

MEDITERRANEAN

Manual of Pollution Prevention in the **Cement Industry**

CLEANER production



Regional Activity Centre for Cleaner Production (CP/RAC)
Mediterranean Action Plan



Regional Activity Centre
for Cleaner Production



 **Generalitat de Catalunya**
Government of Catalonia
**Department of the Environment
and Housing**

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EXECUTIVE SUMMARY

The challenge today in the cement industry consists in adopting the necessary measures so as to allow sustainable development and guarantee its competitiveness. Although the cement industry has already begun to protect the environment, it must still make greater efforts to minimise the consumption of natural resources and its impact on the environment.

This Manual of Pollution Prevention in the Cement Industry aims to provide the tools and decision-making criteria for the implementation of progressive improvements to the environment in companies in the countries pertaining to the Mediterranean Action Plan to achieve Cleaner Production.

The purpose of Cleaner Production is the continuous application of a preventive environmental strategy incorporated into processes, products and services in order to increase efficiency and reduce hazards for people and the environment. This strategy includes the gradual assessment and adoption of the best available techniques for minimising environmental pollution that are technically viable in accordance with the specific characteristics of each production process.

This Manual demonstrates that the adoption of alternative pollution prevention techniques allows a reduction in the consumption of natural resources (raw materials, energy, water, etc.), reducing waste flows and increasing the efficiency of the productive process, thus managing to benefit the economics of the process and also contributing to increasing the competitiveness of industrial facilities.

Since the main aim of Cleaner Production is to minimise emissions at source, actions taken are to: prevent, reduce and reuse. Complementarily, the treatment of end emissions to minimise their environmental impact must also be taken into account.

As can be seen in Chapter 2, the scope of such action depends on the legislation in force in each country. Great differences exist between countries, barring the countries of the European Union, which must comply with the Integrated Pollution Prevention and Control (IPPC) Directive. In Chapter 3, the raw materials used and the main production processes are described. Then, in Chapter 4, the main potential sources of pollution are dealt with, as well as the most common energy consumption for each type of process.

The main environmental aspects associated with the production of cement are energy consumption and emissions into the atmosphere of NO_x, SO₂ and CO₂ particles. These particles are due to diffuse sources and specific foci and the gases come from the main focus, which is the clinker kiln.

Wastewater is limited to rain runoffs, the cooling of equipment (usually in a closed circuit) and sanitary water and has no significant environmental impact; the storage and handling of fuels are potential sources of ground and groundwater pollution.

The cement industry is characterised by the intensive consumption of energy and hence production plants have increasingly been implementing measures to foment energy efficiency; this leads to a reduction in fuel-related emissions.

In Chapter 5, different alternatives are presented for the prevention at source of pollution, indicating in each case the improvements that could be achieved. Also, the end treatments that may be used in order to minimise the environmental impact produced by end emissions are included.

Lastly, Chapter 6 includes a series of practical cases with the aim of facilitating decision-making concerning some specific treatments. A range of cases have been selected starting with highly specific

cases in which the advantages achieved are indicated in a plant which implements one of the proposed alternatives and passing through more general cases which show the most commonly used alternatives in a group of plants or which describe the different stages applied in order to achieve Cleaner Production.

The Bibliography includes a series of publications, institutions and websites that may provide the reader with additional, complementary information to the contents of this manuscript.

INTRODUCTION

The production of cement and its applications is closely linked with the construction industry, since its products are used in several stages of the building process; both building and civil engineering works. This close relationship with the activity of construction means that this sector is strategic for industry.

The importance of cement lies in its property of forming resistant, long-lasting stone masses when mixed with aggregate and water. The setting and hardening of the mixture occurs after a certain time has elapsed after the blend has been made, which makes it possible to give shape (mould) to the resulting artificial stone. Cement, as well as being readily available, can be adapted to a variety of requirements and is inexpensive compared to other materials.

Cement has played a key role in the history of civilisation and records of its use date back to ancient times. Economic and industrial progress, the sources of raw materials and climatic conditions have led to different types of progress, in terms of both building materials and systems; to such an extent that today, many types of cement are made according to market requirements.

Cement-derived products are generally products with a long service life, and once their usefulness has ceased, it is difficult to separate their original components, which makes reuse and even recycling a difficult task. Basically, these products are composed mainly of inert matter, and although when they are taken to landfills they neither pollute the ground nor the water, they do take up a large amount of space. The current trend in developed countries is to close the lifecycle of cement and its derivatives by reusing and recycling waste matter from building and demolition.

As in other industrial sectors, the cement industry tries to attain sustainable development, which requires a long-term vision in which enterprises concentrate on preserving the quality of life, which means respecting both local and global human needs and ecosystems. In this dynamic process, not only environmental aspects are considered but also socioeconomic ones such as, for example, social welfare and employment. Some measures can be implemented in the short term but others require long periods of planning and adaptation. Many companies have already adopted effective measures in a broad range of environmental and social issues and have even achieved new market opportunities. However, the application of new technologies compatible with sustainable development requires a large investment by enterprise. This development depends, fundamentally, on the location of the production centres, the shareholders' or owners' expectations and the identification of new market opportunities.

It should also be considered that, currently, factories do not just dealing with the process of sustainable development, with all of the changes involved, but also, in parallel, they must face up to the process of globalisation. In short, sustainable development of the cement industry presents opportunities and challenges in such a way that manufacturers need to adapt to all such changes in order to find the means to maintain the profitability of the factories and, at the same time, reduce their environmental impact.

Growing environmental awareness and its subsequent reflection in countries' environment laws has shown the need for all productive sectors, including the cement sector, to concentrate their efforts on controlling, reducing and preventing pollution at source, minimising emissions into the atmosphere and optimising their energy needs.

- Energy costs account for around 30 % of cement production costs; hence, cement companies have begun to optimise their processes and equipment, progressively improving the energy efficiency of the manufacturing plants, especially since the 1970s. Moreover, more recently, the cement industry (which globally contributes approximately

5 % to CO₂ emissions) has been affected in some countries of the Mediterranean Action Plan by the new legislation deriving from the Kyoto Protocol. In this way, many plants must make use of greenhouse gas emission rights, or they may be possible targets of clean development mechanisms. This lends even greater importance to energy optimisation and the use of renewable raw materials.

Currently, the cement industry contributes to the field of energy recovery with a safe, ecological solution to the handling of certain types of organic waste, by using them as alternative fuels: animal meal, spent oils, solvents, etc. In turn, the cement industry makes a significant environmental contribution to the waste management of other industrial activities, since such waste may be used as raw materials in the preparation of raw meal (ash, paper sludge, foundry sand, etc.) and/or as additives in the grinding of cement (blast-furnace slag, silica fumes, etc.).

In this way, a strategy has been progressively structured in order to optimise the activities of the cement sector, both from the environmental point of view and from that of yield and competitiveness. The essential lines of this strategy can be summed up as follows:

- To improve the environmental behaviour of manufacturing facilities via improved environmental management, the modernisation of equipment and means to protect the environment.
- A reduction in the necessary energy consumption for cement manufacture, and the costs involved, by:
 - Improving the energy efficiency of the production equipment and processes.
 - Carrying out research into and fomenting cements with additives, whose manufacture requires less clinker, and, therefore, less fuel.

The use of waste and by-products as alternative raw materials and fuels, which, in addition to the saving of unrenovable resources, contributes environmentally due to recycling of material and energy recovery from waste.

- Adaptation to the new framework of energy liberalisation towards which most countries of the Mediterranean Action Plan are heading.
 - The need for companies to deal with international competition and come into line with quality and other international standards such as those of the ISO-9000 and ISO-14000 standards or EMAS.

Thus, it is therefore acknowledged that the most efficacious solution to the problems of environmental pollution is to minimise the generation of waste flows by applying clean technologies that correct the problem at source. This solution can be adopted both in new industries and in those that seek the modernisation of their production facilities.

This Manual seeks to provide tools and criteria for decision making for the implementation of a progressive improvement to the environment in companies, providing information for the prevention of pollution in the cement sector for the countries of the Mediterranean Action Plan.

According to the Study published in January 2004 by the Regional Activity Centre for Cleaner Production (RAC/CP) on the "State of Cleaner Production in the countries of the Mediterranean Action Plan" and in accordance with the manifestations of the national Focal Points of the RAC/CP with regard to the concept of cleaner production, most Mediterranean countries have adopted the definition of the UNEP (United Nations Environment Programme), according to which: "Cleaner production consists of continuously applying a preventive and comprehensive environmental strategy for processes and products, to reduce risks that affect the human race and the environment". However, cases exist in which cleaner production is assimilated in concepts such as best available techniques (BATs) and cleaner technologies.

In order to draw up this Manual, first the potential environmental problems of factories in the cement sector are detected, which are:

- Energy consumption.

- Emissions into the atmosphere.
- The generation of waste.

Secondly, the sector's manufacturing processes are studied in the countries of the Mediterranean Action Plan, describing in detail the aforementioned environmental problems; and, finally, alternatives for pollution prevention at source are proposed, specifying, for the purposes of illustration, applicable practical cases of some of the proposed alternatives.

Thus, the document is structured as follows:

PART I: Clean Production / Objectives and Benefits of Pollution Prevention

In this section, the concept of "pollution prevention" is defined and the benefits of applying such prevention techniques are summarised.

PART II: Pollution prevention in the Cement Sector

This section describes both the current situation of the cement sector in the Mediterranean region as well as the processes associated with the sector, the main environmental impacts, and it provides alternatives for pollution prevention.

PART III: Practical Cases

This section includes specific samples of companies that have used different alternatives for pollution prevention. These case studies describe the strategy followed as well as the benefits, in particular cost savings, that companies have achieved.

1. CLEAN PRODUCTION / OBJECTIVES AND BENEFITS OF POLLUTION PREVENTION

Cleaner Production in an industrial environment focuses on the efficacious execution of the productive processes in such a way that a minimum of by-products or waste flows that cannot be taken advantage of internally are generated, with minimal consumption of raw materials and resources.

Cleaner production encompasses three areas of activity:

- Prevention.
- Reduction.
- Internal reuse.

Prevention is aimed at decision making in the design of a new plant or redesigning existing ones in order to “prevent” pollution, i.e., to avoid generating the waste flow. In this way, the choice of alternatives that minimise the generation of waste flows takes priority, thus reducing the environmental impact on the surroundings.

Reduction, or minimisation, is applied in those processes which, despite being fully implemented, have room for improvement. Modifications shall consider the reduction of waste flows generated and/or the consumption of raw materials and natural resources.

Internal *recovery* considers the use of waste flows as a raw material within the company, this being the last resort for limiting the environmental impact.

The more emphasis is placed on the concept of cleaner production, the more positive the environmental effects of these measures will be.

From the point of view of costs, cleaner production should be thought of as a process that generates profits with the passage of time, and thus, cleaner production reduces costs by improving the efficacy of production.

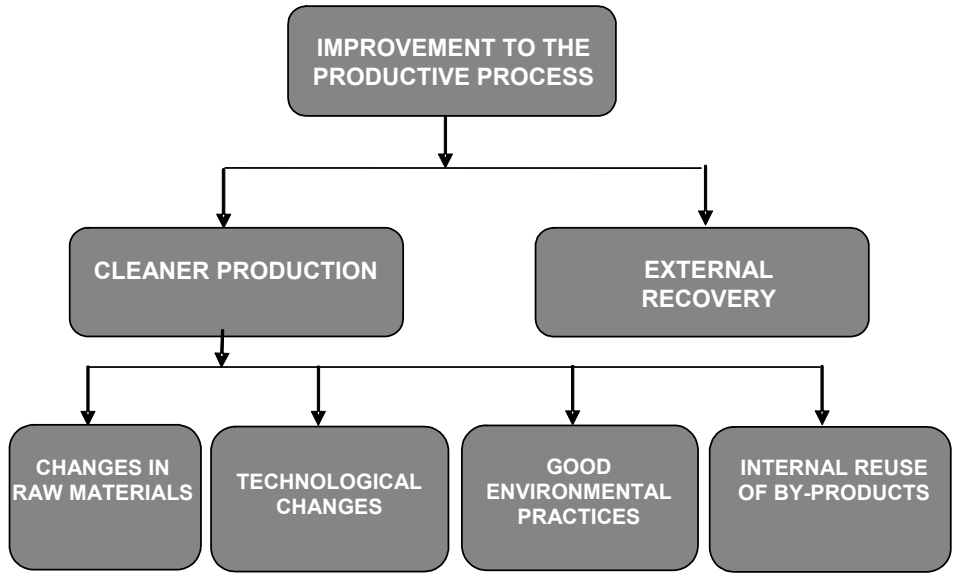
In this way, the planning and design of a process in which techniques are chosen to minimise the generation of waste flows will, in the medium to long term, be far more beneficial, both environmentally and economically than those processes in which proper management of the treatment of waste flows takes place at the end of the process.

Among the main causes that are progressively leading to cleaner production being increasingly present in the cement sector, are the following:

- An increasingly strict, more controlled legal framework.
- High energy consumption.
- The inclusion of the environmental costs involved into the financial management of the product.
- Growing environmental awareness among manufacturers, consumers and customers.
- Technical improvements applying processes of cleaner production offering products of equal or higher quality.

Cleaner production measures can be grouped in accordance with the lines of action shown below:

- Changes in raw materials and fuels: Measures concentrating on improvement by substituting or changing those raw materials and fuels consumed in the process for others with lower overall pollution potential.
- Technological changes: Measures that represent changes to processes.
- Organisational measures: Measures targeted at achieving the correct use of equipment and systems in order to optimise plant functioning.
- The internal recycling of by-products or waste flows: Reuse, with or without prior treatment in the process itself (depending on each case) of waste flows generated, considering them as new raw materials.



Pollution prevention is, as defined by the EPA (the US Environment Protection Agency): "... the maximum feasible reduction of all wastes generated at production sites. It involves the judicious use of resources through source reduction, energy efficiency, reuse of input materials during production, and reduced water consumption. There are two general methods of source reduction that can be used in a pollution prevention program: product changes and process changes. They reduce the volume and toxicity of production wastes and of end-products during their life-cycle and at disposal."

OBJECTIVES OF POLLUTION PREVENTION
The aim of the programme of pollution prevention at source is to improve the quality of the environment by eliminating and/or reducing the generation of waste flows. Pollution prevention includes any activity undertaken by a company to reduce the amount of waste generated by its manufacturing processes prior to recycling, treatment or disposal of the aforementioned waste products elsewhere.

BENEFITS OF A POLLUTION PREVENTION PROGRAMME

Companies with an effective, continuous plan to prevent pollution will be at a significant advantage to compete in their industry, since they reduce operating costs and production costs. Thus, a pollution prevention programme may present the following benefits:

- **It will protect human health and the quality of the environment:** The reduction in pollutants emitted into the atmosphere, ground and water will help to protect the environment and human health.
- **It will help reduce operating costs:** In the long term, an effective programme of pollution reduction may lead to savings that cover the costs of developing and implementing the programme.
- **Employee motivation:** Employees will feel better in their company if they believe that the management is committed to providing them with a safer work environment and which, at the same time, collaborates as a responsible member of the community.
- **An improved company image:** Demonstrating environmental awareness improves the image the company gives. Far more positive opinions are given of companies that have a culture of respect for nature. This may open up new market opportunities for certain products.
- **An improvement in the fulfilment of environmental legislation:** By following a pollution prevention plan, the company increases its chances of avoiding committing offences and being fined on environment-related issues.

2. SITUATION OF THE COUNTRIES OF THE MEDITERRANEAN ACTION PLAN

The aim of this section is to provide the reader with a general overview of the current situation of the different countries of the Mediterranean Action Plan, supplying socioeconomic information about the country, concrete aspects concerning the industry of the country and the main environmental impacts associated with industrial activity (especially within the cement manufacturing sector), laws and regulations existing in the current legal framework for the prevention and control of pollution, agents involved in the promotion of cleaner production, programmes and plans of action created to promote cleaner production, as well as the activities and tools used to promote and disseminate cleaner production.

The information has been obtained from bibliographical sources of Official Bodies such as Statistics Institutes, Environment Agencies, Energy Agencies, Ministries of the Economy, etc., as well as from the second edition of the recently published study by the Regional Activity Centre for Cleaner Production (RAC/CP): "The state of cleaner production in the countries of the Mediterranean Action Plan". This new edition updates and complements the study published by the Centre in 2001, analysing the main advances recorded in the countries of the Mediterranean in respect of the adoption of regulations, schemes and plans of action for pollution prevention and the promotion of cleaner production.

Below, the different countries of the region are studied, grouped into three subregions (South, North and East). Due to questions of practicality, this information has been neither reviewed nor approved by the national Focal Points of each country.

2.1. COUNTRIES IN THE SOUTH OF THE MEDITERRANEAN

This group encompasses Algeria, Egypt, Lebanon, Libya, Morocco, Syria and Tunisia, all of which are members of the League of Arab States and have specific characteristics in common, in spite of the political differences that may exist between them. All of them share some cultural principles and similar languages which are conducive to common action.

Some of the main aspects of this subregion are the modernisation of the existing industry, the development of environmental law and of the legal system, the adoption of environmental action plans in the national scope and the founding of national centres for cleaner production that support the strategy adopted by each country.

Industry and environment

Over the last three decades, the countries of the south of the Mediterranean have undergone improvements with regards to health, education and welfare. However, this development has been negatively influenced by increased population pressure, economic recession and armed conflict.

The rapid growth in the population of the countries of the south of the Mediterranean, together with the increase in human activities, especially in urban areas, increases both the pressure on the environment and the production of waste and pollution.

The gross domestic product (GDP) of the countries of the south of the Mediterranean has grown considerably in the last decade. Most countries have economic reforms and restructuring underway, they promote the market economy and decentralisation and have managed to reduce inflation levels.

The weight of industry in these countries is considerable; it represents more than 25.5 % of the total GDP of the subregion (not including the extraction of raw meal). Industrialisation is an important source of income for the states thanks to the commercialisation of their products, the creation of employment and the contribution of added value on primary products.

The industrial structure of the countries of the south of the Mediterranean have some features in common:

- The industrial development of the countries of the south of the Mediterranean is mainly based on the exploitation of natural, non-renewable energy sources. The petroleum and the gas extracted in Libya, Algeria and Egypt have taken on great importance, both from the point of view of exportation and from that of the energy-intensive industries and added value that have proliferated in the area.
- In addition to concentrating on petroleum and gas, the countries of the south of the Mediterranean show a trend towards focusing on other extraction activities or the processing of their raw materials such as, for example, phosphates and other minerals in Morocco, or agricultural industry in Syria.
- The presence of industries that produce capital goods is relatively scarce despite the importance there would be by boosting this sector in countries like Egypt, Morocco and Tunisia.
- Lastly, exportations of manufactured products continue to be greatly limited and the deficit of the balance of trade very high. All in all, the situation could change if new policies governing the promotion of exports were encouraged.

Despite the recent attempts to diversify the industrial fabric, by assigning significant amounts of the national budgets to industry and to the infrastructures it needs, the behaviour of the manufacturing sector in the countries of the south of the Mediterranean has not proved satisfactory. This responds to the dominant tendency to import goods, to the lack of industrial development strategies applied, to the artificial protection of national industries and to the lack of cooperation insofar as trade and industry are concerned between the different countries comprising this subregion.

Mining and the processing of minerals and industrial metals have grown, as has the extraction of fossil fuels.

Countries like Egypt, Syria, Tunisia and Morocco, whose economies are diversified, continue to concentrate on the traditional industries, such as the production of foods, cement and textiles.

Few countries have been able to establish competitive industries through the introduction of modern technology. In addition, in many such countries industrialisation continues to be strengthened by means of policies that are incompatible with the concept of sustainability.

The industrial development model which has been applied in the countries of the south of the Mediterranean have contributed to the appearance of «pollution black spots» which have led to severe environmental deterioration and the overloading of public infrastructures for the protection of the environment in large towns and cities.

In the countries with a comparatively higher degree of industrialisation (for example Egypt, Morocco, Tunisia or Syria), environmental problems are still more serious as a consequence of:

- inadequate end-of-pipe treatment, and improper handling and elimination of hazardous waste.
- difficulty controlling industrial effluents and emissions due to a lack of instruments and qualified personnel.

- the lack of predisposition by most pollutant companies to invest in pollution reduction measures.
- a lack of specialised, trained personnel to manage the running of waste treatment facilities.

Nevertheless, industry currently recognises the need to avoid or reduce the generation of waste via new pollution prevention technologies. This trend has gradually managed to improve the behaviour of production and consumption.

Political and legal framework

The environmental legislation of all of the countries of the south of the Mediterranean has been broadly reviewed and modified in recent years. In general, the countries of the subregion adopt a general environmental law (framework) which is complemented with sectorial regulations. All have passed laws to control the industrial pollution of waters which protect, directly or indirectly, the marine environment and most of them have also passed regulations governing Environmental Impact Assessment (EIA) in systems for the awarding of licences.

In most countries, the modernisation of the legal framework has favoured the legal regulation of aspects related with CP, mainly via laws on waste and the introduction of new environmental requirements in the process of obtaining licences.

This is the case, for example, of Algeria's Waste Law or of the waste minimisation requirements established in Egyptian legislation; CP also appears in Morocco's draft law on waste. A review of the legal framework has helped Tunisia to include more concrete requirements for energy and water saving. Algeria has also included pollution prevention and reduction measures at source and, as a second option, the recovery of the waste generated.

However, a certain amount of time may be needed to achieve the full application of the laws, since a suitable administrative structure is needed. In addition to the fact that the industrial sector will be better disposed to being subjected to effective application of the regulation if the measures for the control of their fulfilment are accompanied by other proactive measures such as, for example, voluntary agreements or economic incentives, few other incentives exist to adopt CP, apart from avoiding possible fines.

Lebanon funds audits and has increased the amount of credits it awards in order to accelerate the adoption of new environmental technologies, and, among others, environmental modernisation.

In Syria too, other incentives exist for cleaner industries and for investors who invest in environmental modernisation and in the adaptation of cleaner technologies.

Some countries are starting up voluntary agreements and instruments in order to raise the awareness of the industrial sector and increase its responsibility towards the environment. To this end, Morocco has implemented its 'Responsible Care' programme, which has been adopted by some industries, and in Algeria, environmental management systems and environmental audits are being encouraged and publicised.

In the international framework for the protection of the environment through pollution prevention, all of the countries of the south of the Mediterranean are members of the Basel Convention on Hazardous Waste and most have signed the Stockholm Convention on Persistent Organic Pollutants. As for the reduction of the ozone layer, all have signed or also ratified the Montreal Protocol and its amendments, barring that of Peking in 1999. As regards climate change, Algeria, Egypt, Morocco and Tunisia have ratified the Kyoto Protocol.

Within the framework of the Mediterranean Action Plan, and in respect of the protocols that mainly concentrate on land-based activities, all of the countries of the south of the Mediterranean have ratified the Protocol for the Protection of the Mediterranean Sea against Pollution Caused by Land-based Sources and Activities, although only some have accepted the modifications of 1995, which include, among others, the principles of precaution and of 'polluter pays', the best available

techniques (BATs), the best environmental practices (BEPs) and cleaner technologies, which must be taken into account when drafting national plans to combat pollution.

2.1.1. Algeria

Introduction

Algeria is an Arab country in North Africa, on the banks of the Mediterranean. It has a total surface area of 2,381,740 km² and a population of approximately 31.3 million inhabitants.

Great importance in this country's economy lies with the hydrocarbons sector. Algeria possesses the fifth largest reserves of natural gas in the world, it is the second biggest exporter of gas and it is ranked fourteenth for its oil reserves.

In recent years, the Algerian economy has seen an annual growth of approximately 4 %, however, it has managed to do little to reduce the high rate of unemployment or substantially improve the standard of living of the population. The government aims to continue in its efforts to diversify the economy and attract investments from home and abroad in sectors other than the energy sector.

Table 2.1.1. Indicators as to the socioeconomic situation of Algeria.

Surface area	10 ⁶ km ²	2.4
Population	million	31.3
Life expectancy	years	73
Energy per capita	equiv. kg of petroleum	956
Current GDP	10 ⁹ \$	212.3
Growth in GDP	%	6.1
Purchasing power parity of GDP per capita	\$	6,600

*Source World Bank Group and globalEDGE (2004)
(PPP = purchasing power parity)*

Industry and environment

Algeria has undergone significant economic growth in the last four decades, which has been marked by large industrial development. Consequently, many industries have set up in the north of the country, near the large urban areas, and sustainable development has practically not been taken into account.

Technologies were chosen exclusively in accordance with the criterion of productivity and, often, at the expense of pollution, and so today, Algeria has serious problems of pollution. Industry, specifically the mining sector and the petrochemical, chemical and metallurgy sectors, is principally to answer for the country's pollution.

Industry is concentrated on coastal areas (less than 2 % of the total surface area of the country), where the population is denser (around the large industrialised urban areas and towns and cities and, above all, in Algiers, Oran, Constantine, Annaba and Skikda).

The private industrial sector is comprised, in the great majority, of small and medium-sized companies (SMEs), which number between 25,000 and 35,000. Ninety-three percent of them are microcompanies with less than 10 workers. These SMEs can be found in all branches of activity, especially the sectors of textiles and garments, tanning and shoemaking, building materials,

agrofoods and the transformation industries, and they generate a large amount of waste and wastewater.

The main impacts on the environment caused by industry in Algeria are:

- the deterioration in air quality (emissions of atmospheric pollutants, such as exhaust gas, smoke and dust, heavy metal vapours, etc.);
- the pollution of water resources (rivers, aquifers, dams, coastal waters, etc.);
- the generation of industrial waste;
- the country's main areas of industrial activity are along the coast.

The cement industry

The cement sector, like a great many others in the Algerian economy, is increasingly heading towards privatisation. The country is making an effort to attract potential investors, which would improve the opportunities within the sector.

Cement consumption in Algeria grew by an average of 6.1 percent between 1997 and 2003 as a consequence of a significant development in the country's building sector. The construction of new housing, along with a greater number of infrastructures is contributing to an increase in the national demand for cement, and hence it is expected to grow at an annual average rate of 6.5 % at least until 2009.

As regards cement production, local production in 2002 reached 8.95 Mt and grew to 9 Mt in 2003. The opening of a new plant of 2.1 Mt capacity in 2004, by the Algerian Cement Company (ACC), gave rise to a significant increase in the nation's production.

In recent years, new plants have been constructed. Currently, Algeria has 15 integrated plants and a capacity to produce a total of 14.5 Mt of cement.

Cement exports are null. Conversely, imports play an important role within the sector, with Egypt being the main supplier of cement and clinker to Algeria, followed by Turkey. Imports hit their peak value in 2003 at 2.5 Mt but decreased in 2004 to 2 Mt. Imports are expected to continue to decrease as of 2005 but even so maintaining a significant influence within the sector.

Table 2.1.2. Principal data from the cement industry in Algeria in 2004.

Production (kt/year)	10,500
Cement consumption (kt/year)	12,000
Number of integrated cement works	15
(Approx.) no. of employees	6,029
Clinker kiln production capacity kt/year (*)	12,500
Cement prod. capacity in kt/year	14,500

Source. *Global Cement Report 2005*
 (*) *2002 World Cement Directory*

Table 2.1.3. Types of kiln used.

Number of dry process kilns	16
Number of wet process kilns	3
Number of semi-wet process kilns	0
Number of semi-dry process kilns	0
Number of vertical kilns	0
Total kilns	19

Source: World Cement Directory 2002

2.1.2. Egypt

Introduction

Egypt is an Arab country in North Africa, on the banks of the Mediterranean. It has a total surface area of 1,001,450 km² and a population of approximately 66.4 million inhabitants.

In addition to the agricultural capacity of the Nile delta and valley, among Egypt's natural resources are petroleum, natural gas, phosphates and iron ore. The country has sufficient natural gas as to meet domestic demand for many years to come.

The industrial sector continues to be dominated by state-owned companies, which control practically all heavy industry, although a process of reforms and privatisation of the public sector has begun with the aim of increasing opportunities for the private sector. Building, non-financial services and the home market are, in the main, privatised. This has encouraged constant growth in the GDP and the annual growth rate.

Egypt is the second economy in the Arab world. The economy is dominated by the service sector, which accounts for practically half of the GDP.

Table 2.1.4. Indicators as to the socioeconomic situation of Egypt.

Surface area	10 ⁶ km ²	1.0
Population	million	77.5
Life expectancy	years	71
Energy per capita	equiv. kg of petroleum	726
Current GDP	10 ⁹ \$	316.3
Growth in GDP	%	4.5
Purchasing power parity of GDP per capita	\$	4,200

Source World Bank Group and globalEDGE (2004)
(PPP = purchasing power parity)

Industry and environment

Industry is one of the main sectors that are contributing to boosting the economy of Egypt. Including manufacturing and mining, Egypt's industrial sector contributes some 20 % of GDP and employs approximately 14 % of the workforce. Egypt's manufacturing capacity concentrates on relatively few industrial sectors. Seven sectors represent more than 80 % of establishments. The three biggest are

the food and drinks sector, textiles and the chemical industry, the oldest in Egypt. After them come the non-metallic minerals, the production of metals, chemical products and base metals.

Egypt is highly dependent on importation; for example, it needs to import practically all of the wood and paper it consumes.

In Egypt, geographically speaking, industry is highly irregularly distributed. Currently, 41 % of industrial production is located in Greater Cairo, 17 % in the Nile delta, 16.8 % in Alexandria and 14.2 %, in the area of the Suez Canal. The remaining 11 % of industrial production is located in Upper Egypt. This unequal distribution has pushed the country to embark on a new plan to stimulate industrial investment in new communities located in the country's non-agricultural areas.

The public sector, dominated by large companies, holds a predominant position in the chemical and pharmaceutical industries, in engineering and in the electricity industry. Moreover, it has large textiles factories and sugar refineries.

The private sector, dominated by small and medium sized companies (SMEs), includes companies devoted to food and drink, dairy products, spinning and weaving and a variety of crafts. Some of the companies in the private sector with the biggest profits are involved in the production of light tools and electrical equipment as well as fabric and garment printing.

