to use AFRs.

Figure 16  PPC Riebeck, Western Cape. Long dry kiln with exit gas conditioning/cooling (kiln to the left). No plans to use AFRs.
• Most plants are located far away from industrial areas and waste generation centers and its questionable if large scale transport of AFRs and hazardous wastes, at least to some of these plants, will be economic viable.

• Several kilns are using planetary cooler.

• With increasing costs of energy and raw materials, as well as stricter emission regulation, it can be expected that some of the existing South African kilns will be closed and replaced with modern and energy efficient technology.

Figure 17  PPC De Hoek, Western Cape.
6.3 A summary

All of the kilns visited could, from a technical standpoint, be able to co-process AFRs and treat hazardous wastes adequately, provided that they were able to prepare and feed the materials properly, i.e. expose them for high enough temperatures etc. (see chapter 5).

 Compared with “international” technology, for example in Europe, many of the South African kilns, especially the long dry without preheating or exit gas conditioning, are old with low energy efficiency and low environmental performance. It is doubtful if it’s economical feasible to upgrade these kilns and improve the performance significantly.

Most of the “new” South African kilns are comparable to “international” performance standards, i.e. equipped with preheaters (and calciner), efficient clinker coolers and raw mills, exit gas conditioning, sufficient air pollution abatement capacity, on-line emission monitors, and independent measurements of for example dioxins. It would probably be economic feasible to upgrade all of the “new” South African kilns to comply with for example the EU emission limit values (those who are not already).

“Inherent” kiln features is however not enough to be qualified to co-process AFRs and treat hazardous wastes adequately seen from an institutional and social point of view. The plants will need qualified and skilled employees to manage AFRs and hazardous wastes, as well as health, safety and environmental issues; they will need adequate emergency and safety equipment and procedures, and regular training; they will need authorised and licensed collection, transport and handling “systems”; they will need safe and sound receiving, storage, preparation and feeding facilities; they will need adequate laboratory facilities and equipment for AFR and hazardous waste acceptance and feeding control; and they would need to demonstrate the destruction performance of hazardous wastes through test burns.