Alexandria is a highly industrialised area where the following are produced: paper, metal, chemical products, pharmaceutical products, plastics, food products, oils, detergents and petroleum. Most of the waste generated by this industry is dumped into lake Mariout, which also receives treated wastewater coming from the treatment works in Alexandria.

The cement industry

Due to the country's bad economic situation, cement consumption has decreased in recent years. Domestic cement consumption in 2002 was 27.2 Mt and it subsequently dropped to 24.5 Mt in 2004. Between 85 and 95 % of all cement sales in Egypt are still in the form of bagged cement; this is indicative of the fact that the main demand comes from the private construction sector. In terms of types of cement, the vast majority of sales are of Ordinary Portland Cement (OPC).

At the end of 2004, Egypt's production of cement consisted of 14 plants with two 2 white cement plants; this means an annual capacity of 33 Mt of cement clinker. Currently, the cement market in Egypt seeks continued expansion and growth in the sector.

In 2003, Egypt was among the five largest cement exporters, to the value of 7.4 Mt, which represents a growth of 5.4 % in comparison with the previous year. The number of Egyptian companies exporting cement rose from 6 in the year 2002 to 13 at the end of 2003. Many markets throughout the world are supplied by Egypt; in the Middle East, the most noteworthy being Yemen and Sudan; and in Europe, Spain and Italy. Egypt even supplies countries in East Africa and the United States.

Since production is far higher than domestic consumption, cement importations are minimal, which is quite a different situation from the 1990s when some 5 Mt were being imported for local consumption. Currently, imports fall short of 0.1 Mt.

Table 2.1.5. Principal data from the cement industry in Egypt in 2004.

Production (kt/year)	31,000
Cement consumption (kt/year)	24,500
Number of integrated cement works	14
(Approx.) no. of employees	6,029
Clinker kiln production capacity kt/year	33,000
Cement prod. capacity in kt/year	38,000

Source. Global Cement Report 2005

Table 2.1.6. Types of kiln used.

Number of dry process kilns	27
Number of wet process kilns	12
Number of semi-wet process kilns	5
Number of semi-dry process kilns	1
Number of vertical kilns	0
Total kilns	45

Source: World Cement Directory 2002

2.1.3. Lebanon

Introduction

Lebanon is an Arab country located in the Middle East on the banks of the Mediterranean sea. It has a total surface area of 10,400 km² and a population of approximately 4.4 million inhabitants.

Lebanon operates a competitive free market system and the country has a strong commercial tradition of *laissez-faire*. The Lebanese economy is principally geared towards the services; the main sectors experiencing growth are banking and tourism.

Table 2.1.7. Indicators as to the socioeconomic situation of Lebanon.

Surface area	10 ⁶ km ²	10.4
Population	million	3.82
Life expectancy	years	72.63
Energy per capita	equiv. kg of petroleum	1,169
Current GDP	10 ⁹ \$	18.83
Growth in GDP	%	4
Purchasing power parity of GDP per capita	\$	5,000

Source World Bank Group and globalEDGE (2004)
(PPP = purchasing power parity)

Industry and environment

In 1999, over 22,000 industrial units were identified in Lebanon, according to the Ministry of Industry, and 29,282 according to the Central Statistics Administration. This figure represented an increase of approximately 50 % since the start of the 1990s. Over 90 % of such units are micro-industries with less than ten employees.

Industry is concentrated in and around Greater Beirut and in Mount Lebanon. Due to the lack of town planning, most small and micro-industries are located in residential areas, outside the industrial estates (95.6 % of industries in Greater Beirut and 75.3 % in Mount Lebanon). Nevertheless, large companies (dedicated to processing food, textiles, chemical products, and cement and building materials), in general, are located in industrial areas.

Data indicate that the recovery of the industrial sector has been surprising, despite the ravages of war. The sector is predicted to grow between 8 and 10 % during the 2001-2010 period.

Approximately 89 % of industries belong to seven main subsectors: food and drink (20 %), metal manufacture (16 %), non-metallic minerals (12 %), furniture (11 %), weaving and textiles finishing (16 %), wood products (10 %) and tanning (6 %).

Most industrial facilities are not equipped with pollution control equipment and they discharge their polluted effluents into coastal and surface waters, which entails a grave risk of pollution for surface and underground water. In addition, the uncontrolled dumping of solid industrial waste and emissions into the atmosphere take place.

The cement industry

The consumption of cement in Lebanon shows a continuous decrease due to the existing state debt, which is reflected in a 50 % fall in consumption per capita, dropping from 1,200 kg in 1997 to 681 kg today. The cement market is relatively unsophisticated: 80 % of the cement used is bagged and the remaining 20 % is sold in bulk.

Currently, Lebanon has four cement works, with a total annual production of 4.8 Mt. This production exceeds consumption and leads to excess capacity for the country. The Lebanese government prohibited imports in 1999 and Lebanon exported 1 Mt to Iraq in 2004 and is struggling to maintain this level and open up exportation to other countries. Hence a growth in the country's exports is foreseen for this sector.

Table 2.1.8. Principal data from the cement industry in Lebanon in 2004.

Production (kt/year)	2,592
Cement consumption (kt/year)	12,000
Number of integrated cement works	4
(Approx.) no. of employees	6,029
Clinker kiln production capacity kt/year (*)	4,416
Cement prod. capacity in kt/year	4,800

Source. *Global Cement Report 2005*

(*) *2002 World Cement Directory*

Table 2.1.9. Types of kiln used.

Number of dry process kilns	8
Number of wet process kilns	0
Number of semi-wet process kilns	0
Number of semi-dry process kilns	0
Number of vertical kilns	0
Total kilns	8

Source: World Cement Directory 2002

2.1.4. Arab Popular Jamahiriya of Libya

Introduction

Libya is an Arab country in North Africa on the banks of the Mediterranean. It has a total surface area of 1,759,000 km² and a population of approximately 5.5 million inhabitants.

The Government dominates the socialist-oriented economy of Libya by totally controlling the country's oil reserves which represent about 95 % of its income through exports and 30 % of the gross domestic product. Revenue generated by petroleum and an relatively small population mean that Libya can enjoy one of the highest GDP (and parity in the purchasing power of GDP) in Africa. Despite the efforts made to diversify the economy and encourage participation by the private sector, the generalised control of prices, loans, trade and currencies hinders growth.

The sectors of building and non-petroleum-related production, which represent approximately 20 % of GDP, have changed from being almost exclusively represented by agricultural product process industries to also encompassing petrochemicals, siderurgy and aluminium industries.

Table 2.1.10. Indicators as to the socioeconomic situation of Libya.

Surface area	10 ⁶ km ²	1.76
Population	million	5.7
Life expectancy	years	76.5
Energy per capita	equiv. kg of petroleum	3,107
Current GDP	10 ⁹ \$	37.48
Growth in GDP	%	4.9
Purchasing power parity of GDP per capita	\$	6,700

Source World Bank Group and globalEDGE (2004)
(PPP = purchasing power parity)

Industry and environment

As previously mentioned, Libya's industrial development has depended to a great extent on the petroleum sector, both as regards the revenue generated by investments and the importation of raw materials. Among industrial activities are those related with petroleum (exploration, production, transport and trading with petroleum-based products), in addition to the sectors dealing with siderurgy, fertilisers, cement, chemical substances and food treatment.

Up until the early 1980s, the whole of the industrial sector was planned by the Government, which had taken control of the aspects of industrial production which were considered to be sensitive or of inaccessible proportions for the country's private sector. Nevertheless, today, Government policy tends towards liberating industry, including the transformation industries, from their dependency on foreign ownership and control. The Government is focussing its attention on developing the petrochemical and oil industries.

The food processing industry heads the production sector, followed by other important industries, such as textiles, and factories producing fertilisers and engineering equipment.

Although the discharging of untreated effluents into the sewage system is common practice among the SMEs in Libyan towns and cities, it is considered not to give rise to serious pollution problems. The large oil refineries, petrochemical, siderurgy, chemical, fertiliser and textiles finishing facilities are, for the most part, located along the coast, particularly in the gulf of Surt. Often, these industries dump untreated effluents via direct outlets into the Mediterranean.

The cement industry

Libya is beginning a promising stage of development and new investments by international companies augur the development of numerous infrastructures so that the construction sector will become one of the most prosperous in the country, which means significant growth in the levels of national consumption of cement.

The annual capacity of cement production by Libya is 6.5 Mt across the seven existing plants, four of which are able to produce 1 Mt, one 800,000 t and the last 350,000 t.

Libya's cement consumption is very similar to the amount it produces, and hence traditionally, Libya has only imported small amounts of cement, from Egypt. It is also supplied by the Far East.

Table 2.1.11. Principal data from the cement industry in Libya in 2004.

Production (kt/year)	3,500
Cement consumption (kt/year)	3,500
Number of integrated cement works	7
(Approx.) no. of employees	6,029
Clinker kiln production capacity kt/year	6,100
Cement prod. Capacity in kt/year	6,500

Source. *Global Cement Report 2005*

Table 2.1.12. Types of kiln used.

Number of dry process kilns	11
Number of wet process kilns	0
Number of semi-wet process kilns	0
Number of semi-dry process kilns	0
Number of vertical kilns	0
Total kilns	11

Source: *World Cement Directory 2002*

2.1.5. Morocco

2.1.5.1. Introduction

Morocco is an Arab country in North Africa, on the banks of the Mediterranean. It has a total surface area of 446,550 km² and a population of approximately 32.725 million inhabitants.

The Moroccan economy is increasingly diversified. Morocco possesses large mineral reserves, has a diversified agricultural sector (including fishing), a broad tourist industry and a developing sector of transformation industries (mainly dealing with garments).

Approximately a third of the transformation industry sector is related with phosphates and another third with agriculture. The remaining third is divided between the textiles industry, the garment industry and the metallurgical industry.

Since the 1980s, the Moroccan Government has pursued a programme of economic reforms with the backing of the International Monetary Fund and of the World Bank. Over the last decade, reforms have contributed to increasing per capita income, to decreasing inflation and to tightening the balance sheet deficit. Nonetheless, the growth in population, rural-urban migration and the increase in active labour force are contributing to push unemployment up in urban areas, despite the strong economic growth and the creation of new jobs.

Table 2.1.13. Indicators as to the socioeconomic situation of Morocco.

Surface area	10 ⁶ km ²	0.45
Population	million	32.72
Life expectancy	years	70.66
Energy per capita	equiv. kg of petroleum	359
Current GDP	10 ⁹ \$	134.6
Growth in GDP	%	4.4
Purchasing power parity of GDP per capita	\$	4,200

*Source World Bank Group and globalEDGE (2004)
(PPP = purchasing power parity)*

Industry and environment

Morocco has one of the largest mining industries in Africa and its oil industry constitutes an essential subsector of the country's economy. The chemical industry is undergoing a period of growth thanks to the exploitation of the wealth of phosphates.

In the parachechemical sector, the pharmaceuticals industry holds a notable position and Morocco is one of the principal markets of the African lubricant industry. The textiles and tanning industries account for approximately a quarter of total industrial production. As for food processing, the main industries are sugar production, flour milling and dairy products. Morocco also has several cement works.

With regard to the activities of the production sector, the breakdown by subsectors is as follows:

- agrofoods industry (35 %, with over 1,641 companies).
- chemical and parachechemical industry (33 %, with 1,963 companies).
- textiles and tanning industry (17 %, with 1,744 companies).

- mechanical, electrical and electronics industry (12 % corresponding to electrical and mechanical industries and 3 % to electronics; over 1,051 companies altogether).

In Morocco, 95 % of the manufacturing framework is made up of small and medium-sized companies (SMEs). Over 14,000 registered SMEs are distributed in the country's urban centres and industrial enclaves, with approximately 50 % of large facilities located in Casablanca, in the El Mohammedia region. Its contribution to GDP is 36 % and it generates 52 % of total employment. The location of the SMEs in densely populated urban areas has negative consequences for both the environment and the inhabitants.

Industrial activities, with special incidence of the chemicals and paracheimical, agrofoods (sugar and vegetable oils), textiles and tanning sectors, have negative effects on the environment, and especially on water resources. The pollution of surface water caused by industrial activities is high, in particular in the Sebu and the Oum er-R'bia basins.

The cement industry

The cement market in Morocco grew by 9.3 % in 2003 reaching approximately 9.3 Mt, putting per capita consumption at about 300 kg. This situation responds to the growth in building activity due to the development of the tourist industry. Casablanca represents the country's biggest cement market, and it accounts for 15 % of the total consumed. In Morocco's cement sector, bagged cement is predominant, but with the development of Moroccan industry, the use of bulk cement is gaining in importance.

Cement production capacity is 11 Mt per year across its 12 plants. However, due to a continued increase in cement consumption, due to the causes mentioned in the previous paragraph, it is expected to reach production of 12.65 Mt in 2008.

Cement exports dropped by 21 % in 2003 and 2004 due to increased domestic demand. Spain, the Canary Islands in particular, is the main market to which Morocco exports clinker; whereas Morocco exports cement to African countries, such as Mauritania, the Gambia and Guinea.

In the field of imports, the importation of white cement clinker from Spain, Greece and Turkey predominates.

Table 2.1.14. Principal data from the cement industry in Morocco in 2004.

Production (kt/year)	9,900
Cement consumption (kt/year)	9,700
Number of integrated cement works	12
(Approx.) no. of employees	6,029
Clinker kiln production capacity kt/year (*)	7,600
Cement prod. capacity in kt/year	11,000

Source. *Global Cement Report 2005*
 (*) 2002 *World Cement Directory*

Table 2.1.15. Types of kiln used.

Number of dry process kilns	10
Number of wet process kilns	1
Number of semi-wet process kilns	2
Number of semi-dry process kilns	2
Number of vertical kilns	0
Total kilns	15

Source: World Cement Directory 2002

2.1.6. Syrian Arab Republic

Introduction

Syria is an Arab country located in the Middle East on the banks of the Mediterranean Sea. It has a total surface area of 185,180 km² and a population of approximately 18.45 million inhabitants.

It is a developing country, of intermediate income and a diversified economy based on agriculture, industry and an expanding energy sector.

Despite the important reforms and development projects that got underway at the beginning of the 1990s, Syria's economy continues to be influenced by poor yielding state companies, scarce investments and relatively low industrial and agricultural productivity. The oil industry has represented almost three quarters of income through exports.

The Government has redirected its economic development priorities, from industrial expansion to a variety of agricultural sectors, with the aim of attaining self-sufficiency, boosting income through exports and containing rural emigration.

Table 2.1.16. Indicators as to the socioeconomic situation of Syria.

Surface area	10 ³ km ²	185
Population	million	18.45
Life expectancy	years	70.03
Energy per capita	equiv. kg of petroleum	1,137
Current GDP	10 ⁹ \$	60.44
Growth in GDP	%	2.3
Purchasing power parity of GDP per capita	\$	3,400

Source World Bank Group and globalEDGE (2004)
(PPP = purchasing power parity)

Industry and environment

The Syrian industrial fabric is highly diversified; the most important sectors, which are predominantly State controlled, are foods, textiles, chemicals, engineering and cement. With all, the private sector has begun to stand out in the textiles, foods and cement industries.

Syria considers that quality is a decisive factor in order to survive the competition of world industrial trade, and hence it has paid special attention to publicising the concepts of Total Quality

Management (TQM) and Cleaner Production (CP) and promoting ISO certification by national industries.

Most industries are SMEs, and the main areas of activity are located around Damascus, Aleppo and Homs.

The main pollutants generated by these industries are wastewater and emissions into the atmosphere. Solid waste is not considered a priority because companies recycle it and reuse it or sell it off for other uses.

The treatment to which the waste generated must be subjected is very expensive for this type of enterprise, which cannot afford to do so without economic aid or some kind of incentive. Thus, the treatment of pollutants depends on the availability of low cost techniques in the context of existing regulations and requirements.

The present Government has demonstrated its commitment to a significant increase in the consignments allocated for the preservation of the environment and the corresponding public services in the budgets of the ministries and institutions involved.

The cement industry

In Syria per capita cement consumption in 2004 was 304 kg. This figure is lower in the eastern half of the region which is currently witnessing an emerging construction process. Official data show that in 2004, cement consumption in Syria reached its historic peak of 6.4 Mt, a figure which is higher than the 5.5 Mt recorded for the previous year.

Cement is produced in Syria at 8 operative plants controlled by 9 state companies, which produce a total of 4.83 Mt of cement clinker. It is expected to reach 5 Mt this year.

The predominant process in the production of cement is the dry process, which leads to significant energy savings. However, most of its production lines are not equipped with modern pollution control systems.

The cement industry has to date been a state monopoly; it is currently opening up to the private sector, which is arousing great interest by foreign investors from Saudi Arabia, Egypt, Turkey and China.

OMRAN is the only company authorised to import cement; its imports from Lebanon, Jordan, Egypt and Turkey have increased in recent years. In 2004, they reached 1.2 Mt, however, this amount does not satisfy existing demand.

Table 2.1.17. Principal data from the cement industry in Syria in 2004.

Production (kt/year)	5,200
Cement consumption (kt/year)	6,400
Number of plants	8
(Approx.) no. of employees	6,775
Clinker kiln production capacity kt/year	4,830
Cement prod. capacity in kt/year (*)	6,010

Source. *Global Cement Report 2005*

(*) *2002 World Cement Directory*

Table 2.1.18. Types of kiln used.

Number of dry process kilns	12
Number of wet process kilns	6
Number of semi-wet process kilns	0
Number of semi-dry process kilns	0
Number of vertical kilns	0
Total kilns	18

Source: World Cement Directory 2002

2.1.7. Tunisia

Introduction

Tunisia is an Arab country in North Africa, on the banks of the Mediterranean Sea. It has a total surface area of 163,610 km² and a population of 10.07 million inhabitants.

Historically, Tunisia's economic growth has been dependent on oil, phosphates, agriculture and tourism. The Government's economic policies were of little success during the first years of independence. In 1986, the State launched a structural adjustment programme aimed at liberalising prices, reducing tariffs and reorienting Tunisia towards a market economy.

Since the application of the stabilisation programme, growth in domestic production, measured in accordance with real growth of GDP, increased from the 2.8 % recorded between 1982 and 1986 to the 4.8 % recorded between 1991 and 2001. In parallel, inflation and the current account deficit decreased significantly.

In 1990, Tunisia joined the General Agreement on Tariffs and Trade (GATT). Moreover, prior to 2002, the Government privatised 163 state companies.

Unemployment continues to be very high for the country's economy (with a rate of 15 % of the active population) and has been worsened by the rapid growth in the workforce.

Table 2.1.19. Indicators as to the socioeconomic situation of Tunisia.

Surface area	10 ³ km ²	163.6
Population	million	10.07
Life expectancy	years	74.89
Energy per capita	equiv. kg of petroleum	825
Current GDP	10 ⁹ \$	70.88
Growth in GDP	%	5.1
Purchasing power parity of GDP per capita	\$	7,100

Source World Bank Group and globalEDGE (2004)
(PPP = purchasing power parity)

Industry and environment

The production sector has come to be one of the most dynamic of the Tunisian economy, showing a clear tendency towards the privatisation of industry, in the framework of economic restructuring

programmes. Although the service sector dominates the economy, industry continues to be one of the main contributors to the growth of GDP (nearly 20 % in 1999), the creation of employment and the generation of a strong currency as a result of exportation.

According to available data, in 2001, the Tunisian industrial sector consisted of 5,262 companies with 10 employees or more, 2,292 of which were devoted entirely to exportation. With regard to industrial sectors, the textiles sector represents 41 % of the country's industry, followed by the food processing sector with 15 %, and the building materials, ceramics and glass sector with 8 %.

The main problems of pollution are linked with the disproportionate consumption of water and energy and the substantial generation of solid waste.

The cement industry

Tunisia's cement sector, just as other sectors in the economy, is heading towards privatisation.

Tunisia is currently implementing a programme to build highways to link the centre with coastal routes as well as the building of other infrastructures, which constitute an important engine for the cement industry.

Cement consumption in 2003 reached 5 Mt, with per capita consumption at 500 kg; hence, regarding cement consumption, Tunisia is ahead of other African countries including Morocco and Egypt. In 2004, the demand for the consumption of cement rose to 5.3 Mt and is expected to grow annually by between 4 and 8 % in the short to medium term.

Today, Tunisia has six cement works, four of which are privatised and are undergoing improvements. Tunisia has a clinker production capacity of 6.3 Mt per year, although this figure is expected to increase to 6.7 Mt once these improvements are fully completed between 2005 and 2006.

At present, imports are negligible, and so, since 2003, Tunisia has gone from being an importer of cement and clinker, to being a new exporter.

Table 2.1.20. Principal data from the cement industry in Tunisia in 2004.

Production (kt/year)	6,000
Cement consumption (kt/year)	5,300
Number of plants	6
(Approx.) no. of employees	3,219
Clinker kiln production capacity kt/year	6,300
Cement prod. capacity in kt/year	7,100

Source. *Global Cement Report 2005*

Table 2.1.21. Types of kiln used.

Number of dry process kilns	10
Number of wet process kilns	3
Number of semi-wet process kilns	0
Number of semi-dry process kilns	0
Number of vertical kilns	0
Total kilns	13

Source: *World Cement Directory 2002*

2.2. COUNTRIES IN THE NORTH OF THE MEDITERRANEAN

The five countries in the north of the Mediterranean that make up this group - Greece, France, Italy, Monaco and Spain – are considered high-income European states and all, barring Monaco, are members of the European Union (EU). These countries share the obligation to fulfil EU regulations and adapt their directives to national Law in the short term. Likewise, they are obliged to adopt the necessary measures so as to meet the requirements of said European regulation.

Industry and environment

The state of the environment in the EU has worsened constantly over the last decades. Each year some 2,000 million tonnes of waste are generated and this figure is increasing. For all of this, the protection of the environment is one of the biggest challenges Europe faces today.

As in the other member States of the EU, the industrial sector in the north Mediterranean subregion is very heterogeneous, it presents big differences between regions and is often concentrated near highly populated urban areas. Industry has been forced to invest in environment-treatment equipment for many years, and also to adopt more environmentally friendly technologies. One of the main industrial activities is the production of automobiles, which represents a quantitative and qualitative difference with regard to other areas of the Mediterranean and acquires special importance when analysing the effect of the supply chain, which facilitates the dissemination of CP and environmental management systems.

Political and legal framework

As EU member States, the countries in the northern Mediterranean subregion, except Monaco, are subject to European regulations.

Environmental measures are normally adopted by means of directives or rulings proposed by the European Commission, though they must also be accepted by the European Council. Once adopted, it is the Commission's task to control their application. The Directorate General for the Environment is the body of the Commission whose job it is to deal with matters such as the environment, nuclear safety and civil protection.

During the 1970s and the 1980s, EU environmental legislation concentrated on establishing limits to the emission of certain pollutants. Towards the 1990s, initiatives of greater significance were put in place, such as the regulation of the consumption of natural resources or pollution prevention through 'horizontal' regulations.

Many such regulations were adopted during the Fifth EC Environmental Action Programme, which established the Union's environment strategy for the 1992-2000 period. The Programme included an integrated approach to fighting pollution and action to be taken to reduce waste which were transposed in the IPPC Directive, which to a great extent coincides with the principles of CP.

With the IPPC Directive, the EU introduced the concept of best available techniques (BATs) and began the publication of relative documents for consultation, the BREFs, which describe CP solutions adopted by certain sectors and applied to concrete technologies.

The aim of this Directive is to prevent or reduce to a minimum the pollution of the atmosphere, ground and water resulting from the emissions given off by industrial facilities in the countries of the member states, in order to achieve a greater degree of environmental protection. In the IPPC Directive, the minimum obligations are defined, and these must be met by all affected industrial plants that already exist or are to be built. These minimum obligations consist of a list of pollution prevention measures (atmospheric, ground and water) deriving from industrial effluents and other waste and serve as a basis for drawing up exploitation licences for industrial facilities.

2.2.1. Spain

Introduction

Spain is an industrialised European country located in the western part of the Mediterranean basin. It covers a total surface area of 504,750 km² and has a population of 44 million inhabitants.

Table 2.2.1. Indicators as to the socioeconomic situation of Spain.

Surface area	10 ³ km ²	504.8
Population	million	44
Life expectancy	years	79.52
Energy per capita	equiv. kg of petroleum	3,084
Current GDP	10 ⁹ \$	937.6
Growth in GDP	%	2.6
Purchasing power parity of GDP per capita	\$	23,300

Source World Bank Group and globalEDGE (2004)
(PPP = purchasing power parity)

Employment has increased considerably, which has allowed the economy to grow more quickly than the average for the euro zone.

In recent years, Spain's economic performance has enjoyed notable strength thanks to the structural reforms carried out as of the 1990s and the stability of the macroeconomic political framework.

Industry and environment

The rapid development undergone by Spain in the last quarter of a century has turned the country into the eighth world economy among the countries of the OECD. In many cases, this growth has been accompanied by greater pressure on the environment, both as regards the use of natural resources (water, land, etc.) and the generation of pollution.

The country's main industries are food and drink, metallurgy, chemical products, shipyards, the automobile industry, machinery manufacturing, textiles and garments and tourism. Among the goods Spain exports, the most notable are machinery, motor vehicles and food and consumer products.

Some of the greatest threats to the environment are caused by transport, electrical energy production and agriculture.

The cement industry

Spain maintains its position as the largest market for cement in Europe and the countries of the MAP, with its per capita consumption at 1,127 kg — a high figure indeed. The consumption of cement in Spain grew by some 3.9 % to reach 48 Mt in 2004.

The civil engineering industry consumed 41 % in 2004 compared to 44 percent in 2003. The construction market has grown in importance rising from 56 to 59 % of cement consumption in the year 2004.

By autonomous communities, Andalusia is the biggest cement market in Spain, with an increase on the year 2003 of 14.2 %, followed by Valencia, Catalonia and the Mediterranean coast, with a growth of 7.7 % on 2003.

In the year 2004, domestic production reached 46.6 Mt, distributed across 36 integrated plants, in addition to a dozen grinding plants.

There are ten groups in Spain that produce both clinker and cement. The three leading groups are Cemex, Cementos Portland Valderrivas and Holcim, and the three produce half of the cement consumed in Spain. Nearly 88 % is delivered by road, 10 % by sea and 2 % by train.

Cement exports continue to decline; nearly 0.3 Mt of the 1.3 Mt exported are white cement and around 18,000 t are clinker. The United States was the Spanish export market's largest customer with 0.28 Mt.

Imports of cement and clinker in 2004 grew by almost 10 percent last year to 8.2 Mt, but within this total, cement imports decreased by 2.3 Mt in 2003 to 1.9 Mt in 2004 and clinker imports increased by 5.9 Mt in 2003 to 6.3 Mt in 2004. Egypt is the number one market of Spanish imports with 3.5 Mt and a growth rate of 119%.

Table 2.2.2. Principal data from the cement industry in Spain in 2004.

Production (kt/year)	45,500
Cement consumption (kt/year)	47,200
Number of integrated plants	36
(Approx.) no. of employees	7,000
Clinker kiln production capacity kt/year (*)	35,300
Cement prod. capacity in kt/year	56,000

Source. *Oficemen*

Table 2.2.3. Types of kiln used.

Number of dry process kilns	53
Number of wet process kilns	3
Number of semi-wet process kilns	0
Number of semi-dry process kilns	4
Number of vertical kilns	0
Total kilns	60

Source: *Oficemen2004*

2.2.2. France

Introduction

France is an industrialised European country whose southern part borders the Mediterranean Sea. It covers a total surface area of 547,000 km² and has a population of approximately 60.66 million inhabitants.

Table 2.2.4. Indicators as to the socioeconomic situation of France.

Surface area	10 ³ km ²	547
Population	million	60.66
Life expectancy	years	79.6
Energy per capita	equiv. kg of petroleum	4,366
Current GDP	10 ⁹ \$	1.74
Growth in GDP	%	2.1
Purchasing power parity of GDP per capita	\$	28,700

Source World Bank Group and globalEDGE (2004)
(PPP = purchasing power parity)

France is the fourth largest western industrialised economy. It has important agricultural resources, a broad, consolidated industrial base and a highly qualified workforce. It also has a dynamic services sector whose economic activity is increasing more and more and is responsible for practically all of the new jobs created in recent years.

France has successfully developed the telecommunications, aerospace and arms sectors. As for energy production, the country has especially concentrated on developing nuclear energy, which today represents 80 % of the country's electricity production. The nuclear waste is stored in reprocessing facilities on French territory.

Industry and environment

France is the fourth industrial producer in the world. Its manufacturing industry is highly diversified and constitutes the main source of income deriving from exports.

The main industrial sectors are:

- **Food industry: currently**, the food industry sector is the one that generates the greatest number of work posts in the country. France is the main producer of sugar beet in the world and is second for wine and cheese production. Other significant food products include meat, bread and sweets.
- **Manufacture of automobiles, aeroplanes, ships and trains:** France is the fourth largest producer of automobiles in the world and, moreover, has an important ship, aeroplane and train building industry.
- **Electric and electronics industry:** in France, equipment is produced for telecommunications, computers, televisions, radios and other devices.
- **Metallurgy industry:** the production of iron and steel, and the aluminium industry, constitutes another important source of employment in France.
- **Chemical and pharmaceuticals industry:** France's chemical industry produces a broad range of products, ranging from industrial chemical substances to plastics, fertilisers, solvents, cosmetics and pharmaceutical products.
- **Textile industry:** it produces articles made from cotton, silk and wood.

2.2.2.1. The cement industry

Cement consumption in France decreased by 0.2 % in 2003, at 20.68 Mt. Nevertheless, the growth in the activity of house building will lead to a growth in demand by this sector.

Industry accounted for 47.3 % of domestic cement consumption in 2003 and certain products with 18.2 %. Bulk cement increased its market share from 71.1 % in 2002 to 72.2 % in 2003 while the consumption of bagged cement fell to 27.8 %.