A summary of the the gross production and consumption data and the environmental performance for the kilns visited, are given on the next two pages (not all of these plants plan to use AFR). Company name and kiln location is given at the top of the column.
<table>
<thead>
<tr>
<th>Company</th>
<th>Afrisam</th>
<th>NPC-Cimpor</th>
<th>Lafarge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant location/name</td>
<td>Ulco</td>
<td>Simuma</td>
<td>LIC</td>
</tr>
<tr>
<td>Kiln #</td>
<td>#2</td>
<td>#3</td>
<td>#5</td>
</tr>
<tr>
<td>Clinker production (t/y)</td>
<td>~780000</td>
<td>~1100000</td>
<td>~130000</td>
</tr>
<tr>
<td>Coal consumption (t/y)</td>
<td>~130000</td>
<td>~160000</td>
<td>~170000</td>
</tr>
<tr>
<td>Electricity consumption (MWh/y)</td>
<td>~150000</td>
<td>~110000</td>
<td>~160000</td>
</tr>
<tr>
<td>Energy consumption (MJ/t clinker)</td>
<td>&lt;5.000</td>
<td>&lt;4.000</td>
<td>&lt;4.000</td>
</tr>
<tr>
<td>Kiln type / Process technology</td>
<td>FLS/DS2</td>
<td>FLS/PC4</td>
<td>Polysius PC4</td>
</tr>
<tr>
<td>Exit gas cooling/conditioning</td>
<td>Conditioning tower</td>
<td>Conditioning tower</td>
<td>Conditioning tower</td>
</tr>
<tr>
<td>By-pass</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Air Pollution Control Device's)</td>
<td>Bag Filter</td>
<td>Bag Filter</td>
<td>EP</td>
</tr>
<tr>
<td>Temperature in APCD / stack (°C)</td>
<td>~160/~150C</td>
<td>~160/~150C</td>
<td>~160/~150C</td>
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<tr>
<td>Dust recovery(%)</td>
<td>99,997%</td>
<td>99,997%</td>
<td>&gt;98%</td>
</tr>
<tr>
<td>On-line emission gas monitoring (system and parameters)</td>
<td>Opsis/Durag</td>
<td>Opsis/Durag</td>
<td>Opsis/SICK</td>
</tr>
<tr>
<td>Emissions: Dust (mg/Nm³) - Average value and number of measurements</td>
<td>14 (CEM)</td>
<td>9 (CEM)</td>
<td>129 (CEM)</td>
</tr>
<tr>
<td>NOx (mg/Nm³) - Average value and number of measurements</td>
<td>590 (CEM)</td>
<td>450 (CEM)</td>
<td>680 (CEM)</td>
</tr>
<tr>
<td>SO2 (mg/Nm³) - Average value and number of measurements</td>
<td>40 (CEM)</td>
<td>8 (CEM)</td>
<td>3 (CEM)</td>
</tr>
<tr>
<td>VOC / TOC (mg/Nm³) - Average value and number of measurements</td>
<td>4.6(CEM)</td>
<td>3 (CEM)</td>
<td>2 (CEM)</td>
</tr>
<tr>
<td>HCl (mg/Nm³) - Average value and number of measurements</td>
<td>9.7 (CEM)</td>
<td>10.8 (CEM)</td>
<td>13 (CEM)</td>
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<tr>
<td>HF (mg/Nm³) - Average value and number of measurements</td>
<td>n/a</td>
<td>&lt;1 (CEM)</td>
<td>&lt;1 (CEM)</td>
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<tr>
<td>PCDD/PCDF (ng TEQ/Nm³) - Average value and number of measurements</td>
<td>0.0023</td>
<td>0.0016</td>
<td>0.0085</td>
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<tr>
<td>PCBs (ng TEG/Nm³) - Average value and number of measurements</td>
<td>0.0000</td>
<td>0.0013</td>
<td>0.0003</td>
</tr>
<tr>
<td>Heavy metals (µg/Nm³) - Average value and number of measurements</td>
<td>See attachment</td>
<td>See attachment</td>
<td>See attachment</td>
</tr>
<tr>
<td>Co-processing AFR and/or mineral substitutes (types and volumes t/y)</td>
<td>Nil</td>
<td>Nil</td>
<td>Nil</td>
</tr>
<tr>
<td>Infrastructure and equipment for AFR-handling, pre-treatment and feeding</td>
<td>Limited</td>
<td>Limited</td>
<td>Limited</td>
</tr>
<tr>
<td>Environmental management system, e.g. ISO 14001</td>
<td>Certified</td>
<td>Certified</td>
<td>Certified</td>
</tr>
<tr>
<td>Reliable and adequate electricity supply (?)</td>
<td>Yes - Eskom</td>
<td>Yes - Eskom</td>
<td>Yes - Eskom</td>
</tr>
<tr>
<td>Reliable and adequate water supply (?)</td>
<td>Yes - Own</td>
<td>Yes - Own</td>
<td>Yes - Own</td>
</tr>
<tr>
<td>Laboratory for quality control</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Laboratory for control of AFR (?)</td>
<td>Partial</td>
<td>Partial</td>
<td>Partial</td>
</tr>
<tr>
<td>Plant location/name</td>
<td>Slurry</td>
<td>Hercules</td>
<td>Jupiter</td>
</tr>
<tr>
<td>---------------------</td>
<td>--------</td>
<td>----------</td>
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<tr>
<td>Kiln #</td>
<td>#5</td>
<td>#6</td>
<td>#7</td>
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<tr>
<td>Clinker production (t/y)</td>
<td>15500</td>
<td>15500</td>
<td>295000</td>
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<tr>
<td>Coal consumption (t/y)</td>
<td>274000</td>
<td>110000</td>
<td>80000</td>
</tr>
<tr>
<td>Electricity consumption (MWh/y)</td>
<td>130000</td>
<td>130000</td>
<td>28000</td>
</tr>
<tr>
<td>Kiln type / Process technology</td>
<td>Long Dry</td>
<td>Long Dry</td>
<td>1 St PH</td>
</tr>
<tr>
<td>Exit gas cooling/conditioning</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>By-pass</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Air Pollution Control Device's)</td>
<td>ESP</td>
<td>ESP</td>
<td>ESP</td>
</tr>
<tr>
<td>Temperature in APCD / stack (°C)</td>
<td>250</td>
<td>318</td>
<td>120</td>
</tr>
<tr>
<td>Dust recovery(?)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>On-line emission gas monitoring (system and parameters)</td>
<td>Dust</td>
<td>Dust</td>
<td>Dust</td>
</tr>
<tr>
<td>Emissions: Dust (mg/Nm³) - Average value and number of measurements</td>
<td>250</td>
<td>100</td>
<td>80</td>
</tr>
<tr>
<td>NOx (mg/Nm³) - Average value and number of measurements</td>
<td>1400</td>
<td>800</td>
<td>700</td>
</tr>
<tr>
<td>SO₂ (mg/Nm³) - Average value and number of measurements</td>
<td>200</td>
<td>130</td>
<td>&lt;10</td>
</tr>
<tr>
<td>VOC / TOC (mg/Nm³) - Average value and number of measurements</td>
<td>Not available</td>
<td>Not Available</td>
<td>Not Available</td>
</tr>
<tr>
<td>HCl (mg/Nm³) - Average value and number of measurements</td>
<td>Not available</td>
<td>&lt;1</td>
<td>Not Available</td>
</tr>
<tr>
<td>HF (mg/Nm³) - Average value and number of measurements</td>
<td>Not available</td>
<td>&lt;0.4</td>
<td>Not Available</td>
</tr>
<tr>
<td>PCDD/PCDF (ng TEQ/Nm³) - Average value and number of measurements</td>
<td>Not available</td>
<td>Not Available</td>
<td>Not Available</td>
</tr>
<tr>
<td>PCBs (ng TEQ/Nm³) - Average value and number of measurements</td>
<td>Not available</td>
<td>Not Available</td>
<td>Not Available</td>
</tr>
<tr>
<td>Heavy metals (µg/Nm³) - Average value and number of measurements</td>
<td>Not available</td>
<td>Not Available</td>
<td>Not Available</td>
</tr>
<tr>
<td>Co-processing AFR and/or mineral substitutes (types and volumes t/y)</td>
<td>None</td>
<td>None</td>
<td>SPL Volume N/A</td>
</tr>
<tr>
<td>Infrastructure and equipment for AFR-handling, pre-treatment and feeding</td>
<td>None</td>
<td>None</td>
<td>Feeding</td>
</tr>
<tr>
<td>Environmental management system, e.g. ISO 14001</td>
<td>ISO 14001</td>
<td>ISO 14001</td>
<td>ISO 14001</td>
</tr>
<tr>
<td>Reliable and adequate electricity supply (?)</td>
<td>Reliable</td>
<td>Power outages 1 per month</td>
<td>Reliable</td>
</tr>
<tr>
<td>Reliable and adequate water supply (?)</td>
<td>Reliable</td>
<td>Reliable</td>
<td>Reliable</td>
</tr>
<tr>
<td>Laboratory for quality control</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Laboratory for control of AFR (?)</td>
<td>Integrated into plant lab</td>
<td>Integrated</td>
<td>Integrated</td>
</tr>
</tbody>
</table>

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7. Conclusion

The objective of this study has been to compare the cement kiln technology used internationally and that currently used in South Africa and to evaluate their ability to co-process AFRs and treat hazardous wastes in these kilns.

The South African cement industry consists of four main companies, Pretoria Portland Cement (PPC), Natal Portland Cement (NPC-Cimpor), Lafarge, & Holcim-Afrisam. They have 11 plants and 20 kilns, distributed all over the country. At least two new kilns are under construction and some are planned. Current production in the kilns planning to use AFR is approximately 8 million tons of clinker per year and the current coal consumption is approximately 1.3 mill t/y.

Cement kilns have proven to be effective means of recovering value from waste materials and co-processing in cement kilns is now an integral component in the spectrum of viable options for treating hazardous and industrial wastes, mainly practised in developed countries. A modern preheater cement kiln possess many inherent features which makes it ideal for hazardous waste treatment; high temperatures, long residence time, surplus oxygen during and after combustion, good turbulence and mixing conditions, thermal inertia, counter currently dry scrubbing of the exit gas by alkaline raw material (neutralises all acid gases like hydrogen chloride), fixation of the traces of heavy metals in the clinker structure, no production of by-products such as slag, ashes or liquid residues from exit gas cleaning and complete recovery of energy and raw material components in the waste. The most effective way of reducing raw material consumption, energy use and emissions from the cement industry is to reduce the clinker content of cement products by using secondary raw materials and mineral additives; then both thermal CO₂ from fossil fuels and CO₂ from the decarbonation of raw materials are reduced.

The cement industry has capacity to treat a significant part of South Africa’s own waste and all companies are today interested in co-processing. The joining of the cement industry to the waste management needs in South Africa could, under a well managed and controlled environment, provide a viable, economical and environmentally sound mean of treating many
hazardous and non-hazardous industrial wastes. Some of the cement companies are planning to build blending platforms for waste fuel in Durban and Gauteng and some kilns have already been using alternative fuels and raw materials (AFR) for some years, specifically spent pot lining (SPL) from the Aluminum Industry. Some kilns use boiler and fly ash as an alternative raw material and mineral substitute.

Compared with “international” technology, for example in Europe, many of the South African kilns, especially the long dry without preheating or exit gas conditioning, are old with low energy efficiency and low environmental performance. It is doubtful if it’s economical feasible to upgrade these kilns and improve the performance significantly.

Most of the “new” South African kilns are comparable to “international” performance standards, i.e. equipped with preheaters (and calciner), efficient clinker coolers and raw mills, exit gas conditioning, sufficient air pollution abatement capacity, on-line emission monitors, and independent measurements of for example dioxins. It would probably be economically feasible to upgrade all of the “new” South African kilns to comply with for example the EU emission limit values (those who are not already).

All of the kilns visited would, from a technical standpoint, be able to co-process AFRs and treat hazardous wastes. “Inherent” kiln features, as high temperatures and long residence time, is however not enough to be qualified to co-process AFRs and treat hazardous wastes adequately seen from an institutional and social point of view. The plants will need qualified and skilled employees to manage AFRs and hazardous wastes, as well as health, safety and environmental issues; they will need adequate emergency and safety equipment and procedures, and regular training; they will need authorised and licensed collection, transport and handling “systems”; they will need safe and sound receiving, storage, preparation and feeding facilities; they will need adequate laboratory facilities and equipment for AFR and hazardous waste acceptance and feeding control; and they would need to demonstrate the destruction performance of hazardous wastes through test burns.

Those kilns who have conducted dioxin and furan measurements show very low levels. No laboratory can however perform this analysis in South Africa for the time being.
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