In terms of the use of cement, civil engineering represents 38 % of consumption, followed by 36 % in the construction of housing, 20 % in the construction of commercial and industrial buildings and 14 % for the repair of buildings.

Domestic cement production is at 27.2 Mt across 29 integrated plants, in addition to 5 grinding plants.

The use of alternative fuels in the kiln dropped from 34 percent to 33 percent in 2003, the use of limestone and slag as cement increased whereas the use of fly ash continued to decrease.

Total French exports increased by 12 % reaching the figure of 1.71 Mt in 2003, with cement exports greater than 8.7 % and clinker exports growing by 17.2 % to 0.70 Mt. Germany is the leading market of French exports with 0.30 Mt.

Total imports fell by 5 % to 2.45 Mt, of which clinker imports dropped by 13.1 % to 0.24 Mt and cement imports by 4.7 % to 2.21 Mt. Greece is the main market of clinker imports. Spain and Belgium are the predominant markets of cement imports, with 1.02 Mt and 0.45 Mt respectively.

Table 2.2.5. Principal data from the cement industry in France in 2004.

Production (kt/year)	20,900
Cement consumption (kt/year)	21,800
Number of integrated cement works	29
(Approx.) no. of employees	14,291
Clinker kiln production capacity kt/year (*)	21,051
Cement prod. capacity in kt/year	27,200

Source. *Global Cement Report 2005*
 (*) 2002 *World Cement Directory*

Table 2.2.6. Types of kiln used.

Number of dry process kilns	20
Number of wet process kilns	2
Number of semi-wet process kilns	1
Number of semi-dry process kilns	18
Number of vertical kilns	3
Total kilns	44

Source: *World Cement Directory 2002*

2.2.3. Greece

Introduction

Greece is an industrialised European country located in the south of Europe bordering the Mediterranean Sea. It has a total surface area of 131,940 km² and a population of 10.6 million inhabitants.

Table 2.2.7. Indicators as to the socioeconomic situation of Greece.

Surface area	10 ³ km ²	131.9
Population	million	10.67
Life expectancy	years	79.9
Energy per capita	equiv. kg of petroleum	2,635
Current GDP	10 ⁹ \$	226.4
Growth in GDP	%	3.7
Purchasing power parity of GDP per capita	\$	21,300

Source World Bank Group and globalEDGE (2004)
(PPP = purchasing power parity)

The Greek economy has undergone solid growth for years, above the forecast average for the EU. The services sector has experienced the greatest, quickest growth. Tourism is one of the main sources of the country's income in currencies, although the industry has taken its time to expand and its infrastructure is insufficient. The food industry, however, has proliferated in response to the new markets of Greece's neighbouring countries. The production of high technology equipment, especially in the field of telecommunications, is one of the most dynamic sectors. Agriculture still employs 15 % of the workforce.

Industry and environment

Below are the details of some of the economic activities which have the greatest environmental impact in Greece:

Chemical industry

This sector has managed to accommodate the need for companies that comprise it to have an outstanding environmental profile. To this end, it is well known that the Greek chemical industry has achieved a sufficient level of adaptation to international technological developments on pollution prevention and control issues, giving priority to intervention at source.

Paper / textiles / tanning industries

Most of the Greek paper industries fulfil the directives of the IPPC Directive (European directive on integrated pollution prevention and control), use progressive production techniques and quickly adopt most best available techniques (BATs) as they appear. Sometimes, however, improper handling of equipment reduces the efficacy of the technology.

Only one of the tanning industries (the biggest both in terms of size and production) meets the stipulations of the IPPC Directive and has already implemented some BATs. In the rest of the companies on the sector, the BATs and any other measure aimed at reducing pollution are non-existent.

The textiles industry is very important in Greece; it creates a large number of jobs and makes a significant contribution to national income given that it is an export sector which mainly uses locally produced raw materials (cotton). Some 220 companies of varying sizes exist in the textiles sector, 75 % of which are family-sized, with less than 10 employees. Despite everything, there is now a tendency to create bigger companies; small businesses are progressively disappearing.

Many of the problems of water pollution are brought about by textiles finishing industries. The large companies that continue to invest in BATs show continuous improvement, whereas those that remain anchored in the old practices are suffering a constant decline. The main requirement as regards

pollution control is the treatment of liquid effluents and the removal of red sludge. The areas where textiles finishing industries are located are those of Athens, Viotia and Thessaloniki.

Cement, glass and ceramics industries

In cement-producing industries, the degree of implementation of technologies included among the BATs is very high; conversely, the current level of environmental protection of the industries producing lime is far from satisfactory. The strict levels of emissions put forward by the BREF document are a problem. Greek companies that produce asbestos and derivatives have apparently implemented most BATs, especially for the purposes of workers' health and safety. Glass industries, however, have only adopted some basic measures against pollution.

Metal transformation industries

The sector's small and medium-sized companies have economic problems in implementing new technological developments, unlike the large industries, which have achieved an acceptable degree of adaptation to international technological developments with regard to pollution prevention and control, giving priority to acting at source.

Energy sector

This sector is made up of large lignite and petroleum fuel plants. The facilities have large units for combustion, the treatment of crude oil and natural gas and the production of electricity on the basis of lignite or petroleum, in addition to the four existing refineries.

Food industry

The food industry is one of the country's most consolidated sectors (with almost a third of the total number of industrial units), and is dominated by a large number of companies devoted to the rearing of poultry and pig farming, the processing of agricultural produce, the production of oil, the treatment and packaging of consumer goods, dairy produce, drinks, etc. Problems of pollution mainly arise at small facilities or in seasonal companies.

Cement sector industry

Cement consumption grew for the ninth consecutive year in 2003, over 3.5 % on the previous year, reaching an estimated figure of 11 Mt. Per capita cement consumption is at the one tonne mark. It should be pointed out that growth in the demand for cement has been witnessed in the province of Attica, the site of the Olympic Games.

The demand for bagged cement continues to decrease and was less than 24 % in 2002 (statistical data for 2003 are not available).

Due to the geography of Greece and the scarce development of terrestrial infrastructure, maritime transport plays a very important role in the domestic distribution of cement.

Greece presents an annual production capacity of 16.5 Mt shared out across 8 plants belonging to three different companies, of which the Heracles Group has the largest sales ratio.

The presence of large reserves of limestone close to the sea makes Greece an ideal country for cement exportation, and has led to the three producers being involved in the export business. In 2002, when the industry had to deal with scarce cement production capacities and a growing domestic demand, cement clinker exports dropped considerably. As a result, Heracles increased its production and was able to export an estimated 0.45 Mt in 2003. The United States of America is the largest market for Greek cement exports at close to 0.8 Mt in 2003.

As regards the kinds of cement, most exports are of grey cement with the exception of Albania and Serbia and Montenegro, to which large amounts of pozzolanic cement are also exported. Concerning clinker, France was the main destination in 2003.

Table 2.2.8. Principal data from the cement industry in Greece in 2004.

Production (kt/year)	15,700
Cement consumption (kt/year)	10,100
Number of plants	8
(Approx.) no. of employees	3,423
Clinker kiln production capacity kt/year (*)	11,800
Cement prod. capacity in kt/year	16,500

Source. *Global Cement Report 2005*

(*) *2002 World Cement Directory*

Table 2.2.9. Types of kiln used.

Number of dry process kilns	15
Number of wet process kilns	0
Number of semi-wet process kilns	0
Number of semi-dry process kilns	0
Number of vertical kilns	0
Total kilns	15

Source: *World Cement Directory 2002*

2.2.4. Italy

Introduction

Italy is an industrialised European country located in the Mediterranean region and is surrounded by the Mediterranean Sea. It has a total surface area of 301,200 km² and a population of approximately 58.1 million inhabitants.

Table 2.2.10. Indicators as to the socioeconomic situation of Italy.

Surface area	10 ³ km ²	301.2
Population	million	58.10
Life expectancy	years	79.68
Energy per capita	equiv. kg of petroleum	2,974
Current GDP	10 ⁹ \$	1,609
Growth in GDP	%	1.3
Purchasing power parity of GDP per capita	\$	27,700

Source *World Bank Group and globalEDGE (2004)*

(PPP = purchasing power parity)

Italy has changed from being a fundamentally agricultural economy to holding fifth place in world ranking. It is a country of scarce resources. Much of its surface area is not suitable for farming, and hence Italy has become a net importer of food.

Most of the raw materials necessary for manufacture and over 80 % of the country's energy sources are imported. Italy's economic strength is based on the processing and manufacture of goods, principally in small and medium sized family businesses.

Industry and environment

Among priority environmental questions are atmospheric pollution in towns and cities, land and water management, waste management, the preservation of the environment and the landscape, climate change, the management of transport and the protection of a coastal areas and marine life.

The main sectors of industry that generate toxic and hazardous waste are: the organic and inorganic chemical industry, surface treatment, the electronics industry, mining and transport, recycling, the textiles industry, the pulp and paper industry, energy production, the agrofoods industry and the tanning industry.

Industry employs impact reduction measures in certain processes and sectors.

In the 1990s, significant breakthroughs towards improved air quality took place in the Italian industrial sector. Emissions of SO_x, NO_x, CO, VOCs (from solvents), dioxins and furans decreased; in fact it was the only sector to reduce CO₂ emissions. Italy has made much progress for the establishment of the infrastructures that will allow managing industrial atmospheric pollution.

The cement industry

State plans in Italy for the building of new infrastructures have provided Italy with a high demand for cement and turn civil engineering into the sector that consumes the most. Hence, in 2003, demand by Italy for cement grew to 43.5 Mt.

The Italian cement market is fragmented into 20 groups, with a total of 80 plants including 54 integrated plants and 26 grinding plants, with total cement production capacity at 58 Mt per year.

Total exports decreased by around 5 % in 2003 reaching 2.26 Mt. Clinker exports were scarce, always less than 600,000 t, essentially going to Switzerland and Spain. Albania maintains its position as the largest market to which Italy exports, representing 22 % of cement exports.

Imports of both cement and clinker increased in 2003, cement from 2.1 Mt to 2.2 Mt and clinker from 1.8 Mt to 2.3 Mt. Most imports are inside the Mediterranean and Black Sea areas. During the first half of 2004, the drop in cement importations was made up for by an increase in clinker imports, principally by independent grinding plants.

Table 2.2.11. Principal data from the cement industry in Italy in 2004.

Production (kt/year)	44,800
Cement consumption (kt/year)	45,000
Number of plants	80
(Approx.) no. of employees	N/A
Clinker kiln production capacity kt/year (*)	N/A
Cement prod. capacity in kt/year	58,000

Source. *Global Cement Report 2005*
(*) *2002 World Cement Directory*

Table 2.2.12. Types of kiln used.

Number of dry process kilns	58
Number of wet process kilns	11
Number of semi-wet process kilns	0
Number of semi-dry process kilns	39
Number of vertical kilns	1
Total kilns	109

Source: World Cement Directory 2002

2.2.5. Monaco

Introduction

Monaco is a European country located on the banks of the Mediterranean Sea. It has a total surface area of 1.95 km² and a population of 32,409 inhabitants.

Table 2.2.13. Indicators as to the socioeconomic situation of Monaco.

Surface area	km ²	1.95
Population	miles	32.4
Life expectancy	years	79.57
Energy per capita	equiv. kg of petroleum	N/A
Current GDP	10 ⁹ \$	870
Growth in GDP	%	0.9
Purchasing power parity of GDP per capita	\$	27,000

Source World Bank Group and globalEDGE (2004)
(PPP = purchasing power parity)

Monaco is a small country whose economy is principally based on the financial, commercial and tourism sectors. Tourism accounts for almost 25 % of annual income; the Principality of Monaco has been a great tourist centre since the inauguration of its famous casino in 1856. Monaco is also noteworthy for its activities in the field of maritime sciences.

2.2.5.1. Industry and environment

Monaco's industrial sector has achieved a considerable degree of development in less than a century. Since 1906, when the State financed the construction of the first industrial estate in Fontvieille, a number of industries have set up there such as the brewery of Monaco or companies in the flour milling and chocolate production sectors. In the last twenty years, almost 200,000 m² of industrial surface area have been built. Available land in the Principality is so scarce that the industrial facilities have set up in buildings of up to thirteen storeys high.

Currently, Monaco presents quite diversified industry. It has a large number of consolidated companies in a variety of sectors: some 23 belong to the chemical, pharmaceuticals, parapharmaceuticals and cosmetics industry; 13 to the processing of plastics; 21 to the graphic arts, publishing and packing industries; 22 to the electrical and electronics industry and mechanical and precision engineering; 8 to the textiles and garments sector, and others, such as construction companies, make up a total of some 200 companies.

The chemical products, pharmaceuticals and cosmetics sector seems to be the weightiest, but companies dedicated to processing plastics and the manufacture of electrical and electronic equipment are also highly important. Other sectors such as those in the world of mechanical engineering, packaging, graphic arts and garments are also noteworthy, although to a lesser degree. The main environmental problem associated with these sectors is water pollution.

The cement industry

Monaco has no cement production plants, and hence this sector has no relevance.

2.3. COUNTRIES IN THE EAST OF THE MEDITERRANEAN

This group includes countries with a common tendency to implement similar environmental legislation to the European Union. Some of them, like Cyprus, Malta and Slovenia, since their integration into the EU, have been involved in the process of adapting their regulations to those of the EU. Turkey, as a short to medium term candidate for entry into the EU is also in the process of adaptation. Other countries such as Bosnia-Herzegovina, Croatia and Albania have also begun processes to adopt similar environment regulations to those applied in the EU. EU candidate countries have begun an adaptation process, with different programmes depending on the date of integration; these include the adaptation of domestic industry and of environmental conditions. Israel has also been included in this group as, despite not being a member of the EU, it has a great many connections with the EU, due, in part, to the similarities it has in the characteristics of its industries and the commitments it has undertaken to protect the Mediterranean Sea.

Industry and environment

The countries grouped into this subregion differ as regards their recent past. Some east-Mediterranean countries, specifically Albania, Bosnia-Herzegovina, Croatia and Slovenia, are currently going through stages of economic transformation as a result of the reforms undergone following the fall of communism and the gradual liberalisation of the market. Central planning has all but disappeared from their politics and all have embarked on independent liberalisation, macroeconomic stabilisation, legal and institutional reform and privatisation programmes. Since 1990, they have been devoted to changing their economies to capitalism and opening up channels for foreign investment. The industry constitutes an important component of the economy in many such countries, at the same time as the services sector is gaining greater weight in some of them.

Political and legal framework

The countries of this subregion have made notable progress with regard to the passing of new environmental legislation. However, to date, this process has not been accompanied by effective implementation of either old laws and regulations or of recently passed ones. Achievements regarding the enforcement of this regulation and encouraging industry to adopt environmentally friendly practices can, in many cases, be classified as mediocre, if not poor.

For many of the countries in the east of the Mediterranean, European Union legislation is a compulsory reference. The EU has had much influence on many of these countries, not just in terms of economic development, but also in the management of the environment, motivating a timely movement towards harmonisation with European regulations as a means to accelerate their adhesion to the EU.

In most of these countries, the granting of licences for production activities is shared by different government bodies and agencies, which often gives rise to a complete lack of coordination. To this end, some of them are solving this by applying the IPPC system establishing an integrated approach in the awarding of licences. Among them, Slovenia, Cyprus and Malta are at an advanced stage.

In the international framework for the protection of the environment through pollution prevention, all of the countries of the east of the Mediterranean have adhered to, signed or ratified the Basel Convention on Hazardous Waste and the Stockholm Convention on Persistent Organic Pollutants. As for reducing the ozone layer, all have also ratified the Montreal Protocol and, with the exception of Albania, its first amendments. With regard to climate change, most countries have signed or ratified the Kyoto Protocol, including Albania, Cyprus, Slovenia, Israel, Malta and Turkey.

Within the framework of the Mediterranean Action Plan, and in respect of the protocols dealing with land-based activities, all countries have ratified the Protocol for the Protection of the Mediterranean Sea against Pollution from Land-Based Sources and Activities, although only some of them have accepted the amendments of 1995.

As regards the Hazardous Waste Protocol, only Albania, Malta and Turkey have ratified it.

2.3.1. Albania

Introduction

Albania is an East European country located in the Mediterranean area. It has a total surface area of 28,748 km² and a population of approximately 3.5 million inhabitants.

Table 2.3.1. Indicators as to the socioeconomic situation of Albania.

Surface area	10 ³ km ²	28.74
Population	million	3.56
Life expectancy	years	77.24
Energy per capita	equiv. kg of petroleum	522
Current GDP	10 ⁹ \$	17.46
Growth in GDP	%	5.6
Purchasing power parity of GDP per capita	\$	4,900

*Source World Bank Group and globalEDGE (2004)
(PPP = purchasing power parity)*

Albania's conversion from a centralised economy to a market-oriented system dates back to the beginning of 1992, after the GDP fell by more than 50 % in comparison with the highest recorded value in 1989. The democratically elected Government launched an ambitious programme of economic reforms and put the country on the road towards the market economy. Among the reforms considered were the privatisation and reform of the business and finance sectors.

Industry and environment

Albania is a country with a low-to-medium level of income in comparison with other countries in the area. The limited availability of resources restricts investment devoted to protecting the environment. Nevertheless, given that the contribution by industrial production to GDP has dropped since 1990, the impact of industrial activity on the environment has also been considerably reduced as a result of the elimination of multiple hazardous sources of environmental pollution.

Apart from agriculture, which represents almost half of the total of the active population, today, industrial activity comprises the following activities: mining and copper enrichment, chrome ore mining, the extraction and refinement of petroleum, building materials and electrical production. The main industrial waste is generated in these industrial sectors.

Most State-owned industries have closed leaving the waste accumulated in old industrial plants as the main environmental problem.

The cement industry

Cement consumption in Albania is expected to increase rapidly due to the pressure of the building of new infrastructures and housing, but local political problems are retarding the economy and making growth lower than what was originally forecast. Demand jumped from 1.65 Mt in 2002 to 1.76 Mt in 2003.

Albania does not have any substantial cement production capacity; it has 5 plants with a total capacity of 1.6 Mt. In practice, only two plants are operative, which limits total capacity to 0.2 Mt.

The Albanian statistics office pointed out that 1.33 Mt/year of cement were imported in 2001, most of which came from Greece and Croatia.

Table 2.3.2. Principal data from the cement industry in Albania in 2004.

Production (kt/year)	200
Cement consumption (kt/year)	1,850
Number of integrated cement works	5
(Approx.) no. of employees	N/A
Clinker kiln production capacity kt/year (*)	1,600
Cement prod. capacity in kt/year	1,600

Source. *Global Cement Report 2005*

(*) *2002 World Cement Directory*

Table 2.3.3. Types of kiln used.

Number of dry process kilns	0
Number of wet process kilns	0
Number of semi-wet process kilns	2
Number of semi-dry process kilns	0
Number of vertical kilns	0
Total kilns	2

Source: *World Cement Directory 2002*

2.3.2. Bosnia-Herzegovina

Introduction

Bosnia-Herzegovina is a country from the east of Europe on the banks of the Adriatic Sea. It has a total surface area of 51,129 km² and a population of approximately 4.02 million inhabitants.

Table 2.3.4. Indicators as to the socioeconomic situation of Bosnia-Herzegovina.

Surface area	10 ³ km ²	51.1
Population	million	4.02
Life expectancy	years	72.85
Energy per capita	equiv. kg of petroleum	1,096
Current GDP	10 ⁹ \$	26.21
Growth in GDP	%	5
Purchasing power parity of GDP per capita	\$	6,500

*Source World Bank Group and globalEDGE (2004)
(PPP = purchasing power parity)*

The economy of Bosnia-Herzegovina (B-H) still bears the curse of centralised planning. Industry has surplus staff, reflecting the rigidity of a planned economy. Three years of war destroyed the economy and the infrastructures. However, advances have been considerable since the country has enjoyed peace. Inflation has remained low, thanks to the strict exchange rate regime adopted. In spite of everything, growth has not been equal. The most immediate concern is to revitalise the economy. To do so, the general situation should head in the direction of the private sector and the market economy.

One of the main priorities in order to protect the Mediterranean area of B-H is the construction of a wastewater treatment infrastructure. As the region lacks a fully development treatment network, some towns and villages and industries dump their wastewater straight into poorly structured septic tanks which often have leaks, and in turn pollute underground water.

Industry and environment

The pollution of the Adriatic river basin of Bosnia-Herzegovina, which covers a total of 12,410 km², comes both from points of emission and diffuse sources mainly located in the karst areas which, given their vulnerability, quickly percolate pollutants to the subsoil.

Large scale industry is mainly structured into industrial companies: agrofoods, aluminium, surface treatment; wood, building materials, textiles and electrics (hydroelectric and thermoelectric). Due to the situation brought about by war, most of the large scale industries that existed previously work at very low yields, which is, in most cases, less than 10 % of the normal, habitual capacity prior to the war. Moreover, available treatment systems are out-of-use.

The main problem is the inexistence of industrial and municipal wastewater treatment plants, given that effluents are dumped directly.

The cement industry

In the year 2002, the demand for cement in Bosnia-Herzegovina reached a peak of 1.7 Mt but it dropped in 2003 by about 8 %. Per capita cement consumption has stabilised in recent years at around 400 kg.

The high percentage of bagged cement required, 70 % in the year 2003, is beginning to decline.

Bosnia-Herzegovina's total production capacity is 1.05 Mt shared between the two cement plants that belong to HeidelbergCement and Asamer & Hufnagl.

Exports of cement or of clinker are non-existent given that the total capacity is insufficient for the existing demand for cement in the country.

Croatia exports to Bosnia-Herzegovina, followed by Hungary, while white cement is supplied by Italy and Slovakia.

Table 2.3.5. Principal data from the cement industry in Bosnia-Herzegovina in 2004.

Production (kt/year)	920
Cement consumption (kt/year)	1,620
Number of integrated cement works	2
(Approx.) no. of employees	292
Clinker kiln production capacity kt/year (*)	690
Cement prod. capacity in kt/year	1,050

Source. *Global Cement Report 2005*
 (*) 2002 *World Cement Directory*

Table 2.3.6. Types of kiln used.

Number of dry process kilns	2
Number of wet process kilns	0
Number of semi-wet process kilns	0
Number of semi-dry process kilns	0
Number of vertical kilns	0
Total kilns	2

Source: *World Cement Directory 2002*

2.3.3. Cyprus

Introduction

Cyprus is a European island located in the north east of the Mediterranean basin. It has a total surface area of 9,250 km and a population of approximately 780,000 inhabitants.

Table 2.3.7. Indicators as to the socioeconomic situation of Cyprus.

Surface area	10 ³ km ²	9.25
Population	miles	780.1
Life expectancy	years	77.65
Energy per capita	equiv. kg of petroleum	3,203
Current GDP	10 ⁹ \$	15.71
Growth in GDP	%	2.6 (North Cyprus)
Purchasing power parity of GDP per capita	\$	20,300

Source *World Bank Group and globalEDGE (2004)*
 (PPP = purchasing power parity)

Cyprus has an open, free market and a service and, in part, light-industry based economy. The Cypriot people is one of the most prosperous in the Mediterranean. In the last twenty years, the economy has left agriculture and moved to light industry and the services. The services sector, which includes tourism, represents nearly 70 % of the GDP and employs 62 % of all workers.

The commercial sector is vital for the country as the island is not self-sufficient from the point of view of food, and it has scarce natural resources. Cyprus has to import fuel, most raw materials, heavy plant and transport equipment.

Industry and environment

The bases of the Cypriot economy lie in tourism and the services sector, including telecommunications, the shipping industry and banking.

With time, the dense population of the coastal areas, caused by tourism, the services and the considerable emigration coming from urban areas have ended up putting a large amount of pressure on the coastal environment, especially during the high season. Industrial activities also add to this pressure since the main industries (energy production, cement, wine and oil refining) are all located on the coast. These activities are producing signs of small scale, local pollution. With all of this, the quality of the water is good throughout the country thanks to the existence of strict laws as to the dumping of wastewater and the protection of the environment and natural habitat.

The cement industry

The sales of cement in the south of Cyprus totalled 761,400 t in the first half of 2004, which was higher than the 630,900 t for the same period in 2003. Mainly responsible for this increased consumption in cement was the growing demand by the government due to projects to build new infrastructures.

The largest producer of cement in Cyprus is the Vassiliko Cement Works with a capacity of 1.2 Mt/year, followed by Cyprus Cement (CCC) which produces 0.4 Mt/year.

Efforts to improve the economy with tourism and the building of new infrastructures make the cement sector in Cyprus a promising market.

Table 2.3.8. Principal data from the cement industry in Cyprus in 2004.

Production (kt/year)	1,890
Cement consumption (kt/year)	1,570
Number of integrated cement works	2
(Approx.) no. of employees	387
Clinker kiln production capacity kt/year (*)	1,690
Cement prod. capacity in kt/year (*)	1,730

Source: *Global Cement Report 2005*

(*) *2002 World Cement Directory*

Table 2.3.9. Types of kiln used.

Number of dry process kilns	2
Number of wet process kilns	0
Number of semi-wet process kilns	0
Number of semi-dry process kilns	4
Number of vertical kilns	0
Total kilns	6

Source: *World Cement Directory 2002*

2.3.4. Croatia

Introduction

Croatia is a country in the east of Europe on the banks of the Adriatic Sea. It has a total surface area of 56,542 km² and a population of approximately 4.49 million inhabitants.

Table 2.3.10. Indicators as to the socioeconomic situation of Croatia.

Surface area	10 ³ km ²	56.5
Population	million	4.49
Life expectancy	years	74.45
Energy per capita	equiv. kg of petroleum	1,775
Current GDP	10 ⁹ \$	50.33
Growth in GDP	%	3.7
Purchasing power parity of GDP per capita	\$	11,200

Source World Bank Group and globalEDGE (2004)
(PPP = purchasing power parity)

Croatia underwent an accelerated process of industrialisation and diversification after the Second World War. Decentralisation took place in 1965 and allowed the growth of certain sectors, such as tourism. The benefits generated by Croatian industry were used to develop the poorest regions of the old Yugoslavia. This, together with austere programmes and hyperinflation in the eighties, gave rise to much discontent, which ended up feeding the pro-independence movement.

Privatisation under the new Croatian Government had hardly begun when the Croatian war of independence broke out (1991-1995) which ravaged the country's economic infrastructure. After a period of growing unemployment, reforms started to be applied, which included a programme of taxing added value, which enjoyed great success, the planned privatisation of State-controlled companies and the revision of budgets in order to cut back on expenditure and reduce deficit. Low inflation and monetary stability constitute the main economic achievements.

Industry and environment

The industrial sectors that play an active role in the economy and in the environmental pollution of the country are the energy sector, cement works, the food industry, oil refining, metallurgy, chemicals, paper and pulp, textiles and agriculture.

Despite the fact that industry has not adopted voluntary agreements, the energy production sector, more specifically, oil refineries and thermal energy plants, has been most actively involved in promoting cleaner production. The situation is inverted in the sector of the SMEs, since their degree of compliance with environmental legislation is worse than in the large companies and they lack information and training as to the opportunities of CP.

Croatia has concluded the primary training stage in CP. The concept of CP is being introduced to industry. Nonetheless, the country has several hotspots indicating a need for greater action in CP-related issues.

The cement industry

The consumption of cement in Croatia has greatly increased in the last two years. The Croatian Cement Association shows that the volume grew by around 18 %, with per capita consumption at 165 kg, which was, in part, brought about by the start-up of the state motorway programme.

The solidness of civil engineering has given rise to the fact that national bulk cement supply has risen and in 2003 reached 61 % of local supplies compared to the 54 % of the previous year. Eighty-five percent of national supplies are transported by road, around 10 % by train and almost 5 % by boat.

Cement production rose by some 8 % in 2003 reaching 3.57 Mt, despite one existing plant being idle for a long period of time. Currently, overall national cement production capacity in Croatia is at 4.4 Mt across 7 plants.

The use of alternative kiln fuels has been relatively limited to date, but due to recent research, this situation is likely to change.

Traditionally, Croatia has been a cement exporting country, although the levels of exports in the year 2003 dropped as a result of the situation of the nation. Bosnia-Herzegovina is the main market for Croatian cement exports.

With the closure of one of the plants, the volume of cement and clinker imports increased. Imports are from Hungary and Slovenia, and white cement is imported from Slovakia and Greece. Clinker imports fell in the year 2003 but in 2004 reached 40,000 t.

Table 2.3.11. Principal data from the cement industry in Croatia in 2004.

Production (kt/year)	3,800
Cement consumption (kt/year)	2,730
Number of integrated cement works	7
(Approx.) no. of employees	1,811
Clinker kiln production capacity kt/year (*)	2,600
Cement prod. capacity in kt/year	4,400

Source: *Global Cement Report 2005*

(*) *2002 World Cement Directory*

Table 2.3.12. Types of kiln used.

Number of dry process kilns	5
Number of wet process kilns	0
Number of semi-wet process kilns	0
Number of semi-dry process kilns	0
Number of vertical kilns	0
Total kilns	5

Source: *World Cement Directory 2002*

2.3.5. Slovenia

Introduction

Slovenia is a country in the east of Europe, on the banks of the Adriatic Sea. It has a total surface area of 20,273 km² and a population of approximately 2 million inhabitants.

Table 2.3.13. Indicators as to the socioeconomic situation of Slovenia.

Surface area	10 ³ km ²	20.27
Population	million	2.01
Life expectancy	years	76.14
Energy per capita	equiv. kg of petroleum	3,288
Current GDP	10 ⁹ \$	39.41
Growth in GDP	%	3.9
Purchasing power parity of GDP per capita	\$	19,600

Source World Bank Group and globalEDGE (2004)
(PPP = purchasing power parity)

Slovenia became independent from the old Yugoslavia in 1990. Since then, the government has implemented a comprehensive programme of reforms, including the liberalisation of prices and the restructuring of industry and the economy in general. The privatisation process was carried out in accordance with plans. In 1995, 215 large companies had already been privatised and 478 were privatised at a later date. At that time, most SMEs had already been privatised (56,000) to which over 90,000 employees correspond.

Currently, it is one of the most prosperous countries of the changing Europe and holds a privileged position to join the main modern industrial economies. Traditionally, Slovenian companies have been oriented towards a market economy and are endorsed by relatively good economic management. With all of this, the economy of Slovenia depends greatly on foreign trade, some two thirds of which is produced with other countries of the EU, which is one of the fundamental reasons why Slovenia is applying for EU adhesion. All of the above makes Slovenia highly sensitive to any change that arises to its commercial relations with its main partners.

Industry and environment

Slovenia is a small economy and most of its companies are SMEs. It has around 141,000 enterprises. Approximately 1.3 % of the total corresponds to companies with over a thousand employees, whereas 89.7 % are microcompanies or small and medium-sized companies (SMEs), with between 1 and 99 workers. It is clear that these SMEs constitute the bulk of the national economy, though it is true that they do not dispose of the necessary resources to invest in research and development and that they are mainly concentrated in urban areas. SMEs are supported with technical and directional assistance from institutions such as the Chamber of Commerce and Industry, the Centre for the Development of Small Businesses and some technology parks of Maribor, Ljubljana.

Of the 141,000 Slovenian business entities, 80% are private. The most developed industrial sectors are the chemical sector, pharmaceuticals, paper, textiles, food and drink, furniture making, small kitchen appliances, the automobile industry and that of the transformation of metals.

Without a doubt, industry is one of the main pollutants in Slovenia. Most atmospheric pollution comes from the metal transformation industry, the production of electricity, the paper industry, the graphic arts and furniture making industries (dust, SO₂, NO_x, TOC), the chemical industry, (CO, SO₂, NH₃) and the wood industry (TOC). Water pollution is one of the main environmental problems; the main pollutants are insoluble matter (from the paper industry, the graphic arts, energy production, food and metal transformation), the problems of COD (generated by the paper, graphic arts and food industries), nitrates and nitrites (coming from the metal transformation industry), ammoniac nitrogen (coming from tanning and the chemical industry) and metals (from the metal transformation industry and the chemical industry). The production of solid waste is decreasing slightly.

The cement industry

Slovenia's cement consumption grew sharply in the year 2003 due to an increase in the construction of buildings and housing. With a 16.4 % increase in the consumption of cement compared to the previous year, reaching 1.35 Mt, Slovenia's position is strengthened as the east European country with the highest per capita consumption of cement, at some 600 kg/inhabitant.

Eighty percent of cement consumption is bulk. A similar percentage of cement is supplied by road.

Slovenia has 2 cement production plants with a total capacity of 1.5 Mt/year which are in the hands of the largest Austrian cement producers.

The use of alternative fuels is well developed; animal fats, used tyres and oil are the most commonly used.

In the year 2003 cement exports totalled 0.17 Mt, with just over 58 % destined for Italy. As for clinker, exports are quite low, at about 8,000 t, all of which were sent to Italy.

Cement imports grew by 35.5 percent in 2003 reaching 206,000 t, or 15 % of local demand. Italy, the first source of importation, supplied 108,000 t of Portland cement and 5,000 t of white cement in 2003.

Table 2.3.14. Principal data from the cement industry in Slovenia in 2004.

Production (kt/year)	1,260
Cement consumption (kt/year)	1,230
Number of plants	2
(Approx.) no. of employees	387
Clinker kiln production capacity kt/year (*)	800
Cement prod. capacity in kt/year	1,500

Source. *Global Cement Report 2005*

(*) *2002 World Cement Directory*

Table 2.3.15. Types of kiln used.

Number of dry process kilns	3
Number of wet process kilns	0
Number of semi-wet process kilns	0
Number of semi-dry process kilns	0
Number of vertical kilns	0
Total kilns	3

Source: *World Cement Directory 2002*

2.3.6. Israel

Introduction

Israel has a diversified, technologically advanced economy, with an important —though currently shrinking— public sector, and a powerful state-of-the-art technology sector. The main industrial sectors are hi-tech electronics and biomedical equipment, metal products, manufactured food

products, the chemical industry and fittings for transport. Moreover, Israel has a large services sector and is world leader in software development.

Table 2.3.16. Indicators as to the socioeconomic situation of Israel.

Surface area	10 ³ km ²	20.77
Population	million	6.27
Life expectancy	years	79.32
Energy per capita	equiv. kg of petroleum	3,123
Current GDP	10 ⁹ \$	129
Growth in GDP	%	3.9
Purchasing power parity of GDP per capita	\$	20,800

*Source World Bank Group and globalEDGE (2004)
(PPP = purchasing power parity)*

Israel presents a coherent set of environmental regulations and policies. CP is set out in the legislation on toxic and hazardous substances and is controlled by means of a system of licences. The application of preventive activities is backed directly or via the Israeli Center for Cleaner Production and government bodies.

Industry and environment

On an industrial level, important breakthroughs have occurred in the last two decades, in the following fields: medical electronics, agrotechnology, telecommunications, fine chemistry products, computer soft and hardware and diamond cutting and polishing.

High technology sectors, in which capital and training are invested, which require sophisticated production techniques as well as considerable investment in research and development (R&D), are those that have recorded the greatest growth rate. Over 90 % of the annual public R&D budget is targeted at hi-tech industries.

Cement sector industry

Current per capita cement consumption in Israel is at 570 kg, which is a historically low figure for the country but not when compared with the figures for the whole world. Fifty percent of demand is for the building of housing and 33 % for infrastructure.

Israel has three cement production plants with a capacity of 4.70 Mt/year of clinker and 6.2 Mt/year of cement. There are no plans to increase this capacity. Neshor Cement is the only producer of cement in Israel.

Israel is an active market in terms of both exports and imports. However, generally, all exports are to the Palestinian domestic market where there is potential competitiveness with Jordan and other neighbouring countries that are active exporters around the Middle East. Exports to Palestine reached as much as 1.6 Mt per year but in recent years up to the 0.85 Mt in 2003 and has shown signs of recovery with sales of 0.95 Mt in the year 2004.

Historically, cement imports into Israel have come from Rumania, Turkey, Jordan and Cyprus and have been based on Israeli government agreements.

Table 2.3.17 Principal data from the cement industry in Israel in 2004.

Production (kt/year)	4,630
Cement consumption (kt/year)	3,820
Number of plants	3
(Approx.) no. of employees	636
Clinker kiln production capacity kt/year	4,700
Cement prod. capacity in kt/year	6,200

Source: *Global Cement Report 2005*

Table 2.3.18. Types of kiln used.

Number of dry process kilns	2
Number of wet process kilns	6
Number of semi-wet process kilns	0
Number of semi-dry process kilns	1
Number of vertical kilns	0
Total kilns	9

Source: *World Cement Directory 2002*

2.3.7. Malta

Introduction

As Malta has scarce raw materials of its own and a highly limited domestic market, the country has based its economic development on stimulating tourism and the export of manufactured products. Since the mid-1980s, the expansion undergone by these activities has become the main driving force of the strong growth of the Maltese economy.

Table 2.3.19. Indicators as to the socioeconomic situation of Malta.

Surface area	km ²	316
Population	miles	398.5
Life expectancy	years	78.86
Energy per capita	equiv. kg of petroleum	2,089
Current GDP	10 ⁹ \$	7.22
Growth in GDP	%	1
Purchasing power parity of GDP per capita	\$	18,200

Source *World Bank Group and globalEDGE (2004)*
(PPP = purchasing power parity)

A solid base exists for the manufacture of products with high added value such as electronic devices and pharmaceutical products, whereas the manufacturing sector has over 250 foreign-owned export-oriented companies. Tourism generates 35 % of the GDP.

Industry and environment

The contribution by the manufacturing sector to GDP is 26 %, and its total consumption of energy generated is close to 27 %. The main types of industry that make up the sector range from the manufacture of semiconductors and other sophisticated equipment to the making of food and drinks or the repair of boats. The country's other significant activities are tourism and construction.

Nearly 90 % of Malta's companies are considered SMEs, technical assistance and managerial help to which are given by the Institute for the Promotion of Small Enterprises (IPSE). The relationship which exists between SMEs with regard to technology and the possibility of CP is practically nil and the support they receive from large industries to start up CP is very scarce.

The cement industry

Malta is a country where the demand for white cement is high. This accounted for 35 % of the total demand for last year. Per capita cement consumption stands at some 675 kg. The range of annual consumption for the eight years prior to 2002 spans from 0.25 Mt to 0.28 Mt.

All of the cement required in the country is imported. Five years ago, there were plans to build a cement production plant but this was forbidden due to environmental problems. Two cement terminals have been installed in recent years, which has enabled the supply of bagged and bulk cement. Italy is the main supplier of cement since it accounts for 95 % of the volume imported. Italian producers have consolidated their position in the Maltese market with 0.23 Mt in 2003.

Table 2.3.20. Principal data from the cement industry in Malta in 2004.

Production (kt/year)	0
Cement consumption (kt/year)	250
Number of plants	0
(Approx.) no. of employees	0
Clinker kiln production capacity kt/year	0
Cement prod. capacity in kt/year	0

Source. *Global Cement Report 2005*

Table 2.3.21. Types of kiln used.

Number of dry process kilns	0
Number of wet process kilns	0
Number of semi-wet process kilns	0
Number of semi-dry process kilns	0
Number of vertical kilns	0
Total kilns	0

Source: *World Cement Directory 2002*

2.3.8. Serbia and Montenegro

Introduction

Serbia and Montenegro have been separate republics since 3 June 2003, having previously formed a state union. For the purposes of this study, the data considered refers to the former state union.

Table 2.3.22. Indicators as to the socioeconomic situation of Serbia and Montenegro.

Surface area	10 ³ km ²	102.35
Population	million	10,83
Life expectancy	years	74.73
Energy per capita	equiv. kg of petroleum	N/A
Current GDP	10 ⁹ \$	26.27
Growth in GDP	%	6.5
Purchasing power parity of GDP per capita	\$	2,400

Source World Bank Group and globalEDGE (2004)
(PPP = purchasing power parity)

Industry and environment

Due to the economic and political sanctions imposed in 1992, in the last decade, the use of natural resources has intensified. The pollution of water and air, as well as the generation of industrial waste, has reached worrying levels.

In the last 30 years, the quality of the water has decreased considerably due to rapid industrialisation and the pressures of urban development. Some 20,000 km² of the territory of Serbia and Montenegro can be classified degraded areas thanks to erosion, quarrying or the uncontrolled dumping of waste.

Minerals are Serbia and Montenegro's number one natural resource, and hence the country's main industries are the mining industries. It has some of the most important deposits of antimony and lead in Europe. Coal, zinc, gold, chrome and copper can be found and small deposits of natural gas also exist.

The cement industry

The decrease in the country's building activity has led to domestic cement consumption dropping 5.8 % to a figure of 2.3 Mt. The building of housing is the main market for the sector and represents 60 % of the total consumed. Two thirds of cement consumption in Serbia and Montenegro is bagged cement but the use of cement in bulk is significant in the area of Belgrade.

Serbia and Montenegro have 4 cement production plants able to generate a total of 3.7 Mt. All of them are located in Serbia, with the exception of one, which is in the province of Kosovo.

Cement imports are practically nil. Exports are small, reaching 0.15 Mt in the year 2003, normally supplying neighbouring countries.

Table 2.3.23. Principal data from the cement industry in Serbia and Montenegro in 2004.

Production (kt/year)	2,450
Cement consumption (kt/year)	2,400
Number of plants	4
(Approx.) no. of employees	N/A
Clinker kiln production capacity kt/year (*)	2,700
Cement prod. capacity in kt/year	3,700

Source. Global Cement Report 2005
(*) 2002 World Cement Directory

Table 2.3.24. Types of kiln used.

Number of dry process kilns	6
Number of wet process kilns	2
Number of semi-wet process kilns	0
Number of semi-dry process kilns	0
Number of vertical kilns	0
Total kilns	8

Source: World Cement Directory 2002

2.3.9. Turkey

Introduction

Turkey is a country located between the continents of Europe and Asia, on the banks of the Mediterranean Sea. It has a total surface area of 780,580 km² and a population of approximately 70 million inhabitants.

Table 2.3.25. Indicators as to the socioeconomic situation of Turkey.

Surface area	10 ³ km ²	780.6
Population	million	69.66
Life expectancy	years	72.36
Energy per capita	equiv. kg of petroleum	1.1815
Current GDP	10 ⁹ \$	508.7
Growth in GDP	%	8.2
Purchasing power parity of GDP per capita	\$	7,400

Source World Bank Group and globalEDGE (2004)
(PPP = purchasing power parity)

The strategy for growth, based on exports and the free market, have put the Turkish economy among those with the most rapid growth within the Organisation for Economic Cooperation and Development (OECD). However, the reform programme that was set in motion at the beginning of the 1980s has not been fully completed, resulting in high inflation, mainly stimulated by the large deficit of the public sector.

The reduced role of agriculture in the economy coincides with the rapid expansion of the services and industrial sectors. The textiles sector is the main Turkish manufacturing industry and the one that exports the most. With the creation of the Environment Ministry in 1991, environmental issues have gained increasing protagonism.

Industry and environment

Turkey's main industrial sectors are the manufacturing industry (textiles, the chemical industry, metallurgy, paper and food), mining, energy and construction. Other notable sectors are tourist infrastructures, automobiles and electronics. Industrial pollution in Turkey is mainly due to production activities. The manufacturing sector contributes mostly to the country's industrial pollution.

In Turkey, small and medium-sized companies account for 98.8 % of all production facilities; most of the remaining 1.2 % corresponds to medium sized companies. The location of industries has recently become a relevant issue in Turkey. As the investments by the Government show, there is currently a tendency to encourage the development of existing industrial areas and establish other new ones rather than boosting the growth of the SMEs located in isolated areas. Currently, 14 % of SMEs are found in organised industrial areas, and 38 % in small industrial areas; the rest correspond to isolated companies.

The cement industry

Cement consumption in Turkey has, for the second year running, shown an increase in the volume of demand reaching a figure of 28.11 Mt in 2003, or a national increase of 4.8 %.

With regard to the types of cement, ordinary Portland cement accounted for 35.1 percent of the cement consumed in 2003 whereas white cement accounted for 0.7 %.

Turkey's cement production capacity is 38 Mt/year of clinker and 67 Mt/year of cement, across 57 plants. Production grew by 7.13 % in 2003 and reached 30.42 Mt. The main reason for the decrease in the ratio of clinker production is the reduction of clinker exports. The use of alternative fuels is in its early stages although regulations governing this issue have been in place since 2001.

Cement exports grew 23.6 percent in 2003 to 7.39 Mt, 44.29 % of the volume of which was destined for Europe. Clinker exports are decreasing and dropped 31.9 % last year to 3.04 Mt and are expected to continue to fall this year to 2.0 Mt. Spain and Italy account for 81 % of clinker exports.

Cement imports are minimal. Clinker imports in 2003 totalled 12,300 t and most went to feeding the grinders in the Istanbul area.

Table 2.3.26. Principal data from the cement industry in Turkey in 2004.

Production (kt/year)	38,200
Cement consumption (kt/year)	29,300
Number of plants	57
(Approx.) no. of employees	8,743
Clinker kiln production capacity kt/year (*)	38,000
Cement prod. capacity in kt/year	67,000

Source. *Global Cement Report 2005*

(*) *2002 World Cement Directory*

Table 2.3.27. Types of kiln used.

Number of dry process kilns	54
Number of wet process kilns	4
Number of semi-wet process kilns	2
Number of semi-dry process kilns	3
Number of vertical kilns	0
Total kilns	63

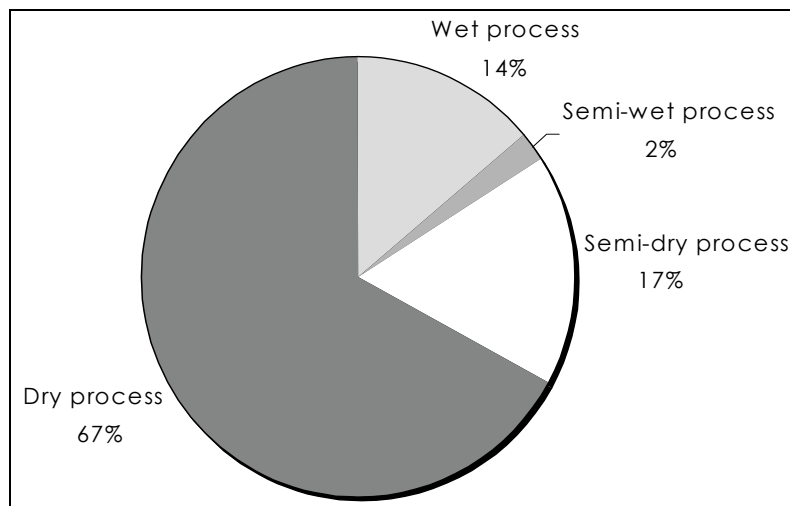
Source: *World Cement Directory 2002*

2.4. SITUATION OF THE CEMENT INDUSTRY IN THE COUNTRIES OF THE MAP

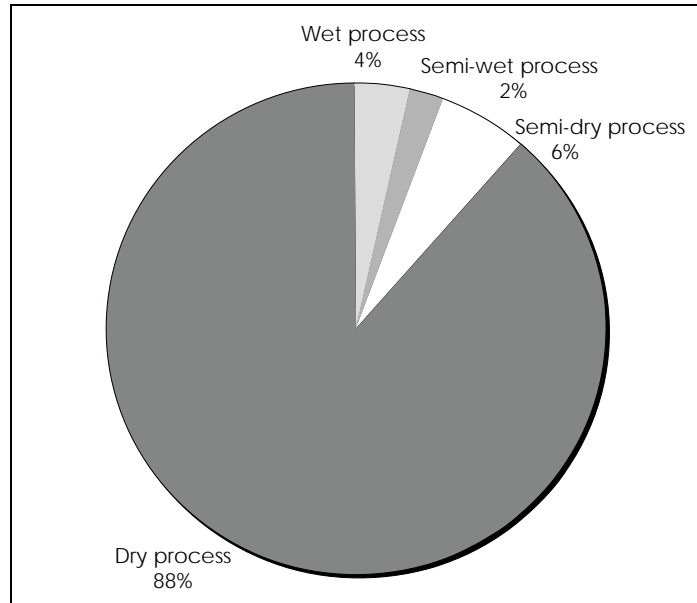
As Will be commented on in greater detail in Section 3. *Description of Processes*, cement production can be carried out by means of four different processes: wet, semi-wet, semi-dry, and dry production. The latter is the process with the greatest energy savings, which is an important aspect for consideration both environmentally (lower fuel consumption, fewer emissions into the atmosphere) and economically (cost savings).

Of the countries of the MAP, Spain, Turkey, and Italy have the largest number of dry kilns. Conversely, Egypt, and Israel are the countries that have the largest numbers of wet process kilns, a process which consumes greater amounts of energy, and therefore the least suitable kilns for cement production both environmentally and economically speaking, with the exception of vertical kilns, which are practically in disuse.

Below is a graph showing the percentage of use according to the type of kiln in the countries of the MAP, as well as a graph with the production capacity percentage to date in these countries, in which it may be observed that 88% of cement production capacity in the countries of the MAP is dry production.



Graph 2.4.1. Types of kiln installed in the countries of the MAP in 2005.



Graph 2.4.2. Capacity installed according to type of kiln in the countries of the MAP in 2005.

The economic situation in recent years has meant that cost reduction is a key factor nowadays for any industrial sector. With this in mind, cement manufacturers have adopted numerous measures to reduce the consumption of raw materials and energy, increasing the efficacy and performance of many of their processes, which has contributed, indirectly, to the environmental improvement of the factories.

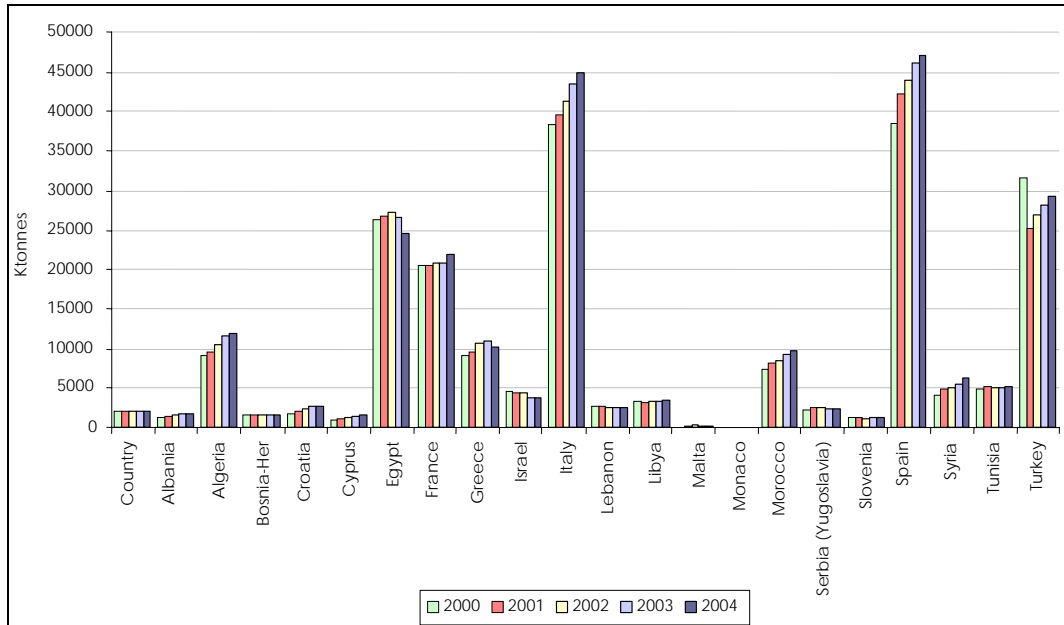
With regard to cement consumption, Spain, Italy, Egypt, Turkey and France are the MAP countries with the highest rates, with figures for 2004 of 47,200, 45,000, 29,300, 24,500 and 21,800 kt, respectively. Consumption by the different countries of the countries of the Mediterranean Action Plan for different years is shown in Table 2.4.1.

Table 2.4.1. Data on cement consumption in the countries of the MAP (Ktonnes).

Country	1999	2000	2001	2002	2003	2004
Albania	950	1,200	1,500	1,650	1,760	1,850
Algeria	7,611	9,000	9,500	10,500	11,500	12,000
Bosnia-Her	1,210	1,580	1,600	1,710	1,570	1,620
Croatia	1,830	1,823	1,923	2,280	2,710	2,730
Cyprus	920	940	1,050	1,350	1,430	1,570
Egypt	27,200	26,300	26,700	27,200	26,600	24,500
France	20,210	20,630	20,660	20,727	20,678	21,800
Greece	8,500	9,100	9,550	10,640	11,000	10,100
Israel	4,850	4,519	4,376	4,350	3,820	3,820
Italy	36,120	38,338	39,469	41,300	43,500	45,000
Lebanon	2,966	2,620	2,720	2,500	2,592	2,592
Libya	3,000	3,220	3,000	3,260	3,300	3,500
Malta	570	0	270	280	270	250
Monaco	0	0	0	0	0	0
Morocco	7,260	7,479	8,057	8,480	9,260	9,700
Serbia and Montenegro	1,500	2,248	2,452	2,475	2,330	2,400
Slovenia	1,206	1,240	1,180	1,160	1,350	1,230
Spain	34,630	38,440	42,150	44,120	46,220	48,003
Syria	4,865	4,200	4,800	5,060	5,500	6,400
Tunisia	4,390	4,948	5,178	5,000	5,100	5,300
Turkey	31,529	31,500	25,250	26,811	28,106	29,300

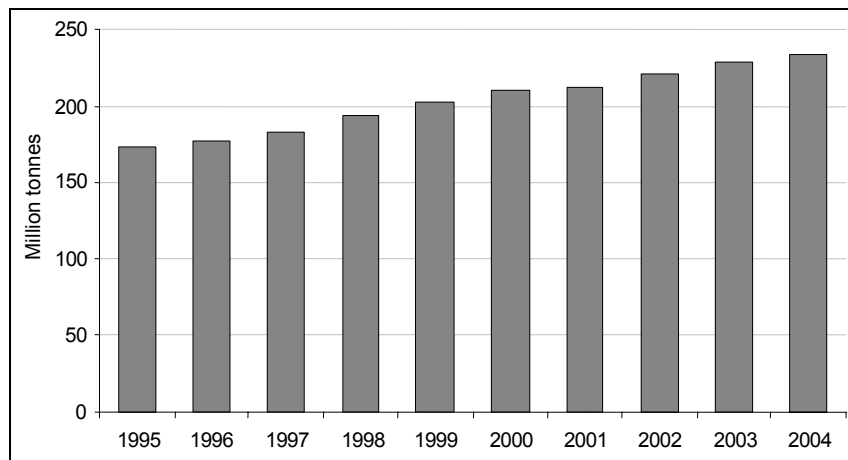
Source: Global Cement Report 2005

The data in the table above are reflected in Graph 2.4.3. It should be pointed out that Egypt's high consumption is a consequence of its large population. Its per capita consumption of cement is relatively low (410 kg/inhabitant/year), as seen in Table 2.4.2.



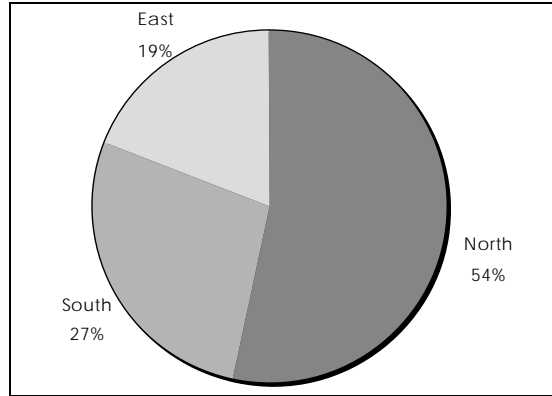
Graph 2.4.3. Cement consumption by the countries of the MAP (k tonnes).

The graph of overall cement consumption in the Mediterranean Region (see Graph 2.4.4) is obtained from the data shown in Table 2.4.1. A continuous increase can be seen from 1995 to 2004. Total cement consumption for 2004 in the Mediterranean region was 232.8 million tonnes, the highest for the time period in consideration.



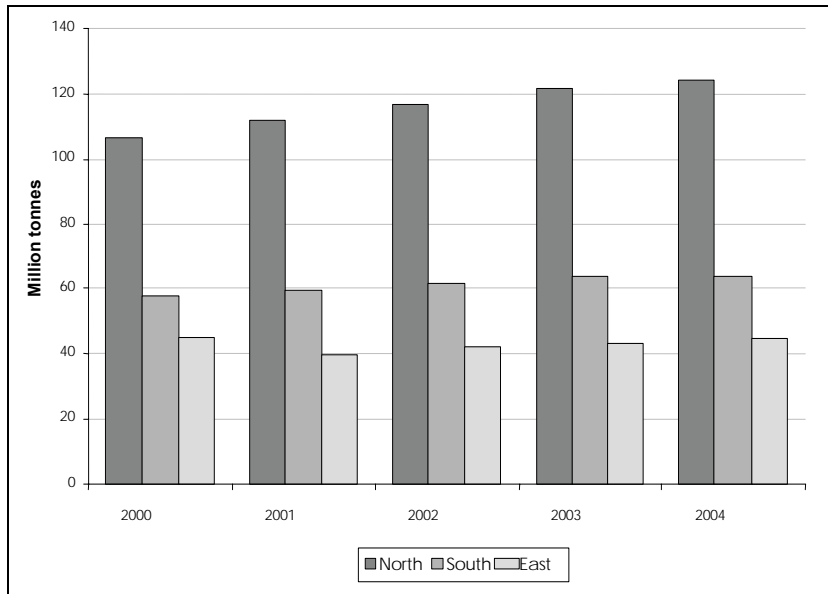
Graph 2.4.4. Overall cement consumption by the countries of the MAP (Mtonnes).

When a distinction is made by subregions (north, south, east), a large difference is observed between the different regions of the Mediterranean (see Graph 2.4.5.). Thus, for example, in the year 2000, 54 % of total cement consumption in the countries of the Mediterranean Action Plan corresponds to countries of the north of the Mediterranean, whereas this figure is of 27 % and 19 % for the countries of the south and east of the Mediterranean respectively.



Graph 2.4.5. Cement consumption by the countries of the MAP in 2004.

This situation has been maintained over time and the north has always been the region of the countries of the Mediterranean Action Plan to have the greatest demand, which has also grown over the years (see Graph 2.4.6). The south has held second place, also with increasing consumption and the east, in last place, with practically constant consumption.



Graph 2.4.6. Cement consumption in the countries of the MAP.

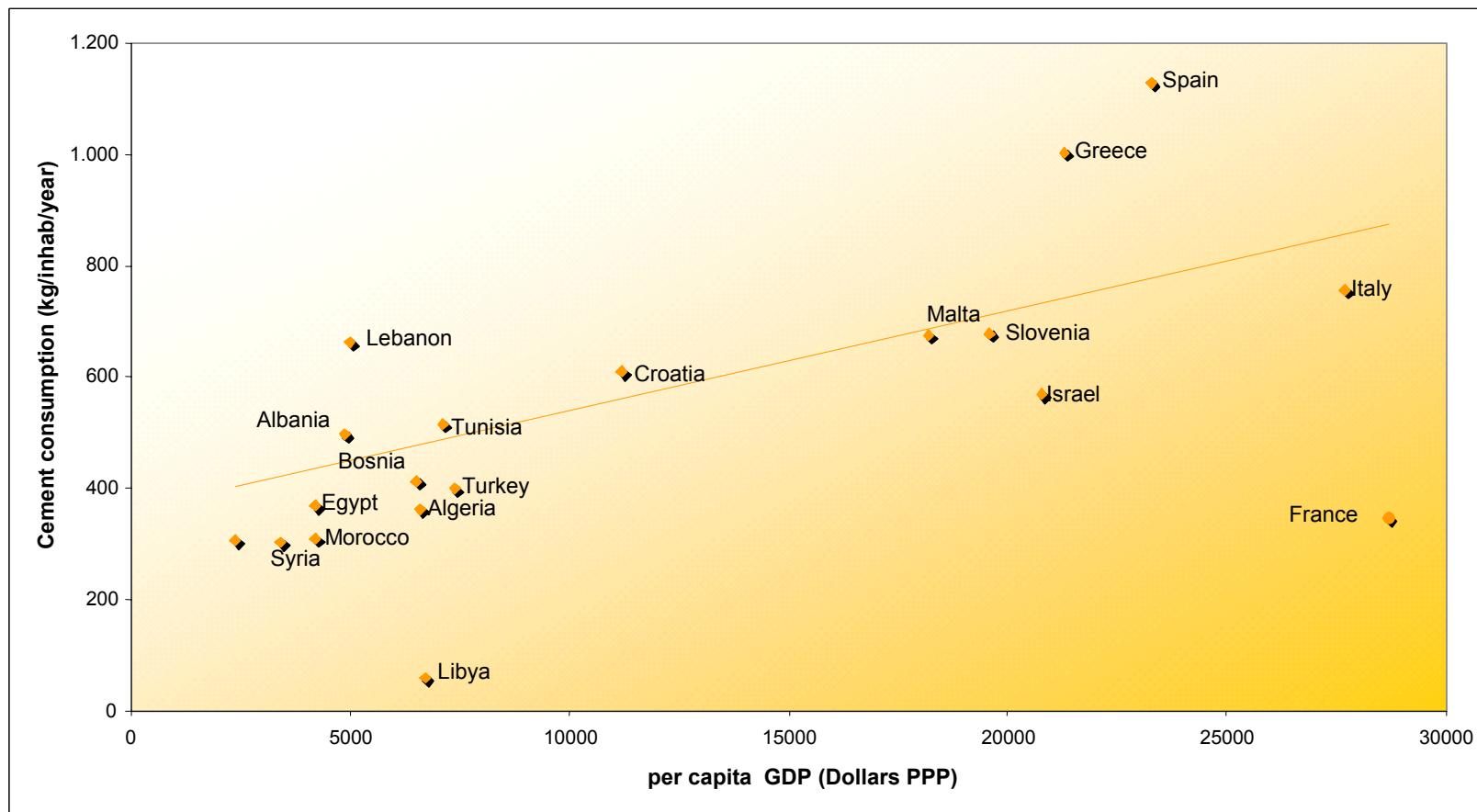
Table 3.4.2. shows the per capita consumption by the countries of the MAP in 2004, as follows:

Table 2.4.2. Per capita cement consumption by the countries of the MAP in 2004.

Country	Consumption (kg/inhabitant/year)
Albania	497
Algeria	362
Bosnia	412
Croatia	1,588
Egypt	369
France	366
Greece	963
Israel	307
Italy	785
Lebanon	663
Libya	60
Malta	570
Monaco	
Morocco	308
Serbia(Yugoslavia)	678
Slovenia	643
Spain	1,126
Syria	304
Tunisia	515
Turkey	675

Source: Global Cement Report 2005

Relating per capita cement consumption with the per capita GDP of each country, Graph 2.4.7 shows a more or less generalised tendency, according to which the countries with greater per capita GDP enjoy greater per capita cement consumption. Two extreme cases should be pointed out, that is the case of France, with very low per capita cement consumption in comparison with GDP, which is a consequence of the fact that the construction industry is not of great importance in the French economy whereas, conversely, in Spain, the construction industry is one of the most influential sectors on the country's economy. And, as has already been commented on, Egypt, despite being one of the countries that consumes the most cement (due to its large population), has a relatively low per capita consumption.



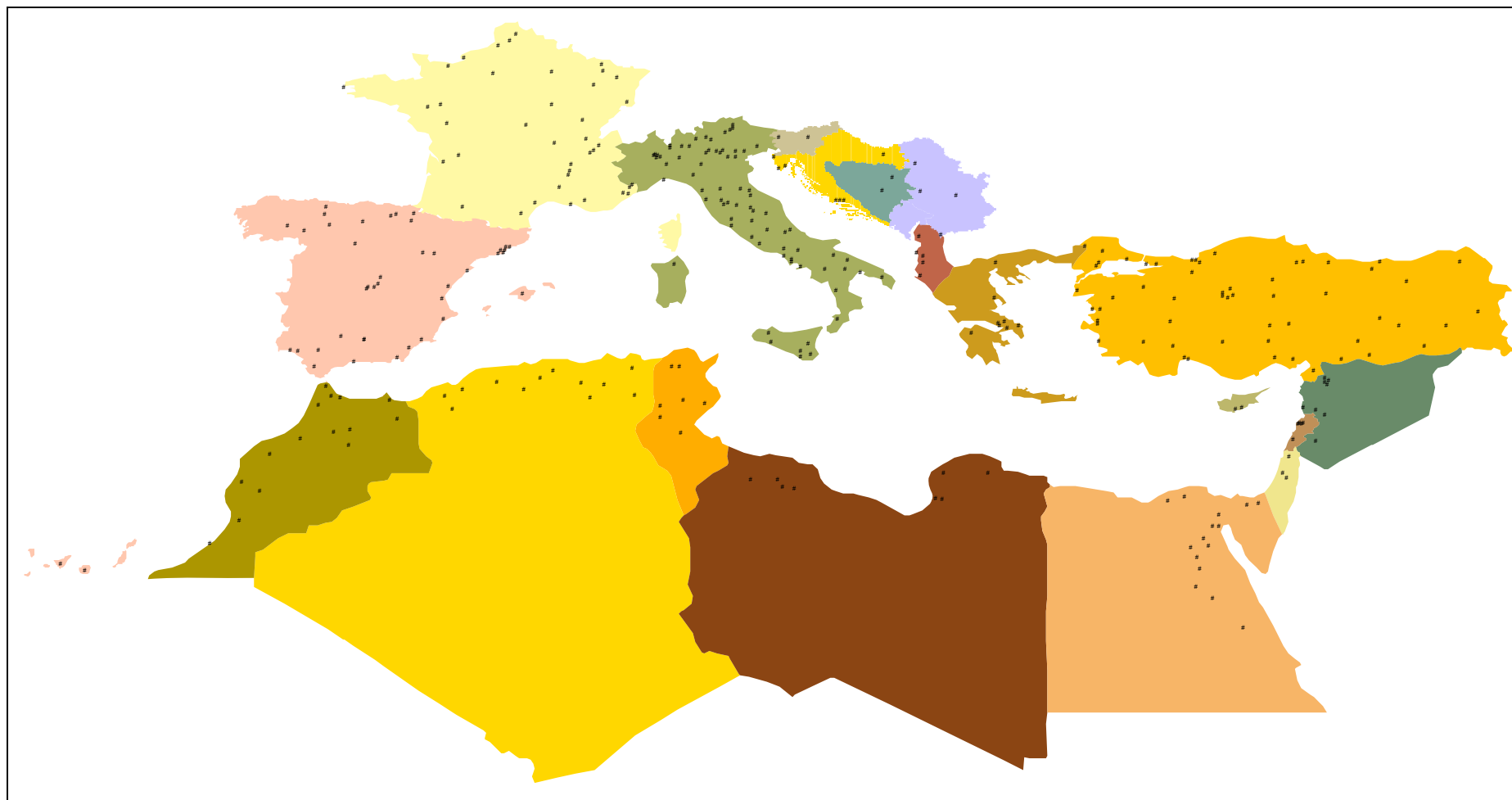
Graph 2.4.7. Cement consumption vs per capita GDP in 2004.

With regard to production, as in the case of consumption, big differences are observed between the different countries of the Mediterranean, as is shown in the data in Table 2.4.3. and represented in Graph 2.4.9.

Table 2.4.3. Cement production in the countries of the MAP (ktonnes).

Country	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Albania	300	300	300	300	300	200	200	190	200	200
Algeria	6,820	7,460	7,130	7,800	7,680	8,400	8,600	8,900	9,000	10,500
Bosnia	0	0	0	500	500	630	700	850	800	920
Croatia	1,690	1,795	2,084	2,190	2,600	2,773	3,165	3,300	3,570	3,800
Cyprus	1,022	1,500	1,450	2,950	2,950	1,450	1,500	1,790	1,860	1,890
Egypt	16,934	18,700	19,700	20,950	22,030	24,100	25,700	28,500	29,100	31,000
France	19,730	19,420	19,610	18,700	19,530	20,040	20,430	19,437	19,655	20,900
Greece	13,940	14,500	14,700	14,750	14,350	15,420	15,200	14,680	15,500	15,700
Israel	5,600	5,600	5,400	6,476	6,354	5,703	4,703	4,582	4,607	4,630
Italy	34,000	33,832	34,378	36,100	37,300	39,020	39,804	41,400	43,500	44,800
Lebanon	2,450	3,780	3,650	3,310	3,200	2,900	2,900	3,200	3,300	4,400
Libya	3,200	0	0	3,000	3,000	3,200	3,000	3,320	3,320	3,500
Malta	0	0	0	0	0	0	0	0	0	0
Monaco	0	0	0	0	0	0	0	0	0	0
Morocco	6,405	6,800	7,500	7,414	7,530	7,830	8,397	8,800	8,397	9,900
Serbia and Montenegro (Yugoslavia)	0	2,200	2,100	1,800	1,500	2,229	2,512	2,485	2,100	2,450
Slovenia	0	1,064	1,011	1,150	1,223	1,255	1,240	1,180	1,200	1,260
Spain	28,491	27,791	26,693	33,080	35,830	38,410	40,900	42,420	44,700	46,602
Syria	4,463	4,471	4,840	4,607	4,781	4,252	5,200	5,010	5,010	5,200
Tunisia	4,960	4,400	4,800	4,750	4,210	5,383	5,464	5,550	5,750	6,000
Turkey	31,500	35,236	36,034	37,488	34,816	35,950	29,960	32,758	35,095	38,200

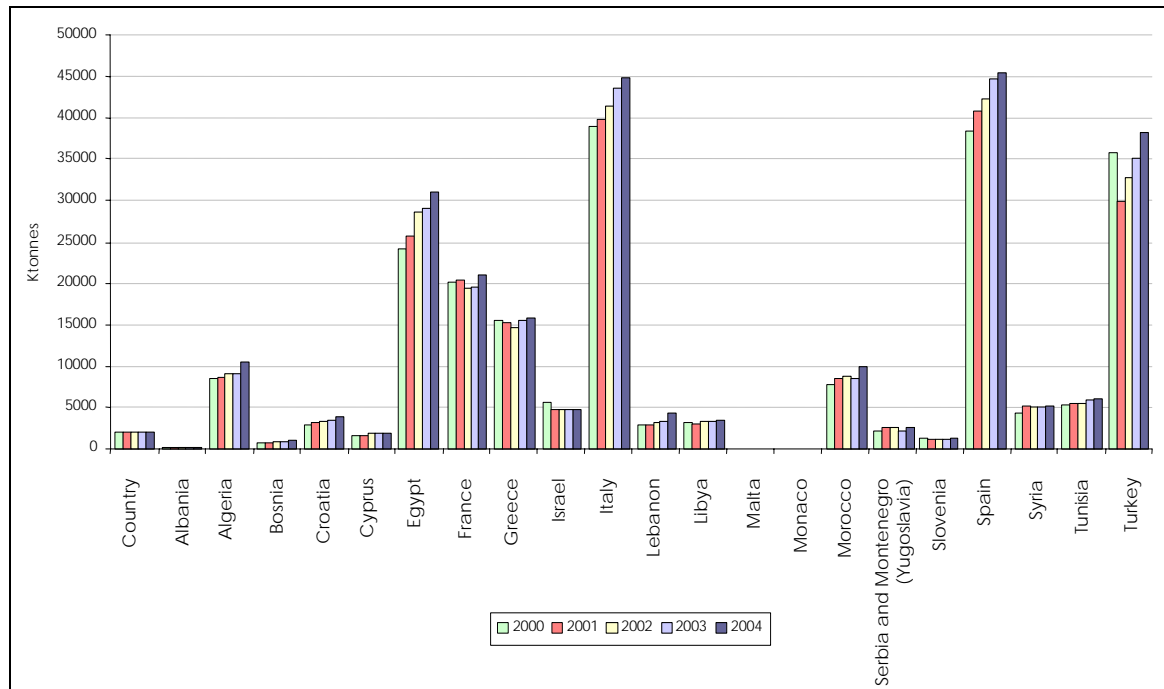
As can be seen, the countries with the highest production are Spain, Italy, Turkey and Egypt, the same countries as have the largest number of cement works, both integrated (clinker and cement production) and grinding plants (without the production of clinker), see Graph 2.4.8.



Source: Global Cement Report 2005

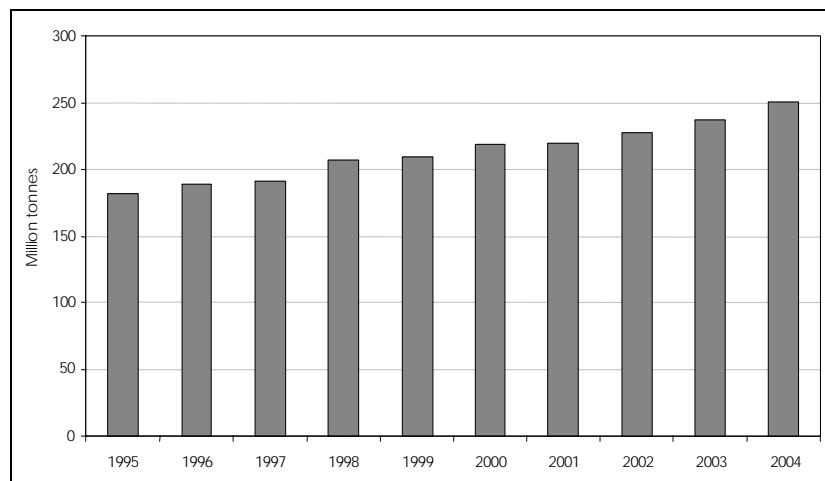
Graph 2.4.8. Distribution of Cement Works in the countries of the Mediterranean Action Plan.

The data in Table 2.4.3. give rise to the following cement production graph for the countries of the MAP between 2000-2004.



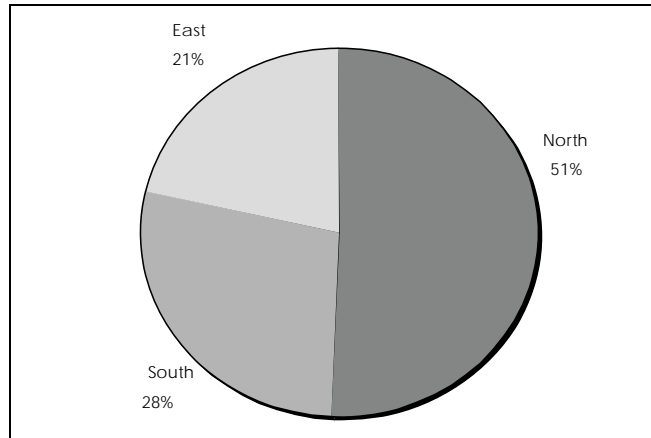
Graph 2.4.9. Cement production in the countries of the MAP (kt).

In turn, from Table 2.4.3 we obtain total cement production in the countries of the MAP. This production has remained at around 200 million tonnes per year, maintaining a certain tendency to increase over the years (see Graph 2.4.10). As can be seen, cement production in 2004 in the countries of the MAP totalled 250.75 million tonnes.

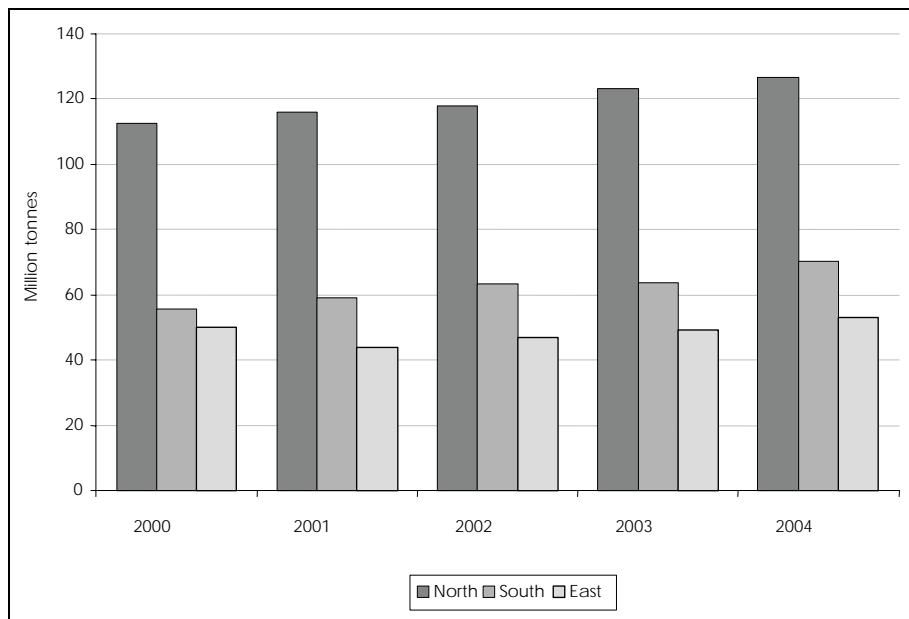


Graph 2.4.10. Overall cement production by the countries of the MAP (Mt).

For cement production, like consumption, there is a considerable difference between the different subregions of the Mediterranean (see Graph 2.4.11). In 2004, 51 % of the all cement produced by the countries of the Mediterranean Action Plan corresponded to the countries of the north of the Mediterranean, whereas for the countries of the south and east of the Mediterranean this figure is 28 % and 21 %, respectively. The same tendency has arisen over time (see Graph 2.4.12).



Graph 2.4.11. Overall cement production by the countries of the MAP in 2004.



Graph 2.4.12. Cement production by the countries of the MAP.

3. DESCRIPTION OF PROCESSES

Cement is a finely ground, inorganic, non-metallic material which is grey or white in colour and when mixed with water and aggregate forms a fluid paste which sets and hardens giving rise to artificial rock (mortars and concrete). This hydraulic hardening is mainly due to the formation of calcium silicate hydrate as a result of a reaction between the water and the components of the cement. This property of a hydraulic conglomerate has made cement a basic material in construction which is essential for building and infrastructure works.

It is made from a mixture of clinker (the result of calcining until the partial fusion of mixtures of limestone and clays) and gypsum which acts to control setting. Other active ingredients may be added such as fly ash, blast-furnace slag, limestone, silica fumes, pozzolans, bauxite, sand or iron minerals.

3.1. RAW MATERIALS

3.1.1. Basic raw materials

The cement manufacturing process starts by obtaining the necessary raw materials so as to achieve the desired composition of metal oxides for the production of clinker (see Section 3.2.4. *Clinker burning*).

The basic raw materials for the manufacture of clinker are mainly:

- A carbonate contributor: generally limestone or marl. They provide the CaO which will later react in the kiln to form silicates, which are the relatively active components of clinker.
- A flux contributor: generally clays or shale. They provide the oxides that work as fluxes and contribute to the formation of liquid phase in the kiln, helping the reactions to take place.

As commented on previously, for the production of cement, gypsum is added to the clinker as a controller for setting.

Table 3.1.1 shows the typical composition of some basic raw materials:

Table 3.1.1. Composition of the basic raw materials.

Component	Limestone	Marl	Clay
SiO ₂	0.5-3	3-50	37-78
Al ₂ O ₃ + TiO ₂	0.1-1	1-20	7-30
Fe ₂ O ₃ + Mn ₂ O ₃	0.1-0.5	0.5-10	2-15
CaO	52-55	5-52	0.5-25
MgO	0.5-5	0.5-5	= 5
K ₂ O	= 0.3	= 3.5	0.55
Na ₂ O	= 0.1	= 0.2	0.1-0.3
SO ₃	= 0.1	0.1-4	= 3
CO ₂ + H ₂ O	40-44	2-42	1-20

Source: VDZ and other references
 (*) Figures expressed as a % in weight

3.1.1.1. Limestone

Limestone is a sedimentary rock, formed by the deposition of the physically and chemically altered products of pre-existing, primitive rocks, such as calcium feldspar. Its main component is CaCO₃. It is found in the upper layers of many hills and mountains, in deposits of varying depth, some measuring over 200 metres. For the manufacture of cement, large volumes of limestone are extracted since it represents approximately 80 % of the raw materials that make up clinker (see Section 3.2.4.1 *Composition of clinker*). In addition, limestone can be milled together with the clinker, where it acts as a filler in the cement, since it does not take part in the hardening reactions.

The limestone quarry is normally located near the cement production plant; otherwise the cost of the cement would rise considerably. Due to its hardness, limestone is extracted from quarries using explosives. One blast may produce from 30 to 100,000 tonnes of raw material.

3.1.1.2. Marl

Marl comprises clays and carbonates. Different types of marl can be distinguished depending on the qualitative ratios of its different components: loamy marl, marl and calcareous marl. Often marl has nodules of gypsum, calcite and pyrite, it is light to dark grey, coffee or greenish in colour. The size of the grains is equal to that of clay (< 0,02 mm). Due to its abundance and the fact that it contains calcareous and argillaceous material in homogenised state, marl is an excellent raw material for making cement.

3.1.1.3. Clay

Clay is the second most important raw material for the manufacture of cement since when the limestone used does not contain sufficient alumina and silica, the addition of argillaceous material is required. Clays mainly consist of alumina hydrosilicates, However, there is a great deal of variation in their mineralogical and chemical composition, ranging from those made up exclusively of aluminium silicates (white), to those which may contain over 50 % of free silica, or contain iron hydroxide, iron sulphide, calcium carbonate, etc. Iron hydroxide is the most common colouring component of clays. Since particle size is important, the presence of finely divided silica is preferred. Clay is also the principal source of alkalis in the cement manufacturing process.

3.1.1.4. Shale

“Shales” are clays principally consisting of 45 to 65 % of silicon oxides, 10 to 15 % aluminum oxides, 6 to 12 % iron oxides and varying amounts of calcium oxide, from 4 to 10 %. It is also the main source of alkalis. Shale represents approximately 15 % of the raw material making up clinker. As these minerals are relatively soft, the extraction system is similar to that of limestone, although less powerful explosives are required.

3.1.1.5. Gypsum/anhydrite

Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) and anhydrite (CaSO_4), calcium sulphates, are considered fundamental raw materials in cement production. They are added to the clinker due to their capacity to regulate the setting and hardening of the products resulting from their partial or total dehydration, when kneaded with limited quantities of water (see Section 3.2.8. *Delivery of cement*). Gypsum, which is widespread in the lithosphere, presents as selenite (monocrystalline crystals), as sericolite (fibrous gypsum), as gypseous alabaster, granular in structure, or in mixed crystalline masses constituting highly abundant gypsum stone.



Limestone



Clay



Shale



Gypsum

Image 3.1.1. Raw materials for cement manufacture.

3.1.2. Secondary raw materials

Very often, other, secondary raw materials must be resorted to; these may be either natural (pozzolanic materials, bauxite, sand, etc.) or by-products/waste matter from other manufacturing processes (ash, blast-furnace slag, silica fumes, etc.).

The incorporation of these secondary raw materials may be as small "additions" or even as a "main component" depending on the type of cement. This is the case of the pozzolanic materials that give rise to pozzolanic cement (see Section 3.2.6. Cement products).

With the addition of these materials the desired quality and properties of the cement can be achieved.

3.1.2.1. Corrective materials

In order to rectify the composition of the desired compounds in the raw materials, natural rectifiers are used which provide the main oxides that will make up the principal phases of the clinker (calcium silicates - tri and di calciums – and calcium aluminates) such as: bauxite (Al_2O_3), iron ore (Fe_2O_3) and sand (SiO_2) (see Table 3.1.2. *Composition of corrective materials*).

Table 3.1.2. Composition of Corrective Materials.

Component	Sand	Iron minerals	Bauxite
SiO ₂	80-99	4-11	2.9
Al ₂ O ₃ + TiO ₂	0.5-3	0.2-3	57.5
Fe ₂ O ₃ + Mn ₂ O ₃	0.5-2	19-95	22.8
CaO	0.1-3	0.1-34	2.4
MgO	= 0.5	= 1.5	0.04
K ₂ O	= 1	Traces	0.04
Na ₂ O	= 0.5	Traces	0.02
SO ₃	= 0.5	Traces	0.12
CO ₂ + H ₂ O	= 5	0.1-30	13.5

Source: VDZ and other references
 (*) Figures expressed as a % in weight

Sand

Sand is a type of aggregate whose particles are between 0.16 and 5 mm in size. The most important characteristics for the use of aggregate are particle size, the degree of roundness, the lithology and the absence of glass, organic matter, soluble salts and clays.

Iron Minerals

Natural iron oxides, especially haematite, are used as a source of Fe₂O₃ in the manufacture of cement. Moreover, iron oxide is used to colour the cement and, therefore, the concrete prepared with it, since its colour depends on the colour of the aggregate and the cement. For cement manufacture, iron oxide must contain more than 75 % of Fe₂O₃ and have a particle size less of than 1”.

Bauxite

Bauxite minerals are hydrated aluminum oxides, known as gibbsite (Al₂O₃ x 3H₂O) which contain 65.4 % Al₂O₃ and boehmite and diaspor (Al₂O₃ x H₂O) which contain 85 % Al₂O₃. Bauxitic clay is used in the manufacture of cement as it presents a high Al₂O₃ content—in excess of 35 %— and a favourable Al₂O₃ and SiO₂ ratio.

3.1.2.2. Pozzolanic materials

Another natural material that is used in cement manufacture is pozzolan. It is a natural, fine-grained, siliceous or silico-aluminous material (see Table 3.1.3. *Composition of pozzolans*) which, in the presence of calcium hydroxide and water, can harden at ambient temperature. The products of the pozzolanic reaction are hydrates of calcium silicate, which are the components that provide mechanical resistance. Sedimentary rocks that contain larger quantities of reactive silica, as well as rocks with a high organic origin free silica content, also belong to the group of natural pozzolanic materials.

Table 3.1.3. Composition of Pozzolans.

Component	Pozzolans
SiO ₂	53.9 , 63.2
Al ₂ O ₃	15.2-20.4
TiO ₂	0.6-1.2
P ₂ O ₅	0.1-0.2
Fe ₂ O ₃	5.2-7.9
Mn ₂ O ₃	0.1-0.3
CaO	2.7-8.5
MgO	1.1-2.7
SO ₃	0.0-0.3
K ₂ O	1.5-6.0
Na ₂ O	1.5-4.3
LOI	7.1-11.6
CO ₂	0.6-4.8
H ₂ O	–
S ²⁻	–
CaO _{free}	–

Source: VDZ and other references

(*) Figures expressed as a % in weight

3.1.2.3. Material and energy waste recycling and recovery

The cement industry uses certain mineral wastes products and by-products whose composition is similar to that of its raw materials, or which even enhance the performance of cement. Given the huge quantities of raw materials processed by the sector, such recycling means a huge saving of natural resources and avoids the dumping of large volumes of usable materials.

The use of mineral waste and by-products as a raw material in the cement making process contributes the following benefits to the environment:

- It avoids the use of landfills and associated impacts.
- It reduces the working of quarries, substituting natural resources by waste products.
- It decreases energy consumption as less clinker is manufactured thanks to the use of additives.
- It reduces emissions into the atmosphere by decreasing fuel consumption.

Table 3.1.4. shows the most commonly used industrial waste or by-products in the cement industry in the countries of the Mediterranean Action Plan:

Table 3.1.4. Types of waste most frequently used as raw materials in the cement industry.

TYPES OF WASTE
Fly ash
Blast-furnace slag
Silica fumes
Steel slag
Paper sludge
Pyrite ash
Phosphogypsums (from the desulphurisation of gases and production of phosphoric acid)

Source: Cembureau, 1997

Fly ash

Fly ash is a fine grain waste product which comes from the combustion of pulverised coal. It is precipitated in the electrostatic or mechanical precipitators found in power stations. Fly ash may be siliceous or calcareous in nature: the former present only pozzolanic characteristics; the latter ones may also possess hydraulic characteristics, and consist essentially of reactive CaO , SiO_2 , and Al_2O_3 .

Pyrite ash

The name "pyrite ash" is applied to the waste which remains after toasting pyrite in order to obtain sulphuric acid. This material is principally composed of oxides and iron hydroxides and other metals.

Blast-furnace slag

Blast-kiln slag is obtained from smelting iron ore in a blast furnace. The blast-furnace slag in the form of (amorphous) glass is produced by the rapid cooling of the slag quenched with water and/or compressed air to obtain a granulated material. The content of material in amorphous state is decisive for hydraulic characteristics, and hence it should be kept as high as possible. Normally, the content of amorphous material is greater than 90%.

Silica fumes

Silica fumes, which are also known as microsilica or condensed silica fumes, are another material used as a pozzolanic additive. They are a by-product of the production of siliceous or ferro-siliceous alloys. This product, in the form of light to dark grey-coloured (sometimes with a blue-green hue) powder, is the result of the reduction of highly pure quartz with mineral coal in an electric arc furnace during the manufacture of silica or of ferro-siliceous alloys.

Foundry sand

Foundry sand is made up of quartz grains (disilicon oxide) and clay (hydrated aluminium silicate), in such a way that it can be used as a raw material in cement production.

Paper sludge

Paper sludge can be used as a raw material in the production of clinker due to its high calcium carbonate content.

Gypsums and phosphogypsums

Gypsums that come from the desulphuration of gases and the production of phosphoric acid as raw materials in cement grinding can be used.

Burnt shale

This material is obtained by the controlled burning of minerals of natural origin. Burnt shale, particularly oil shale, is produced in a special kiln at temperatures of approximately 800 °C and once ground it has pronounced hydraulic as well as pozzolanic properties. Burnt shale has the following composition: (SiO₂), CaO, (Al₂O₃), (Fe₂O₃) along with other compounds.

Demolition waste

Waste produced by the demolition of buildings, roads and other structures.

Table 3.1.5. Composition of secondary raw materials.

Component	Granulated blast-kiln slag	Burnt shale	Pulverised fly ash
SiO ₂	32.3-40.5	34.3-36.7	40-55
Al ₂ O ₃	7.1-14	11.3-11.4	24-30
TiO ₂	0.3-1.9	0.6-0.6	0.7-1.3
P ₂ O ₅	0.0-0.2	0.2-0.2	0.1-1.5
Fe ₂ O ₃	0.2-2.4	7.3-10.4	5-15
Mn ₂ O ₃	0.2-1.7	0.1-0.1	0.1-0.4
CaO	35.3-45.9	27.3-31.6	1.5-8
MgO	0.0-11.7	1.8-2.0	1.5-3.5
SO ₃	0.1-0.3	10.1-11.2	0.4-2.5
K ₂ O	0.2-1.1	2.0-2.1	1.0-4.5
Na ₂ O	0.2-0.6	0.3-0.3	0.4-1.5
LOI	0.1-1.9	4.2-8.0	0.8-5.0
CO ₂	0.1-1.3	2.6-7.0	–
H ₂ O	0.1-1.1	1.0-1.7	–
S ²⁻	0.9-2.1	0.1-0.2	–
CaO _{free}	–	–	0.1-1.5

Source: VDZ and other references

(*) Figures expressed as a % in weight

This waste may be used in two different stages of the production process. One of them is in the initial preparation of the raw materials or "raw meal". The other is the clinker grinding stage together with other minerals to give rise to cement:

In the preparation of raw meal.

Certain minerals are necessary to obtain clinker, and these may be found in nature or in some waste matter. Waste and by-products that are recycled in other industrial processes and which are used in the preparation of raw meal include the following:

- Pyrite ash, due to its high iron content.
- Dry blast-furnace slag.
- Paper slurry, due to its high calcium carbonate content.
- Foundry sand, due to its high silicon oxide content.
- Demolition waste, calcic or siliceous in nature.

In cement grinding.

Materials that are susceptible for use as components in cement grinding (as additions to clinker) possess characteristics that improve its properties, such as their workability, water retention, durability, mechanical resistance, resistance to sulphates, resistance to ice, etc. These materials may be natural, such as pozzolans, or come from by-products from other industrial processes such as:

- Blast furnace slag.
- Industrial pozzolans.
- Fly ash from a thermal power station.
- Silica fumes from the ferroalloy industry.
- Burnt shale.
- Calcium sulphate coming from the desulphurisation of industrial gases and the preparation of phosphoric acid (gypsums/phosphogypsums).

Doses of additives are controlled using scales and are introduced together into the grinders. The relative proportion of each component is automatically adjusted, on the basis of the results of the analyses carried out by X-ray analysers.

3.2. DESCRIPTION OF THE PRODUCTIVE PROCESSES

The basic chemistry of the cement manufacturing process starts with the decomposition of calcium carbonate (CaCO_3) at some 900 °C leaving calcium oxide (CaO , quicklime) freeing gaseous carbon dioxide (CO_2); this process is known as calcining or decarbonation. Then follows the clinkering process in which the calcium oxide reacts at high temperature (typically 1.400 - 1.500 °C) with silica, alumina and ferrous oxide to form the silicates, aluminates and calcium ferrites that make up clinker. The clinker is milled together with gypsum and other additives to produce cement.

Four processes exist for cement manufacture; the dry, semi-dry, semi-wet and wet processes:

- **Wet process:** the raw materials (often with a high moisture content) are ground in water to form a pumpable slurry. The slurry is fed straight into the kiln, or first to a slurry drier.
- **Semi-wet process:** the moist raw material is partially dried in filter presses. The filter cake is then either extruded into pellets and fed into a grate preheater, or fed directly into a filter cake drier for the production of raw meal, which is ground, dried and fed into a suspension preheater kiln.
- **Semi-dry process:** the dry raw mix is pelletised (granulated) with water and is fed to a grate preheater as a stage prior to the kiln or, in some cases, to a long kiln equipped with chains.
- **Dry process:** the raw materials are ground and dried to form the raw meal or mix, in flowable powder form. The raw meal is fed to a preheater kiln or with a precalciner, or, more rarely, since it is almost in disuse, to a long, dry kiln. In this process, the chemical control of the raw materials is more efficient and energy consumption is lower, since as there is no need to eliminate added water, kilns are shorter and the clinker requires less time at high temperatures. Figure 3.2.1. shows a flow diagram of a dry process with a precalciner kiln.

The choice of process is of great importance and is determined to a great extent by the state of the raw materials (dry or wet).

Historically, the development of the clinker manufacturing process has been characterised by the change from the "wet" to the "dry" system. The first kilns –introduced around 1895– were long, wet process kilns. They allowed the easy handling and homogenisation of the raw materials, especially when the raw materials were wet or when there were substantial fluctuations in the chemical composition of the individual materials. With more modern, more advanced technology it has been possible to feed the process with a homogeneous material in a dry process; i.e. without the addition of water to prepare a raw meal. The main advantage of a modern, dry process over a traditional wet system is lower fuel consumption and therefore lower costs and emissions.

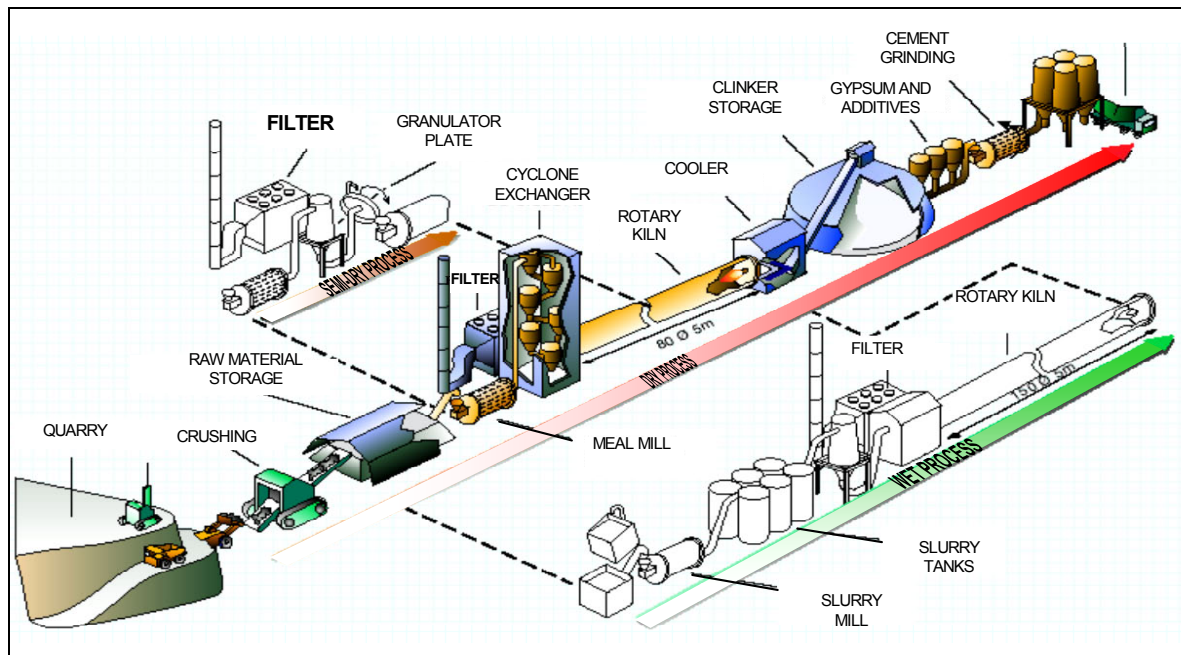


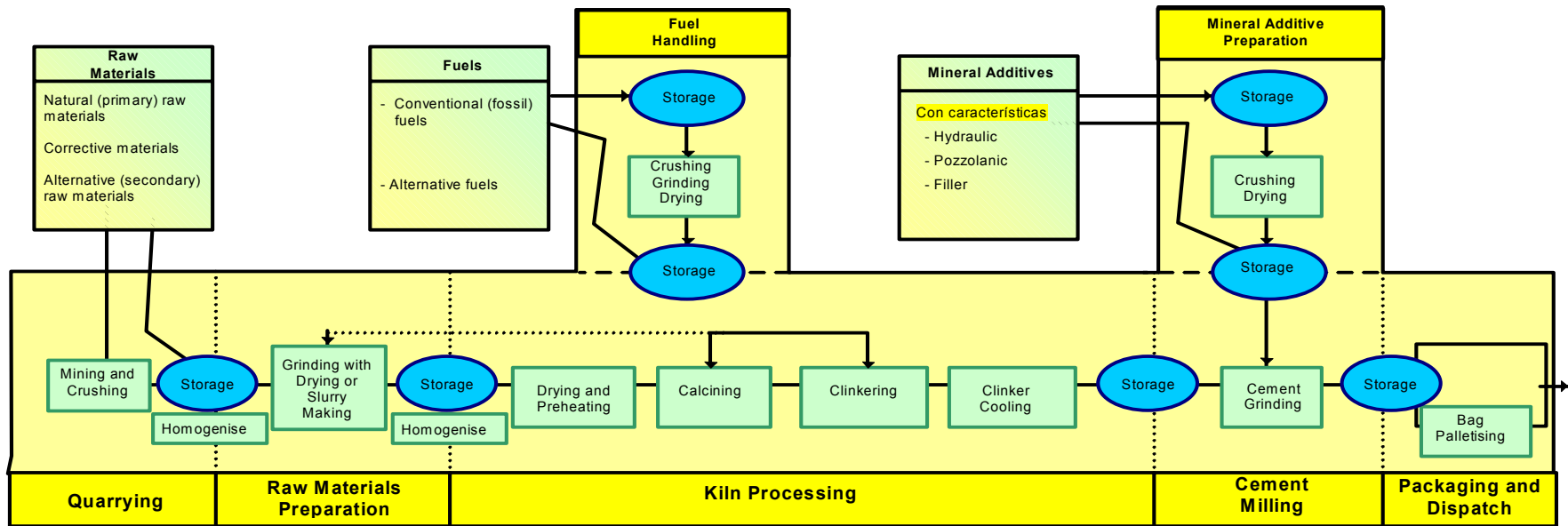
Figure 3.2.1. Cement manufacturing process. Source: Reference documents on the best available techniques applicable to the cement industry.

Nowadays, the choice of the wet process is only used when very special conditions arise in the raw materials and process conditions.

All of the processes commented on above have the following six stages in common:

- Obtaining (extraction of) raw materials.
- Storage and preparation of the raw materials to obtain the *raw meal*.
- Storage and preparation of fuels.
- Burning of raw materials to obtain clinker.
- Clinker grinding with other components to obtain *cement*.
- Storage, bagging and shipment of cement.

Figure 3.2.2. shows the different stages or unitary operations common to cement manufacturing processes:



Source Cembureau, 1997

Figure 3.2.2. Stages or unitary operations common to cement manufacturing processes.

Table 3.2.1. shows the different unitary operations required according to the productive process:

Table 3.2.1. Unitary operations according to the productive process.

Sub-Processes	Stages in the processes	PRODUCTION PROCESSES							
		Dry		Semi-dry		Semi-wet		Dry	
Extraction	Extraction of raw materials	x		x		x		x	
	Crushing of raw materials	x		x		x		x	
	Storage of raw materials	x		x		x		x	
	Prehomogenisation of raw materials	x		x					
Preparation of raw materials	Grinding of raw meal/ drying with ball mill, vertical mills etc.	x		x					
	Storage of raw meal	x		x					
	Blending and homogenisation of raw meal	x		x					
	Pelletisation of raw meal			x					
	Milling of slurry						x		x
	Blending and storage of slurry						x		x
	Homogenisation of slurry						x		x
	Filtering of slurry with filter presses						x		
	Storage of filter cake						x		
Nodulisation of filter cake							x		
Clinker burning	Detailed process identification (*)	1	2	3	4	5	6	7	8
	Long kiln, internal slurry, pellets or nodules drying equipment				x				x
	Separate external slurry, pellets, nodules or filter cake drying			x		x	x	x	
	Preheating of raw meal	x	x	x	x	x	x	x	x
	Calcining of raw meal	x	x	x	x	x	x	x	x
	Clinkering of raw meal	x	x	x	x	x	x	x	x
	Cooling of raw meal	x	x	x	x	x	x	x	x
	Storage of raw meal	x	x	x	x	x	x	x	x
Cement grinding	Cement grinding in ball mills, roller presses, vertical mills, etc.	x		x		x		x	
	Storage of cement	x		x		x		x	
Cement dispatch	Bulk loading, bagging, palletising, dispatch on rail, road and sea	x		x		x		x	

Source: Cembureau, 1997

Detailed process identification(*)

1. 4 or 4 to 6 stage cyclone preheater kilns.

2. Long dry kilns, 1- and 2-stage cyclone preheater kilns.
3. Mobile grate preheater (Lepol) kilns.
4. Long pellet kilns with internal cross systems.
5. Cyclone preheater and precalciner kilns with external dryers.
6. Mobile grate preheater (Lepol) kilns.
7. Two-stage precalciner kilns with external slurry dryers.
8. Long wet kilns with chain systems.

Table 3.2.2. shows the technical characteristics according to the production process detailed in the corresponding sections of this chapter:

Table 3.2.2. Operating characteristics of kiln processes.

Process Type		DRY			SEMI-DRY		SEMI-WET		WET	
Kiln Type Lepol = Travelling grate preheater kiln SP = Cyclone preheater kiln PC = Cyclone preheater / precalciner kiln		Long 1 stage SP 2 stage SP	4 stage SP	4 to 6 stage PC	Long	Lepol	Lepol (3 chambers)	3 and 4 stage SP and PC with dryer	Long	2 stage PC with dryer
KILN CHARACTERISTICS	Feedstock	Dry raw meal			Pelletise raw meal		Filter cake		Slurry	
	Moisture content [%]	0,5-1,0			10-12		16-21		28-43	
	Heat Exchange devices	Chains and cyclone preheater	Chains preheater	Cyclone preheater	Crosses	Travelling grate preheater	Travelling grate preheater	Cyclone preheater	Chains and crosses	Cyclone preheater
	Kiln capacity [t/d]	300-2600	300-4000	2000-10000	300-1500	300-2000	300-3000	2000-5000	300-3600	2000-5000
	Spec. Heat consumption [GJ/t]	3.6-4.5	3.1-3.5	3.0-3.2	3.5-3.9	3.2-4.5	3.6-4.5	3.4-3.6	5.0-7.5	4.5-50
	Spec. Exh. Gas quantity at system stack [Nm ³ /kg cli _{dry}]	1.7-2.0	1.8-2.0	1.8-1.9	1.7-1.8	1.9-2.1	3.4-4.0	2.1-2.3	2.2-3.2	2.1-2.3
EXHAUST GAS CHARACTERISTICS	O ₂ content at system stack [%vol]	4-5	8-9	8-9	4-5	6-10	12-14	8-10	4-5	5-6
	Temperatura at filter inlet (with EP dedusting) [°C]	150	150	150	200	100	100	120-150	180-220	120-150
	Dew point [°C]	45-65			50-60		55-65		70-80	

The dry process

In the dry process, the mix, or raw meal, is introduced to the kiln in dry, powder form. It is prepared by drying and grinding of the raw material components in ball/tube mills or vertical roller mills, making use of the hot kiln exhaust gases or cooler exhaust air for drying.

Then it is homogenised and/or blended in silos by means of continuous or by batch type systems. The finely ground homogenised raw meal, prior to entering the kiln, is preheated to a temperature of approximately 810-830 °C. In suspension preheater kilns (see Section 3.2.4.3. *Rotary kilns*), the raw meal is fed to the top of a series of cyclones passing down in counter-current flow with hot exhaust gases from the rotary kiln. This contact in suspension of the raw meal with the gases causes efficient heat exchange, enabling the meal to enter the kiln partially calcined (at about 1,000 °C) while the

gases leave the exchanger at a temperature of some 400 °C contributing part of this residual heat to the drying of the raw materials as they pass through the raw meal mill, Finally the gases are sent to an electrostatic precipitator for purification (see Section 4.1. *Potential sources of atmospheric contamination*, and Section 5.5. *Technological alternatives for the control of particles emissions*).

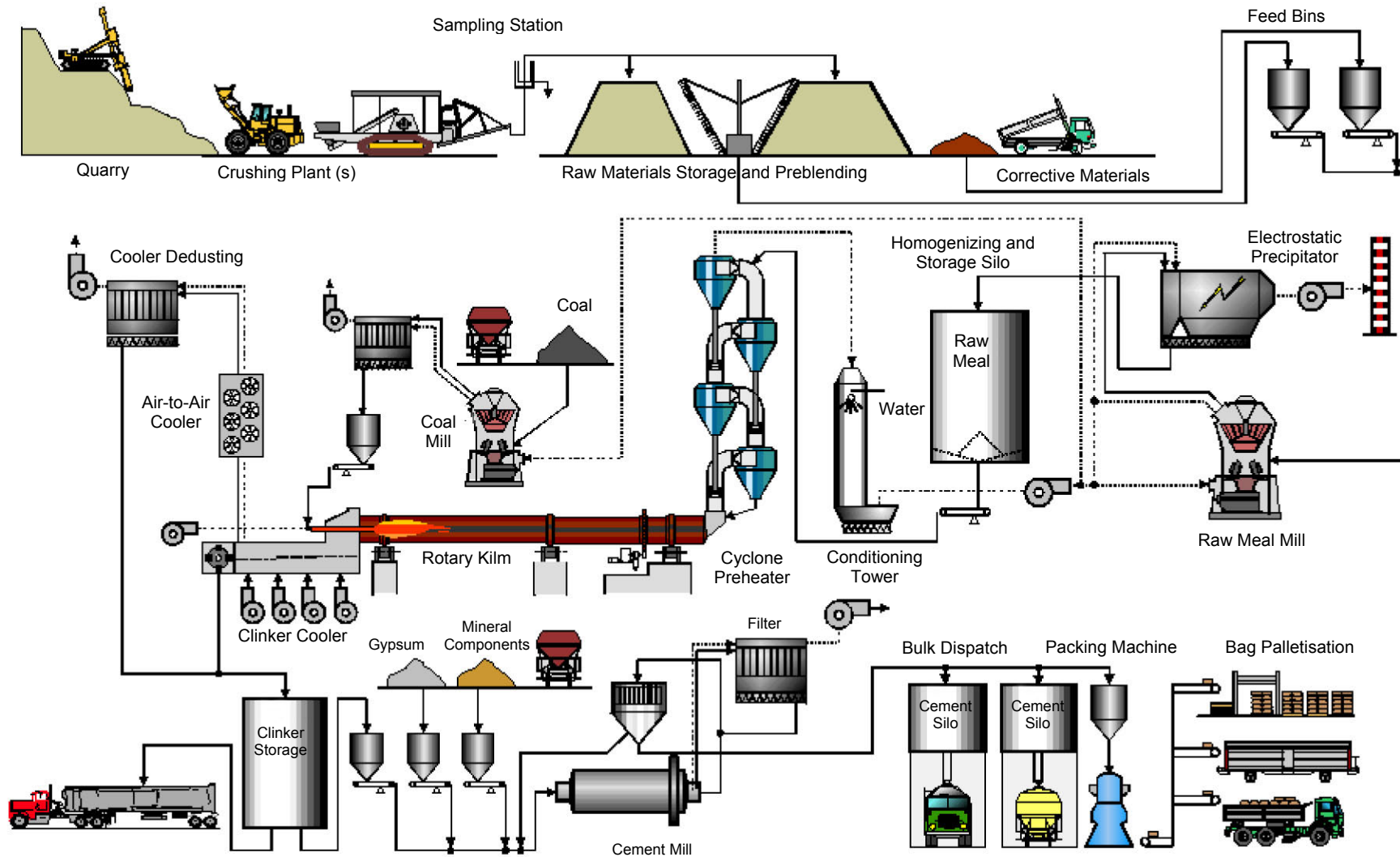
Both the dust collected in electrostatic precipitator or electrofilter, and that collected in baghouses, is reintroduced into the process, either with the raw materials, by burning with the fuel, or added to the cement mill.

In the dry, heat exchanger-kiln process, the high concentrations of alkalis and chlorides can give rise to blockages in the exchanger, especially the lower cyclones. Moreover, in the end product they may cause a reaction with certain aggregate with a high silica content. One way of combating this is to extract some of the gases which draw charged particles of alkali halides in this area by means of a by-pass system, for later cooling and thus condense the alkalis before the particles are collected in the electrofilter or in the baghouse. This dust is usually recycled back into the process.

A considerable increase in clinker production capacity can be obtained with precalciner kilns (see Section 3.2.4.3. *Rotary kilns*), in which a second combustion device is located between the kiln and the preheater section. In the precalciner, up to 60 % of the total fuel of the kiln system can be burnt. Kiln systems with a 5 to 6 stage cyclone preheater and precalciner are considered standard technology for new plants today, as the extra cyclone stages improve thermal efficiency.

In some cases, the raw meal is fed directly to a long, dry kiln without the external preheater. This is the case of long kilns (see Section 3.2.4.3. *Rotary kilns*). A system of chains at the entrance to the kiln provides the heat exchange between the exhaust gas from the hot area of the kiln and the kiln feed.

Nevertheless, if the moisture of the raw materials allows the dry process, new facilities resort to shorter kilns with several heat exchange stages as this is more energy efficient since long, dry kilns consume large amounts of energy.



Source Cembureau

Figure 3.2.3. Dry cement production process.

The semi-dry process

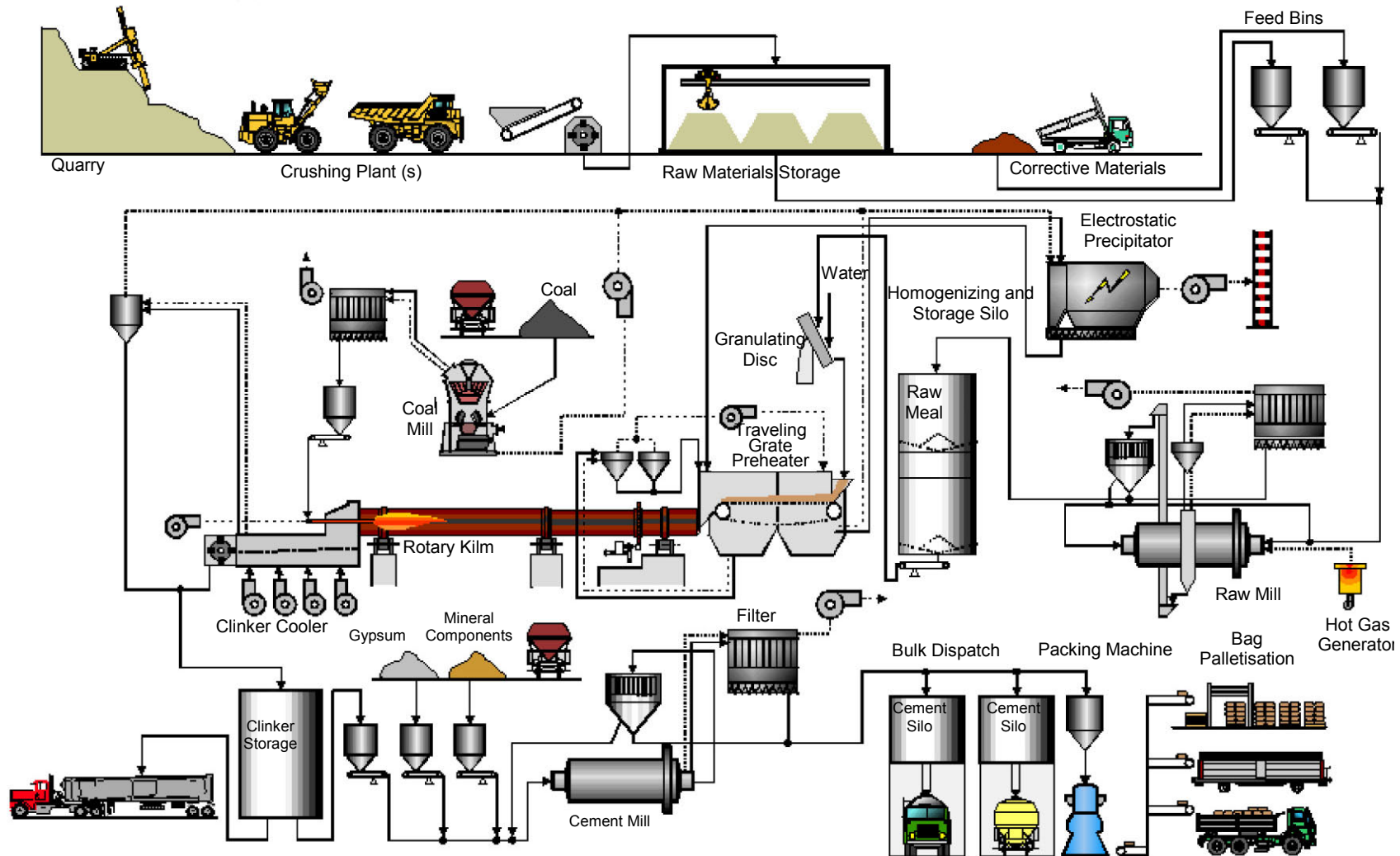
In the semi-dry process, the dry raw meal is pelletised (granulated) with water, forming pellets containing 10-12 % of water, which are fed onto a moving grate through which hot gases circulate which come from the kiln ("Lepol" kiln system) enabling drying, preheating and partially precalcinating the raw meal.

The Lepol kiln (see Section 3.2.4.3. *Rotary kilns*) represents the first system in which part of the burning stage (calcining) takes place in a stationary facility outside the kiln. A higher degree of calcining can be achieved if part of the fuel is burned in the hot chamber of the grate preheater.

The hot exhaust gases from the kiln first pass through a layer of preheated pellets in the hot gas chamber and then through dust collecting cyclones. After partial dedusting in cyclones, the gases are sent through the drying chamber of the grate preheater.

One drawback of the semi-dry process is that the exhaust gases from the kiln cannot be used in either the drying stage or in the grinding of the raw meal due to the low temperature.

Modern facilities rarely use this process, since maintenance costs of the grate preheaters are quite high.



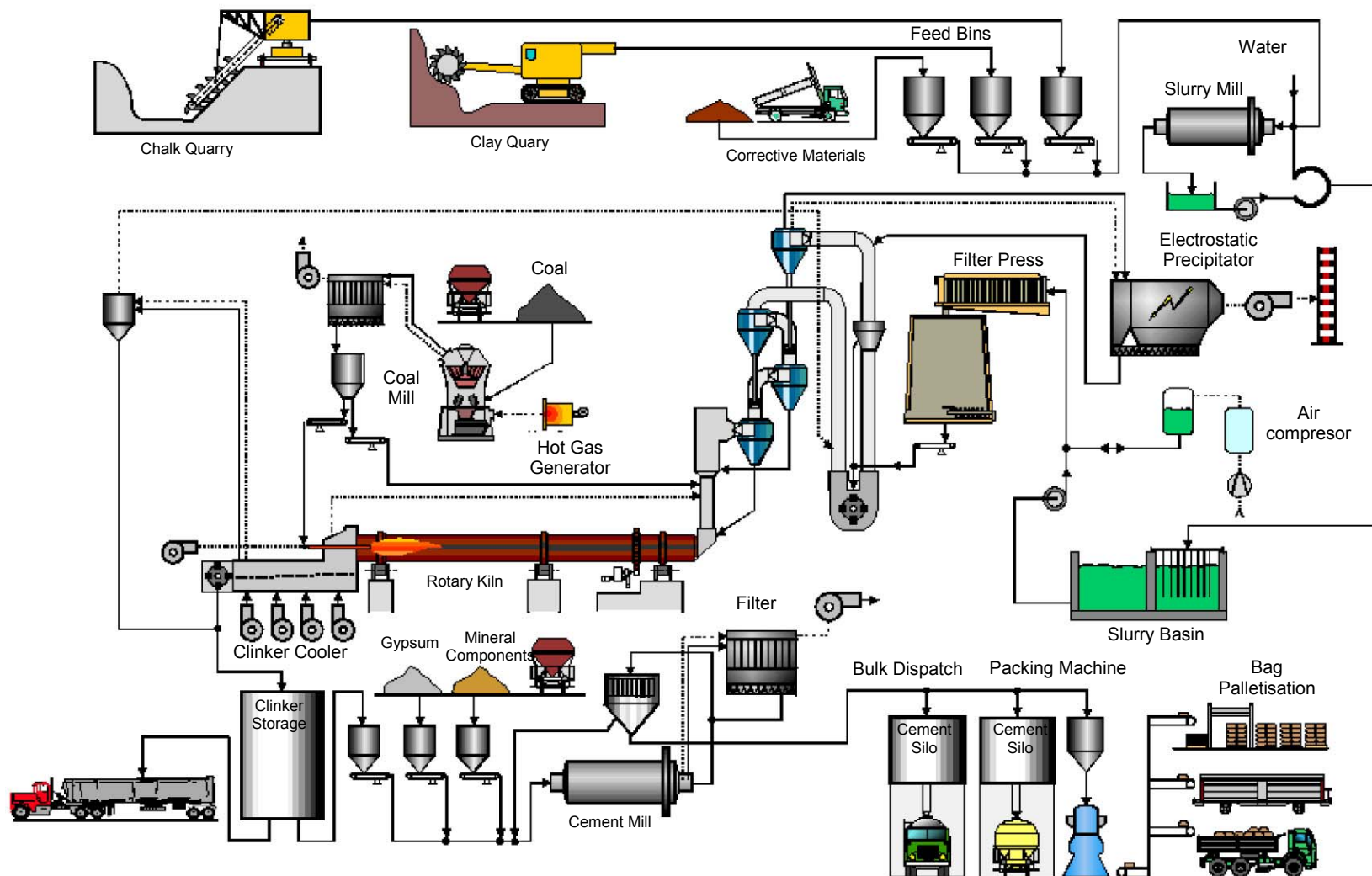
Source Cembureau

Figure 3.2.4. Semi-dry cement production process.

The semi-wet process

Formerly, the raw material, slurry from raw meal and water, was put through a filter press and the filter cakes were extruded in pellet form to be fed grate preheater kilns. In modern plants, the filter cakes are stored in intermediate storage bins prior to being fed to crushers or to driers, where dry raw meal feed is produced which feeds a modern rotary kiln with a precalciner and/or preheater.

Semi-wet grate preheaters work in the same way as the semi-dry ones, which have previously been dealt with, except that triple-pass gas systems can be installed.



Source Cembureau

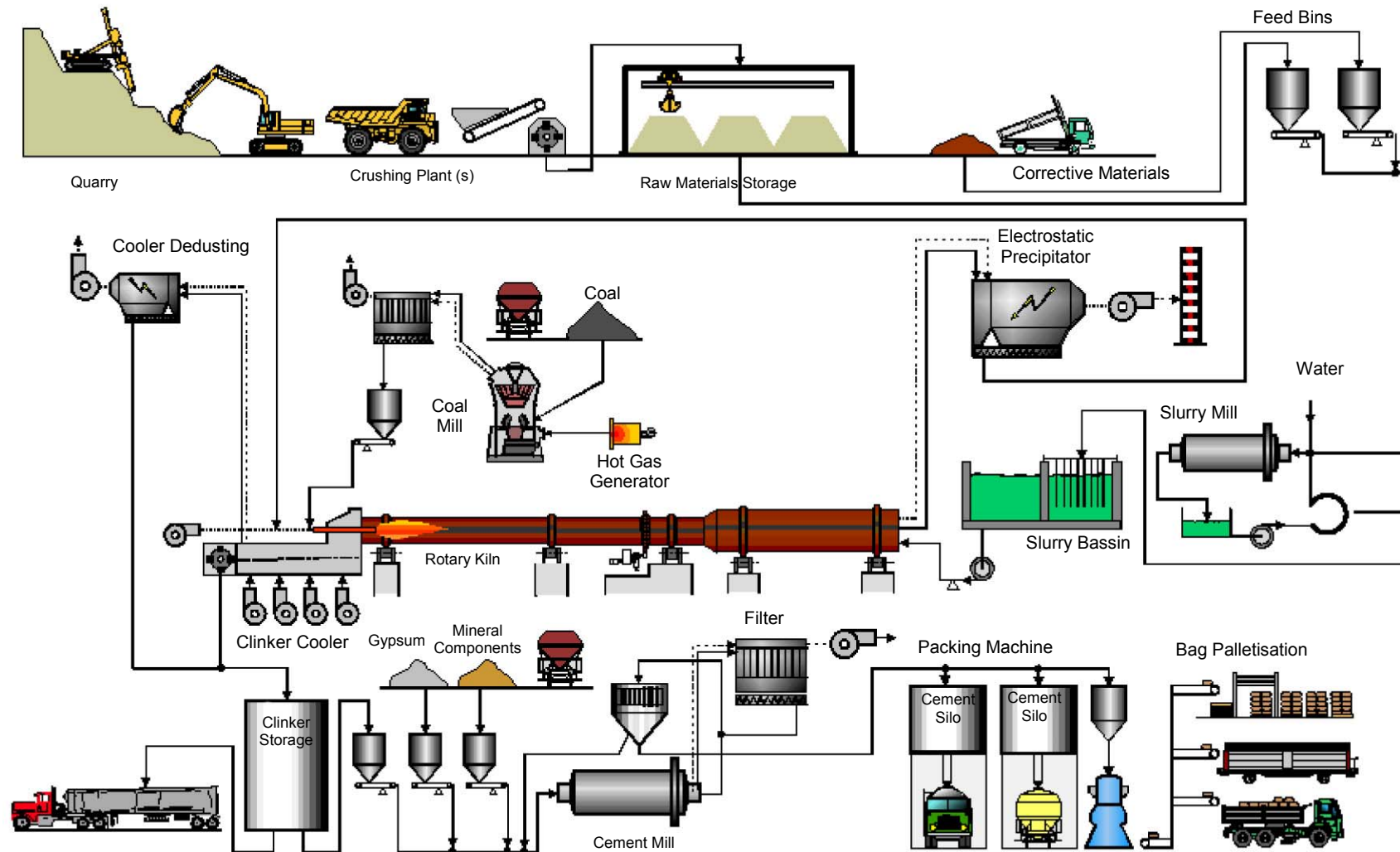
Figure 3.2.5. Semi-wet cement production process.

The wet process

In the wet process, the raw materials are ground with water to form a pumpable slurry with approximately 30 to 40 % water content. The slurry, once blended and homogenised in special silos, can either be directly fed to the kiln or previously passed through a slurry drier (in modern wet process systems).

In the kiln, the water evaporates in the drying area, just at the inlet. The drying area is designed with chains to facilitate heat exchange between the blend and the combustion gases. After having passed the drying zone, the raw material moves down the kiln to be calcined and burnt to clinker in the sintering zone, thus forming the clinker. Wet rotary kilns may reach a total length of up to 240 m compared to short dry kilns of 55 to 65 m length (without the preheater section).

This type of process presents high heat consumption (energy consumption is 100 % greater than in the case of dry processes); furthermore, it produces large volumes of combustion gases and water vapour; for this reason, the process is only usually used if required by the high moisture content of raw materials.



Source Cembureau

Figure 3.2.6. Wet cement production process.

3.2.1. Obtaining the raw materials

Cement manufacturing is an industrial process in which large amounts of raw materials are turned into commercial products, such as clinker or cement.

3.2.1.1. Exploitation of raw materials

As has already been mentioned, the main raw materials such as limestone and clay, are extracted from quarries, usually near the cement works, and this is usually integrated into cement production. They are extracted by means of boring and the detonation of explosives.

If modern technology is used, the impact caused by blasting is minimal.

3.2.1.2. Transport of raw materials

Once the large masses of stone have been broken down, they are transported to the crushing unit in lorries.

3.2.1.3. Crushing of raw materials

The material from the quarry is broken down in the crushers, whose hoppers receive the raw materials, which, due to impact or pressure, are reduced to sizes of less than 40 mm.

Following primary crushing, the raw materials are transported to the cement works for storage and subsequent preparation.



Figure 3.2.7. Crushing of raw materials.



Figure 3.2.8. Crushed limestone.

3.2.2. Storage and preparation of raw materials

3.2.2.1. Storage of raw materials

All crushed raw materials are stored in warehouses, silos, ready to be fed into the raw meal mill. Approximately 1.5 to 1.6 tonnes of (dry) raw materials are needed to produce a tonne of clinker.

The need to use covered storage spaces depends on the climatic conditions and of the percentage of fine particles in the raw materials when leaving the crushing plant. In the case of a plant producing 3,000 t/day of clinker, average storage is estimated at between 20,000 and 40,000 t of material.

The secondary raw materials, which are normally supplied via external sources, can be stored in silos or hoppers, both next to or separated from the basic raw materials, and they are finally prepared together. Secondary raw materials with hazardous properties, such as fly ash and phosphogypsums, must be stored and prepared in accordance with specific requirements.

The raw materials should be fed into the kiln in a form that is as chemically homogeneous as possible. This can be achieved via feed control in the raw meal grinding plant. When the material from the quarry varies in quality, initial prehomogenisation can be achieved by stacking the material in longitudinal (or circular) layers, depending on the type of facility, and it is subsequently extracted by taking transversal sections of the whole pile. In this way, the variation in the quality of the raw material can be compensated with a blend efficacy of 70-90 %. When the material coming from the quarry is homogeneous, simpler stacking and extraction systems can be employed.

Below, the most common storage methods are detailed.

Raw material storage methods (non-preblending)

Non-preblended storage is used for raw materials that do not require homogenisation.

- Strata stacking method: Mainly applied with longitudinal raw material stores, equipped with jib stackers and side, portal or semi-portal scraper reclaimers, resulting in a slight blending effect (see figures 3.2.10. and 3.2.11.).

Cone shell stacking method: Non-homogenised storage equipped with jib stackers and tripper belt stackers in longitudinal stores. Reclaiming is done with claw-wheel reclaimers.

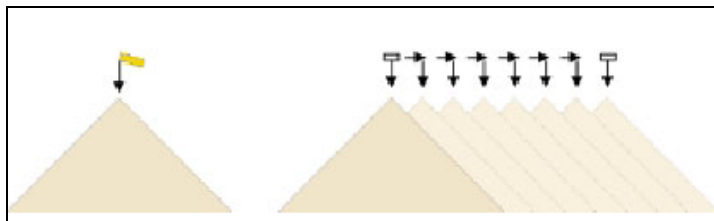


Figure 3.2.9. Cone shell stacking method.

In addition to the above described automatic storage systems, the following semi-automatic storage systems are also used:

- Longitudinal and circular store with gravity discharge feeders.
- Travelling overhead crane store.
- Silo storage with gravity discharge feeders.

NON-PREBLENDING STORAGE SYSTEMS



Figure 3.2.10. Strata storage method.
Full portal scraper.

- Available for all types of materials, including pastelike materials.
- The materials can be loaded or reclaimed from separate piles.
- Storage capacity can be increased.
- Low initial outlay.

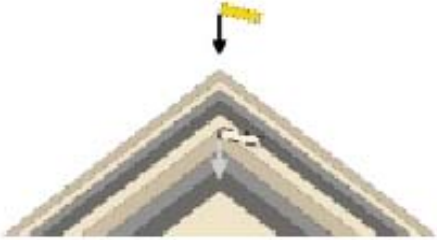


NON-PREBLENDING STORAGE SYSTEMS



Figure 3.2.11. Strata storage method.
Lateral scraper.

- Available for paste-like materials.
- The materials can be loaded or reclaimed from separate piles.
- Storage capacity can be increased.

Preblending is the proportional blend of the different types of limestone, clay, or any other material that so requires. As has already been mentioned, it is used when the quarried material varies in quality, and blend efficiencies of between 70 and 90 % can be achieved.

		
<p>Figure 3.2.12. Chevron storage method.</p>	<p>Figure 3.2.13. Chevron continuous storage method (Chevcon).</p>	<p>Figure 3.2.14. Windrow storage method</p>

- Chevron stacking method: equipped with jib stackers and tripper belt stackers in longitudinal preblending systems, and jib stackers in circular preblending systems. Reclaiming is done with a bridge scraper and bucket wheel reclaimers.
- Chevcon stacking method: Applied with jib stackers in circular preblending systems for continuous stacking. Reclaiming is done with a bridge scraper and disc and bucket wheel reclaimers.
- Windrow stacking method: Equipped with bridge scrapers in stacking systems with pit preblending in connection with sticky materials and swivel jib stackers in preblending systems. Reclaiming is done by means of bridge scraper and bucket wheel reclaimers.

PREBLENDING STORAGE SYSTEMS



Figure 3.2.15. Chevron method with longitudinal preblending system.

- Available for dry to slightly sticky materials.
- Efficient adjustment of large variations in the chemical make-up of materials.
- Stacking capacity can easily be increased.

PREBLENDING STORAGE SYSTEMS

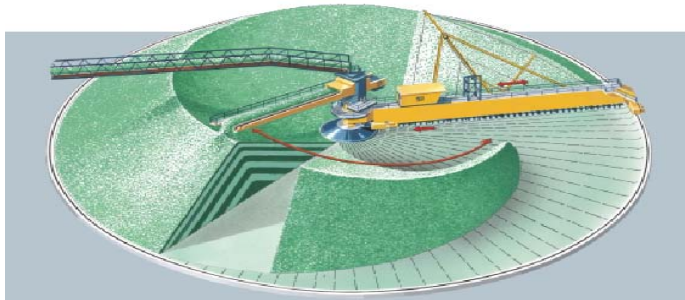


Figure 3.2.16. Chevron method with circular preblending system for continuous stacking.

- Good homogenisation effect in continuous operation.
- No end-of-cone problems exist.
- Optimal use of space.
- Fully automatic continuous operation.



Figure 3.2.17. Windrow method with pit preblending system.

- Stacking system only for highly viscous materials.
- Economical system for large stores designed for the direct feeding of any kind of grinder.
- Optimal use of space.

3.2.2.2. Raw meal grinding

The raw meal is ground by metering the raw materials in precise proportions to obtain the raw mix formulated with the least possible dispersion, given that the feed of raw materials to a kiln needs to be as homogeneous as possible from the point of view of their chemical composition. This is achieved by controlling the feed-in of raw material into the grinding plant, paying special attention to chemical composition and suitable fineness.

Thus, in order to achieve a raw meal that is homogeneous in composition, it is of utmost importance for the raw materials that are fed into the grinder to be weighed and proportioned as precisely as possible. This is an essential step in order to obtain a kiln which works steadily and to obtain high quality clinker. Moreover, the measurement and proportioning are also important factors with regard to the grinder system's energy efficiency.

The most common weighing and metering equipment used in the feeding of raw materials to grinders consists of intermediate product hoppers, filled from the raw materials stocks or external feeding, extraction from the hoppers with dosage scales and a belt feeder to introduce the material into the grinder.

In the cases of dry and semi-dry processes, the raw materials are dried and ground in defined, well controlled proportions in a grinder to produce dry raw meal. In wet and semi-wet processes, the raw materials form a paste which, when ground with the addition of water, makes a slush or slurry.

The raw meal which exits the grinding process later requires blending and homogenisation in order to achieve its optimal composition prior to passing to the kiln.

Depending on the technological process applied, additional stages may be needed such as, for example, the preparation of the raw meal in dry pellets (semi-dry process) or a filtered raw meal, partially drying the mix in the filter presses (semi-wet process).

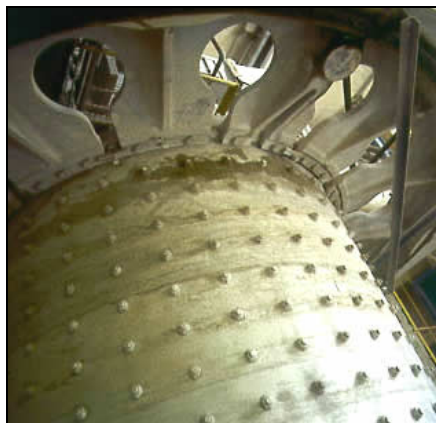


Figure 3.2.18. Raw meal grinding.

The raw materials, as well as the corrective components when necessary, are ground and mixed together in controlled proportions to form a homogeneous blend with the required chemical composition.

For dry and semi-dry kiln systems, the raw materials of approximately 8-12 % moisture, are ground and are dried to fine powder. Depending on the construction of the grinder, the raw material can be dried by making use, principally, of the hot kiln exhaust gases and/or the clinker cooler air. For high moisture raw materials, and in start-up processes, an auxiliary furnace may be needed to provide additional heat. The content of wastewater in the feed raw meal must be less than 0.5 %.

The most common dry grinding systems in the countries of the Mediterranean Action Plan are:

- Ball mill with central discharge.
- Airswept ball mill.
- Vertical roller mill.
- Horizontal roller mill.
 - Drying capacity is limited to approximately 5 % of moisture.
 - Only a few facilities exist to date.

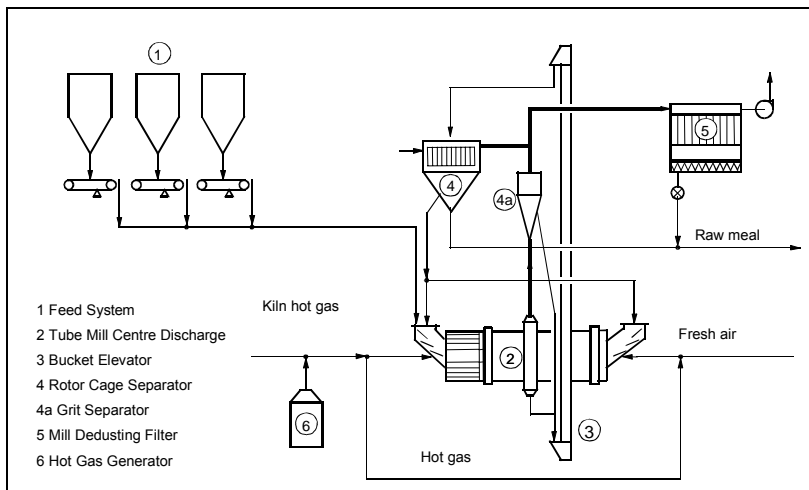
Other less frequently used dry milling systems include:

- Ball mill with end discharge in closed circuit.
 - Drying capacity is limited to 6 % (using kiln exhaust gases).
 - Production capacity limited to 300 t/h.
 - Medium electrical energy consumption.
- Open circuit mill.
- Roller press, with or without crusher drier.
 - Drying capacity without crusher drier is limited to 5 % moisture (using kiln exhaust gases).
 - Production capacity is limited to some 200 t/h per unit.

The fineness and particle size distribution of the particles of raw meal that exit the grinder are of great importance for the subsequent burning process.

The target set for these parameters is obtained by adjusting the separator used for the classification of the product leaving the mill. Dry process grinding systems are equipped with air separators and operate in a closed circuit. The separated large portions of raw materials are fed back into the circuit.

Roller mills require less energy and have a higher drying capacity than ball mills, but they are not suitable for highly abrasive materials. Ball mills have a diameter of up to 6 m and a capacity of up to 400 t/h, and consume 12-16 kW.h/t. Roller mills are designed to process up to 400 t/h and require less energy, in the region of 10-14 kW.h/t., since they work at higher pressure, and need feeding with a relatively lower water content.



Source Cembureau

Figure 3.2.19. Raw meal grinding with centre discharge ball mill.

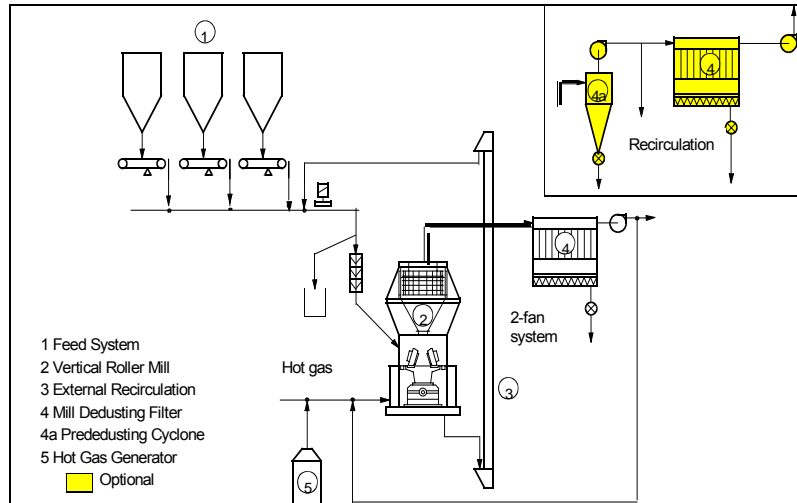


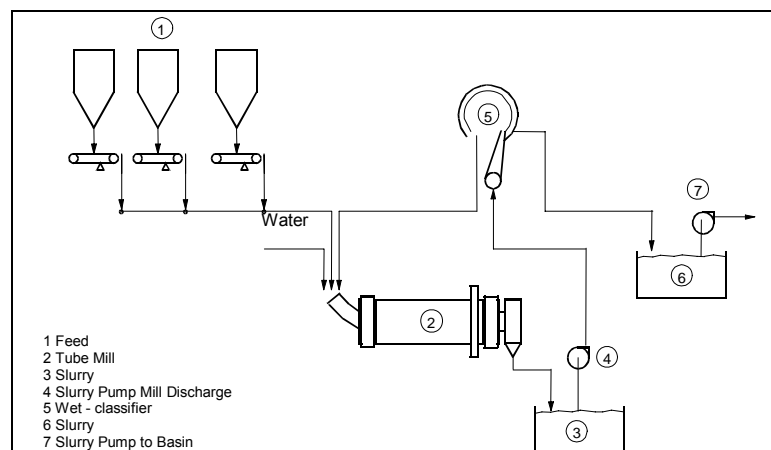
Figure 3.2.20. Raw meal grinding with vertical roller mill.

Raw materials grinding, in wet or semi-wet systems

Wet or semi-wet kilns use wet grinding. The blend of raw materials is ground in a wash mill or ball mill with the addition of water to form a slurry. Especially if sand must be added as a secondary raw material, the material is passed through a ball mill. To achieve the desired slurry fineness to fulfil quality requirements, closed circuit systems are usually used.

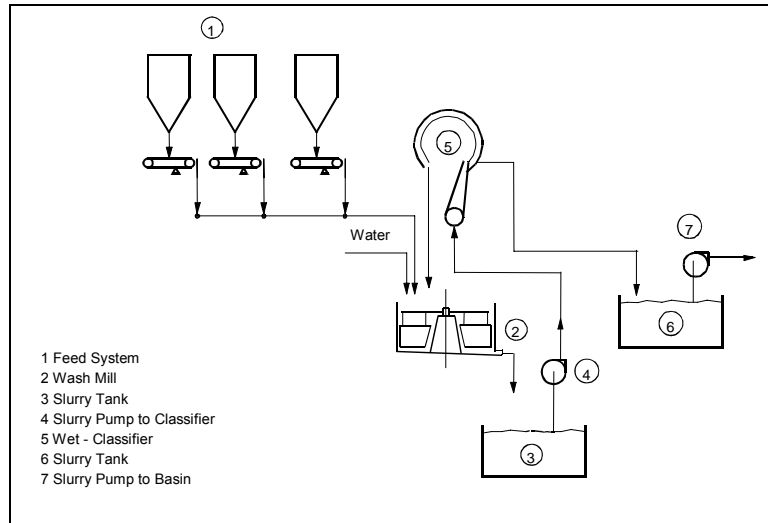
The wet process is especially efficacious when the raw materials contain over 20 % of water.

In order to reduce the consumption of fuels, the addition of water in the grinding of the raw material must be controlled so that it is the minimum need to permit the required flow and the necessary characteristics of the slurry for it to be pumped.



Source Cembureau

Figure 3.2.21. Wet Raw meal grinding with ball mill in a closed circuit.



Source Cembureau

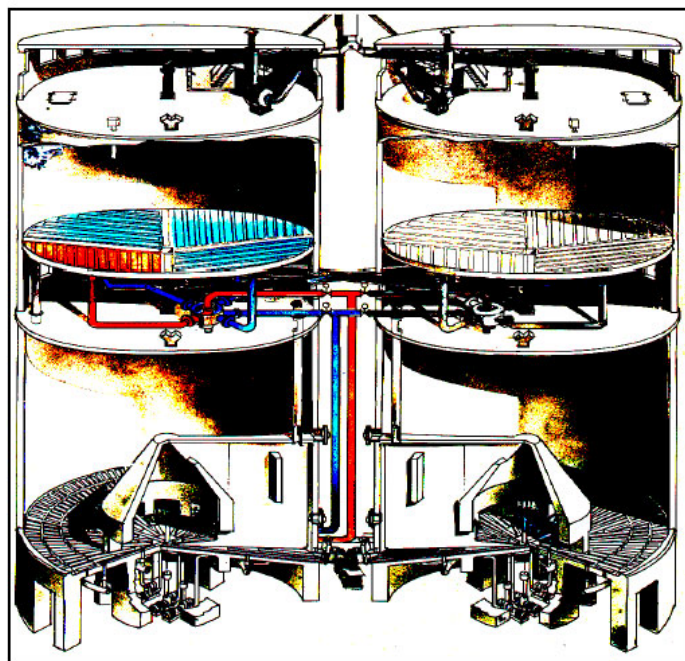
Figure 3.2.22. Wet raw meal grinding with wash mill in closed circuit.

3.2.2.3. Raw meal homogenisation

The raw meal, or the slurry in the wet process, coming from the grinder requires additional mixing and homogenisation in order to achieve the desired composition of the blend, prior to going to kiln.

Batch type homogenising system (BHS)

Batch type homogenising of raw meal (BHS) is normally carried out in two silos and storage in one. Normally the homogenising silos are above the storage silos in such a way that the homogenised raw meal can be discharged by gravity. Homogenisation is achieved by aerating the silo for approximately two hours. The homogenising effect is better than 10:1.



Source: Cembureau

Figure 3.2.23. Raw meal homogenisation and storage silos.

Continuous homogenising silo system (CHS)

The continuous homogenising silo system (CHS) consists of a homogenisation silo, normally located on top of a storage silo. The discharge of raw meal is continuous by means of overflow. The homogenising effect is up to 10:1.

Continuous blending (and storage) system (CBS)

The continuous blending silo (CBS) is used simultaneously both for the homogenisation of the raw meal and for its storage. It consists of a homogenising silo usually located on top of a storage silo. Blending is carried out by the effect of forming sectional discharge funnels. The homogenising effect is up to 5 : 1.

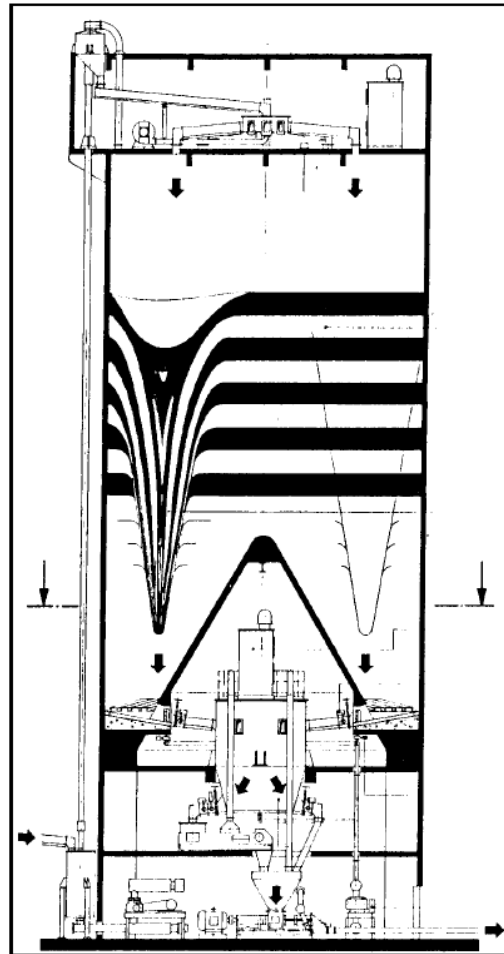


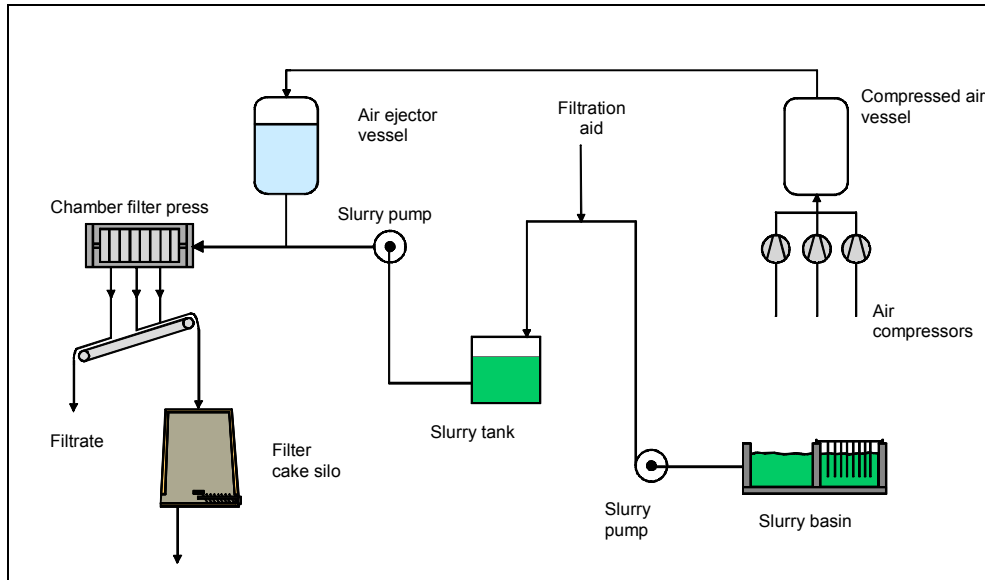
Figure 3.2.24. Continuous blending silo system (CBS).

Slurry blending / homogenising and storage of slurry in basins or silos (SBHB)

For slurry blending and homogenisation, only batch systems can be used. The blending and homogenising of slurry can be carried out both in silos and in basins (*SBHB - Slurry Blending/Homogenising and Storage in Basins or Silos*). The blending and homogenising effect in the silo takes place by means of the introduction of large quantities of compressed air into the slurry, at a minimum of four points. In the basins, this effect takes place by means of rotary stirrers. Additionally, compressed air is introduced to the basins.

3.2.2.4. Special requirements of the semi-wet process

As has already been mentioned, in modern facilities the slurry resulting from the semi-wet process is filtered in a filter press and fed through drying equipment in such a way that dry raw meal is obtained with which to feed the kiln.



Source Cembureau

Figure 3.2.25. Wet process slurry filter press.

The aim of the filter process is to replace the expenditure of purely thermal energy in the dewatering process, as occurs in wet kilns, with far more economical mechanical filter processes using filter presses.

Typically, filtering allows the elimination of 2/3 of the water contained in the slurry (for example, 36 % of slurry blend —0.87 kg water/kg clinker— is filtered down to reach a mixture of 18 % in the filter cake, which thus contains around 0.34 kg water/kg clinker).

Slurry dewatering with a filter press

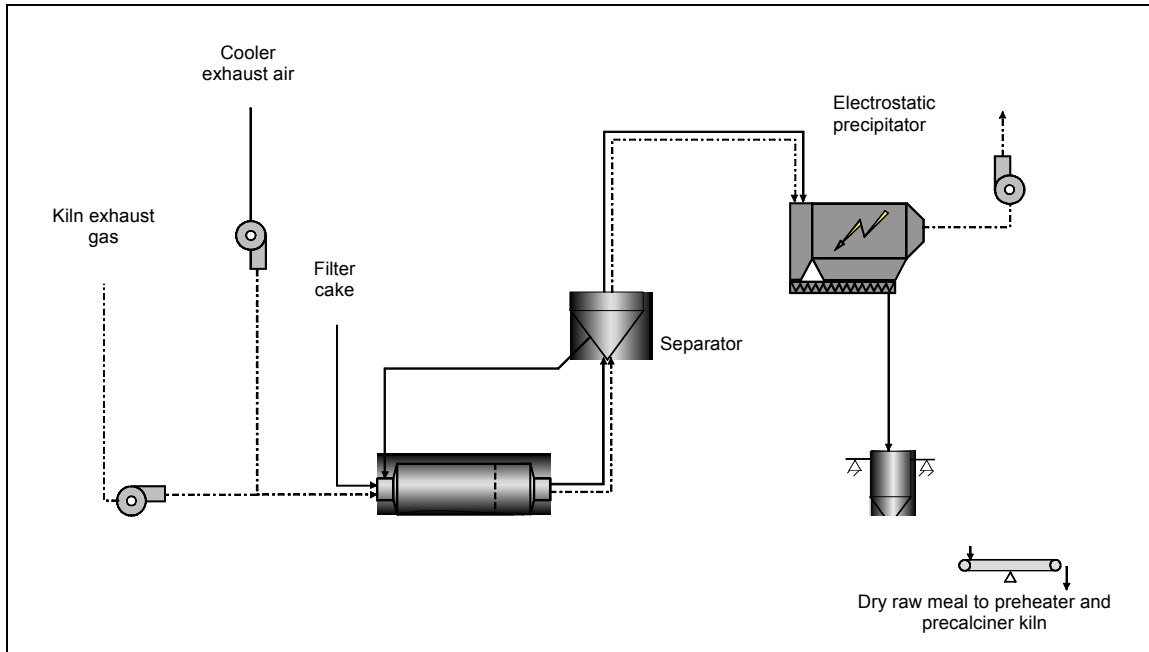
The filter pressure in slurry dewatering filter presses is at around 15 – 20 bar, and filtration times range between 15 and 35 minutes. Press loading/discharging time is 10 minutes.

Filter cake drying

Essentially, two types of filter cake drying systems are used:

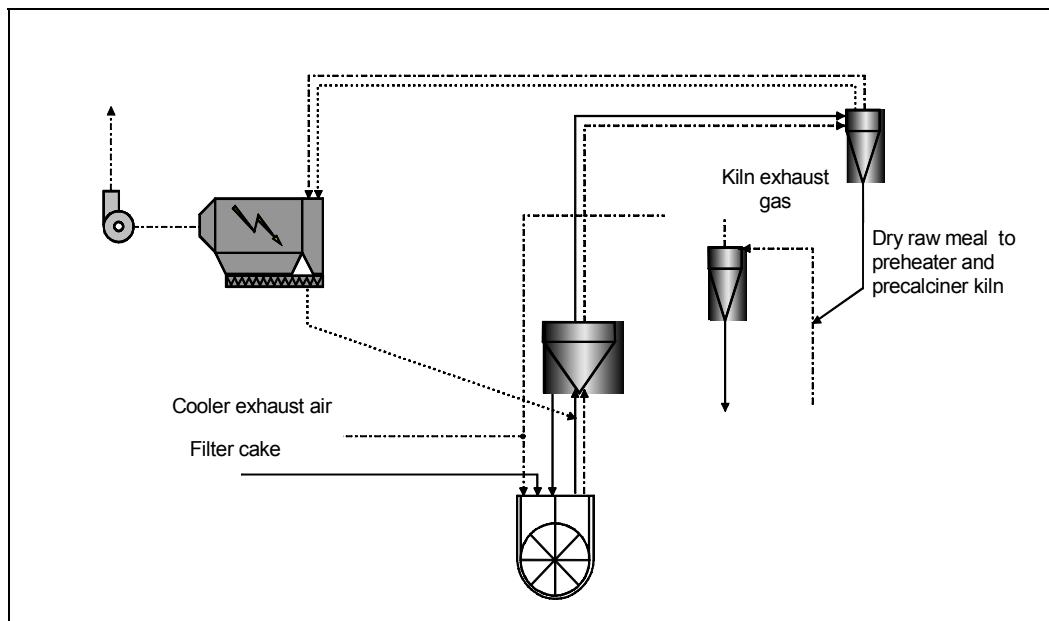
- Dispersion or rotating driers.
- A combination of crushers / driers.

Use is made of kiln and clinker cooler exhaust gases to dry the cake.



Source Cembureau

Figure 3.2.26. Fast rotating and dispersion filter cake dryer system.



Source Cembureau

Figure 3.2.27. Flash dryer/crusher drier for filter cake drying.

3.2.3. Fuel storage and preparation

The cement industry requires a large amount of energy for the burning of the raw materials in kilns. This energy is supplied by the fuel and represents the highest economic cost involved in cement manufacturing.

Different fuels can be used to provide the thermal energy required in the process. Nowadays, two different types of fuel are used to heat the cement kiln:

- Petcoke and/or pulverised coal.
- Fuel oil.

Their high cost normally prevents the use of natural gas or fuel oil, but the choice of fuel depends to a great extent on the local situation.

The high temperatures and lengths of time spent by gases in the kiln, results in a considerable potential for destroying organic compounds. This allows the use of waste from other productive processes as alternative fuels (See Section 3.2.3.3. *Use of waste matter as alternative fuels*).

In the case of white cement manufacturing, the choice of fuel should be made with particular care in order to avoid components that may alter the colour of the end product and so, in general, the aforementioned alternative fuels cannot be used.

3.2.3.1. Fuel storage

Petcoke and coal

Coal and petcoke are stored in a similar way to the raw materials, in many cases, in covered storage areas. For long-term storage, outside storage in large, compact piles are used. These piles must be treated to avoid erosion by rainwater and wind, by means of sprinkling with asphalt, with water and tensoactive materials, seeding with grass, etc. If there is a concrete floor below the piles, the water draining off may be collected and treated.

When coal is stored which contains relatively high volatile compound content, good practices must be observed in terms of the compacting and height of the piles so as to avoid the risk of spontaneous ignition when stored for long periods.

Pulverised coal and petcoke are stored exclusively in silos. For safety reasons (such as the risk of self-ignition or explosion caused by static electricity), such silos should be equipped with safety measures. In most cases, they have antiexplosion valves and inertisation systems using CO₂ or nitrogen.

Fuel oil

Fuel oil is stored in steel tanks. Handling fuel oil requires its prior heating to a temperature of some 80 °C, thus increasing its fluidity. This is achieved via steam or thermal oil heating systems and lagging in the ducts.

3.2.3.2. Fuel preparation

The physical nature of the fuels used at a cement works (solid, liquid or gaseous), as well as the storage systems, determines the preparation of the fuel – both for conventional fossil fuels and alternative fuels.

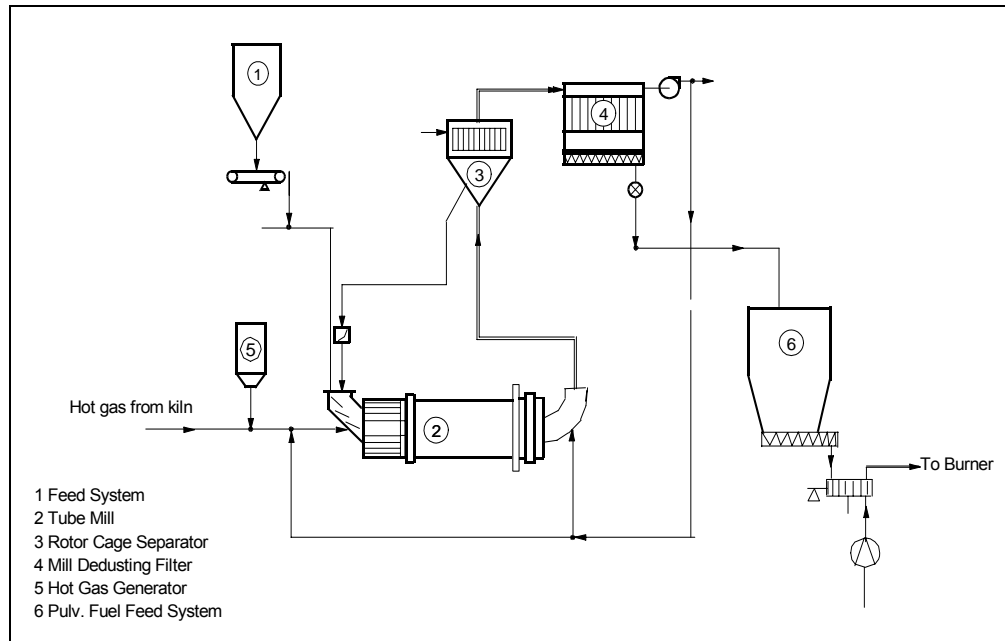
Liquid fuels do not normally require any conditioning, whereas solids usually require costly preparation (crushing, grinding and drying), which is habitually carried out at the plant itself. In all cases, fuel preparation, storage and firing systems must be designed and operated with a high level of safety to avoid fire or explosions.

Petcoke and coal

Three systems are mainly used to crush and grind fuel:

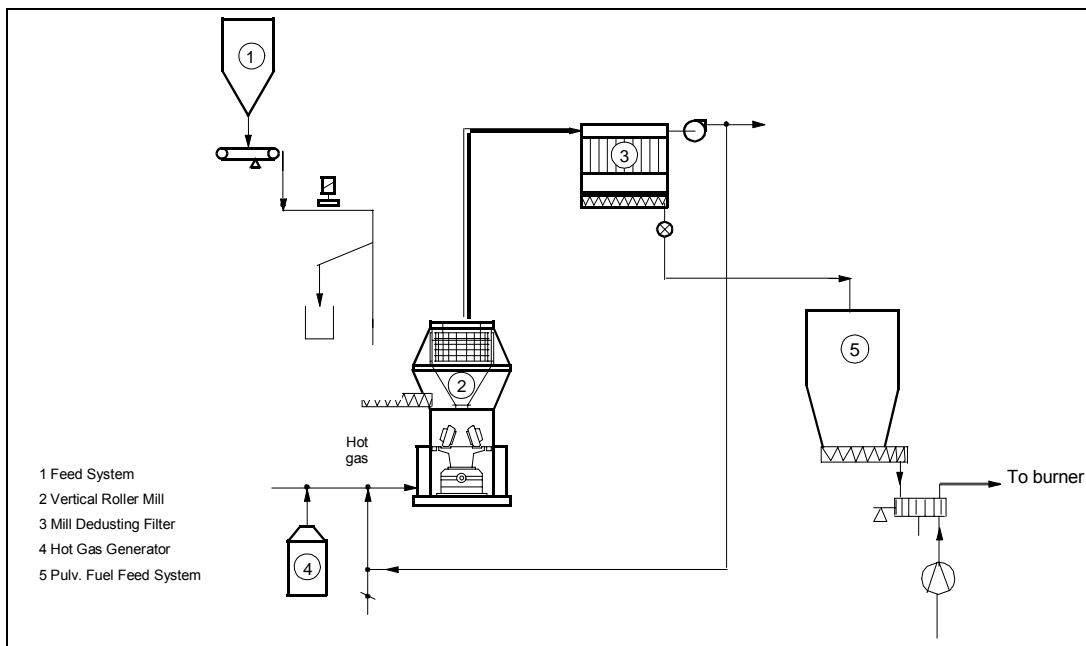
- Ball mill, airswept.

- Vertical roller mill.
- Impact mills.



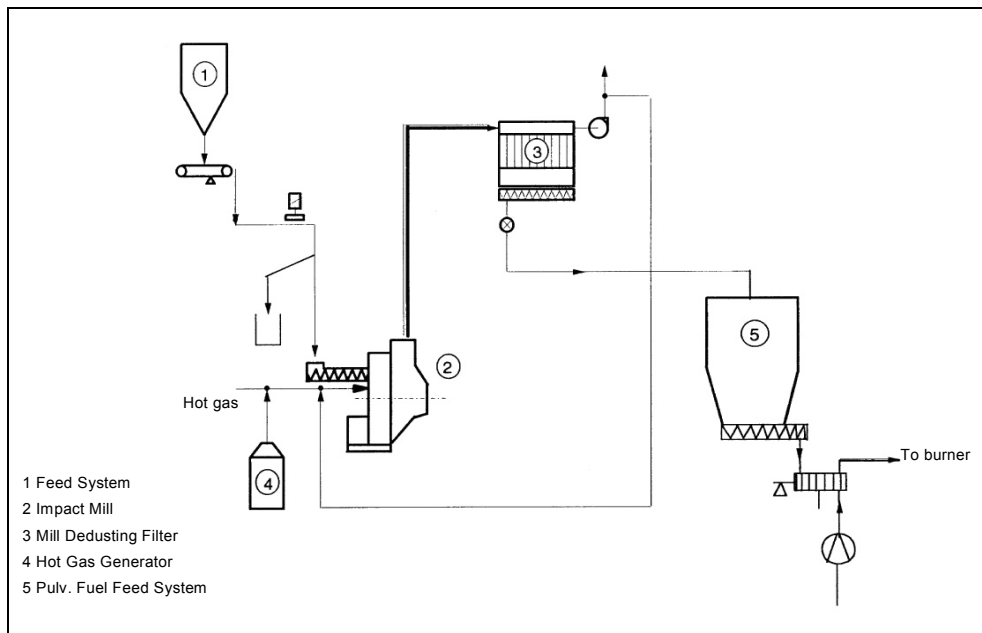
Source Cembureau

Figure 3.2.28. Ball mill fuel grinder.



Source Cembureau

Figure 3.2.29. Fuel grinding with vertical roller mill.



Source Cembureau

Figure 3.2.30. Fuel grinding with impact mill.

The fineness of the pulverised fuel is highly important: if it is too fine, the high temperatures of the flame may be too high; if it is too coarse, poor combustion may occur. Pulverised fuel can be fed directly into the burner (without storage or intermediate handling) or—as commonly practised nowadays—it can be stored in coal silos with suitable metering and feeding systems.

Coal and petcoke can be fed directly or indirectly. In the case of direct injection, the storage of ground fuel is not necessary. Pulverised fuel is injected directly into the kiln with the mill sweeping air acting as a carrier and as primary air. Direct firing plants have a large number of disadvantages; among these is kiln heat loss, which stands at about 200-250 MJ/tonne of clinker (6 to 8 % higher than modern kiln systems). Hence, direct injection is seldom installed today.

Fuel oil

If fuel oil is used, in order to facilitate its handling and combustion, it is heated to between 120 and 140 °C, which reduces its viscosity to 10-20 cSt. Additionally, pressure rises to 20-40 bar. The fuel oil, at suitable viscosity and pressure, is injected through a spray nozzle.

3.2.3.3. Use of waste matter as alternative fuels

The high temperatures in the kilns and the length of residence inherent in the cement manufacturing process results in a high potential for the destruction of organic compounds, which enables the use of a broad variety of fuels, by-products from other industrial processes or from waste matter, whether liquid (used oils, solvents, waste from distillation, etc.) or solid (used tyres, waste wood, paper, cardboard, plastic, urban and industrial sludge, etc.).

Normal waste incinerators operate at 1,100 °C with a gas retention time of 2 seconds in order to achieve 99.99 % destruction of the incinerated waste. In the case of cement kilns:

- Exhaust gas remains for longer periods of residence, at a very high temperature (up to 2,000 °C) and in an oxygen rich atmosphere, and hence the clinker kiln is considered the most effective system for the total destruction of the organic compounds present in waste.
- The heating value of the waste flow is used as a fuel while at the same time, the total destruction of the material is achieved.

- The interaction of the exhaust gases with the raw materials present in the kiln neutralises the acid gases (sulphurous and halogenated) formed during combustion, and the non-combustible mineral part of the waste is retained irreversibly in the structure of the clinker.

In addition, the advantages of using alternative fuels in clinker kilns can be summed up as:

- Avoiding the dumping of such waste and the associated impacts.
- Ecologically and safely treating waste, taking maximum advantage of its energy and minerals without generating added impacts on the environment.
- Saving non-renewable fossil fuels (coal and oil derivatives).
- Globally reducing emissions, in particular of CO₂ (one of the gases responsible for the greenhouse effect) by substituting fossil fuels with materials that would have been incinerated or fermented in landfills, with their corresponding emissions.
- An economical, flexible management alternative, since it permits the reuse of fossil fuels when waste reduction practices improve.

For these reasons, the use of alternative fuels is an established practice in most developed countries. The degree of substitution is tending to increase.

The table below gives examples of waste matter used as alternative fuels:

Table 3.2.3. Waste used as alternative fuels.

Alternative liquid fuels
Low chlorine-content solvents, lubricating as well as vegetable oils and fats, distillation residues, hydraulic oils, insulating oils, etc.
Fine granulated or pulverised solids
Sawdust, black water sludge, granulated plastics, animal mix, agricultural waste, wood production waste, tyres, etc.
Coarse solids
Tyres, rubber/plastic waste, waste wood, organic matter, etc.
Alternative coarse fuels
Whole tyres, plastic bales, material in bags and drums

Storage of alternative fuels

Waste is unloaded at plant for temporary storage, with a capacity that usually involves several days' use and whose purpose is to adequately regulate the flow of waste to the kiln.

The type of storage and the loading and discharge systems must be designed so that safety can be guaranteed, including protection from fires and means of protection against the spillage of waste to the ground or water.

Practically all alternative fuels used at cement works are solids or liquids, barring some cases in which waste gases may be used. Liquid waste is stored in watertight tanks which are fitted with collection tanks to safeguard against possible leaks or spillage. The solid waste is stored in stores, in warehouses or in hoppers.

Preparation of alternative fuels

Solid fuels (tyres, paper, plastic) are subjected to treatments including sizing by means of crushing or cutting in order to adapt the waste to the storage, handling and combustion facilities at the cement works.

Most of the fuel fed to the kiln (65-85 %) must be finely ground, given that it must burn fully and easily whereas the remainder (15-35 %) can be fed in without pulverising (e.g. whole or shredded tyres), which are fed into the burner at alternative points.

Liquid fuels (lubricants, solvents, etc.) can, in the main, be fed into the kiln in their original composition, although they are normally subjected to blending and homogenisation processes at specifically designed plants (waste preparation plants), with the aim of optimising combustion in the kiln, both from the point of view of its operation and its environmental behaviour.

Waste preparation plants are normally operated by companies specialising in waste management which send the liquid waste to the cement works prepared according to the specific specifications corresponding to each kiln.

3.2.4. Clinker burning

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

In the clinker forming (or clinkering or sinterisation) process, it is essential to keep the temperature of the material in the kiln at between 1,400 and 1,500 °C, which is achieved with flame temperatures of close to 2,000 °C. The clinkering reaction is carried out under oxidant conditions and hence an excess of air is required in the kiln clinkering zone.

White clinker manufacture presents exceptions to the two previously described characteristics. On the one hand, the raw materials do not contain fluxes, since they might colour the end product in such a way that clinkering temperatures are at around 1,600 °C, requiring flame temperatures of greater than 2,000 °C. On the other hand, in some cases, there is a need to work in reducing conditions, which increases energy consumption.

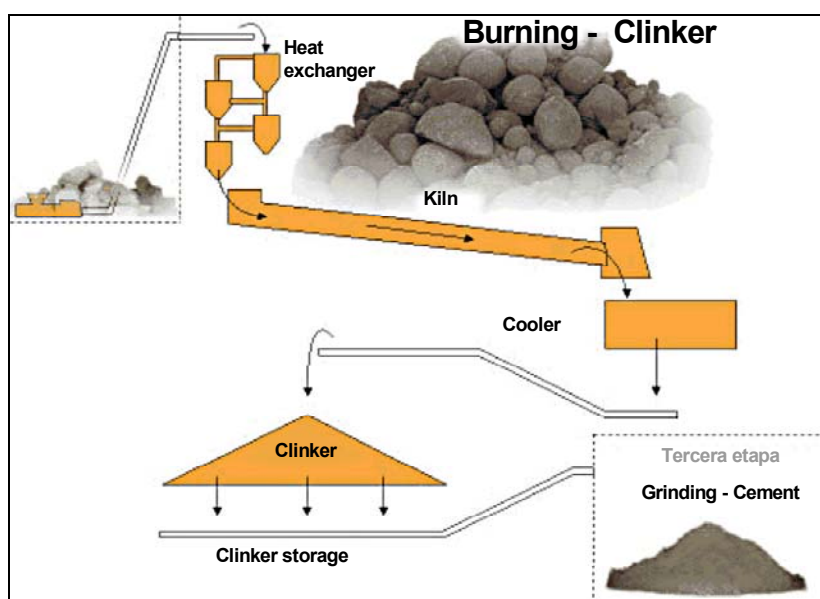


Figure 3.2.31. Burning stage.

3.2.4.1. Composition of clinker

Clinker is principally composed of tricalcium silicate, dicalcium silicate, tricalcium aluminate and tetracalcium aluminoferrite. It is made from a blend of raw materials such as limestone, marl, clay, sand, iron ore, bauxite and other components at specific proportions. When this blend is heated to the sintering range of temperatures, the new compounds form the different clinker phases.

Table 3.2.4. shows the typical proportions of clinker. The terms alite and belite were introduced by Törnebohm, who upon examining clinker through a microscope in 1897 used the first letters of the alphabet to identify the main components as he did not know its composition. These names are still used today to distinguish between pure silicates and the phases of silicate in clinker, which always incorporate small quantities of aluminium, iron, magnesium, alkali metals and traces of other elements.

Table 3.2.4. Composition of clinker.

COMPONENT	FORMULA (Abbreviation)	CONTENT (% in weight)	
		Range	Av.
Tricalcium silicate	3 CaO SiO ₂ (C ₃ S)	46 – 79	61
Dicalcium silicate	2 CaO SiO ₂ (C ₂ S)	5 – 30	15
Calcium aluminoferrite	2 CaO (Al ₂ O ₃ , Fe ₂ O ₃)[C ₂ (A,F)]	4 – 16	8
Tricalcium aluminate	3 CaO Al ₂ O ₃ (C ₃ A)	6 – 18	12
Free calcium oxide	CaO (C)	0.1 – 4	
Magnesium oxide	MgO (M)	0.7 – 1.5	1.5

Source: Ullmann's

Tricalcium silicate (C₃S)

This is the compound with the highest CaO content in the binary system CaO-SiO₂. C₃S. It is decisive and determines the majority of the characteristics of the cement. Its setting is slow and its hardening quite rapid. It attains very high resistance when ground and mixed with water. Hence it appears in high proportions in quick hardening cements and those of high initial resistance.

It is formed by the solid state reaction between calcium oxide and silicon, and can be produced from limestone and pure quartz which are very finely ground and calcined at an extremely high temperature. The kinetics of the reaction are higher in the presence of calcium, aluminium, and iron oxides (III) at a temperature of approximately 1,450 °C. For this reason, the raw materials used in the production of clinker contain calcium oxide and silicon as the main component as well as the necessary amounts of aluminium and iron oxide (III) to form a proportion of the mixture of close to 20-25 %.

C₃S has high setting heat, and it is necessary to decrease its percentage for large concrete mixes, for which cases dicalcium silicate is preferred.

Dicalcium silicate (C₂S)

This is the compound which provides the cement with long-term resistance, as its setting and hardening are slow. Its hydration heat is the lowest of the main components, and its chemical stability is greater than that of tricalcium silicate. Due to this, cements with a high dicalcium silicate content are more resistant to sulphates than those of low content.

Like tricalcium silicate, it is formed by the reaction between calcium oxide and silicon when the cement clinker is not totally saturated with calcium oxide. In lime rich mixtures, C₂S is formed at temperatures

of below 1,000 °C by a solid state reaction. During the sintering process above 1,250 °C, the C₂S incorporates additional Ca²⁺, giving rise to the formation of C₃S.

Tricalcium aluminate (C₃A)

This gives the cement a high hydration heat, extremely high setting speed and great retraction, and, despite it not having pronounced hydraulic characteristics, together with silicates, it improves the cement's initial resistance quite substantially.

Its chemical stability is good faced with certain types of aggressive water (for example, sea water) and very weak against sulphates.

It is the compound with the highest CaO content among the aluminate phases. C₃A contains the aluminum oxide that is not combined in calcium aluminoferrite. It melts to produce calcium oxide. The pure C₃A crystallises in cubic form. The crystalline structure can incorporate several ions in solid solution, for example, Fe₃⁺, Mg₂⁺, Si₄⁺, or K⁺ and Na⁺. Due to the incorporation of alkaline metals, a change is undergone by the crystal, from cubic to orthorhombic and to monoclinic, and this gives rise to higher hydraulic reactivity compared to cubic C₃A.

Tetracalcium aluminoferrite [C₄(AF)]

This compound does not take part in the mechanical resistances and its presence is due to the need to use fundents containing iron in the manufacture of clinker. It has a low hydration heat and high setting speed. Its resistance to selenitic and generally aggressive water is the highest of all components. Its dark hue prohibits it from being used for white cements for whose manufacture other fundents must be used.

In the clinker of common cement, calcium aluminoferrite composition corresponds to the formula 4 CaO Al₂O₃ Fe₂O₃. It can contain up to 2 % of magnesium oxide in its crystalline structure. This brings about colour change from brown to grey — the colour of common cement.

Free lime (CaO) and periclase (MgO).

Cement clinker's less important components are free calcium oxide (free lime) and magnesium oxide (periclase). They react with water to form calcium hydroxide and magnesium hydroxide, which occupy greater space than the original oxides. Therefore, the free calcium oxide and the magnesium oxide can cause expansion when present in high levels. In this case, the reaction with water takes place very slowly and still continues when the cement has begun to harden.

Therefore, all cement standards contain suitable specifications to limit CaO and MgO content so as to avoid any expansion which may negatively affect mortar and concrete (cement-based products).

Alkali metal components

These are, for example, the sulphates and alkali metal compounds containing calcium aluminate. Clinker contains up to 2 % of alkali metal oxides ($\text{Na}_2\text{O} + \text{K}_2\text{O}$) and up to 2 % of sulphate (SO_4^{2-}). Alkali metal sulphates are formed at sintering temperatures. They are not mixed with aluminoferrite in the clinker. The solid solutions of alkali metal sulphate are crystallised during cooling with a composition that depends on the $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ratio. The total amount of alkali metals and the nature of their bond in clinker may noticeably affect the hardening process and the mechanical properties of cement.

Other components

Other components that can be found in common Portland cement clinker have no significant influence on the properties of cement. Special cements may contain different portions of calcium aluminates determining the properties of the end product.

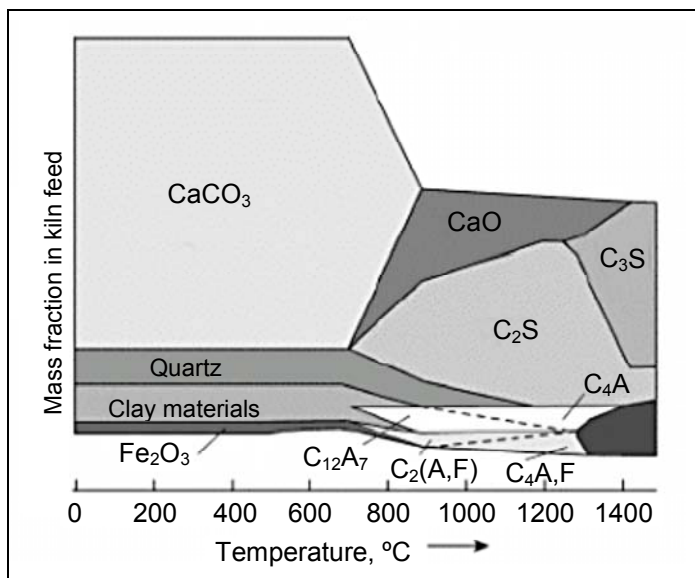
3.2.4.2. Clinker burning stage

During this stage of the process (the most important in terms of product quality, potential emissions and cost), the raw materials are fed into the kiln where they are dried, preheated, calcined and sinterised to produce cement clinker, which is immediately air cooled and stored.

Burning consists of a (very slow) reaction between finely divided solids and the formation of a liquid phase, which accelerates the reactions and the development of the new components (see Figure 3.2.32). The raw meal in the kiln gets increasingly hotter, which leads to the production of a series of physical and chemical transformations. Conventionally, this process is divided into the following stages:

- I. **Initial composition (20 °C):** Calcite (CaCO_3), quartz (SiO_2), clay minerals ($\text{SiO}_2\text{-Al}_2\text{O}_3\text{-H}_2\text{O}$) and iron components (Fe_2O_3).
- II. **Drying and preheating (20-700 °C):** Drying involves the evaporation of the moisture from the raw material at a temperature of 110 °C. In the initial heating, the retained liquid and the absorbed water evaporate, followed by dehydration of clay minerals (at temperatures of over 450 °C), and the activation of oxides due to the decomposition of these minerals.
- III. **Preheating and calcining (700-1,000 °C):** The process of calcium and magnesium carbonate dissociation is completed and a considerable quantity of free calcium oxide appears. Also, the decomposition of dehydrated clay minerals occurs in SiO_2 , Al_2O_3 and Fe_2O_3 oxides. The iron oxides start to react with the quicklime and the alumina to form liquid tetracalcium aluminoferrite at 1,300 °C, at which temperature the minerals dissolve, increasing the reaction between them. As a result of such reactions, the initial formation of clinker phases is obtained which take place in solid state, C_3A , CA , $\text{C}_2(\text{A F})$, C_{12}A_7 , and partly C_2S .
- IV. **Burning (900-1,250 °C):** So far, all reactions that have taken place have been endothermic. Solid phase reactions take place in this phase. At 1,338 °C, the materials dissolved in the tetracalcium aluminoferrite (C_4AF) react to form all of the dicalcium silicate (C_2S) and the initial formation of the C_3A melt. These reactions are exothermic, which causes an intense temperature increase in a relatively short section of the kiln.
- V. **Burning (1,250-1,450 °C):** Tricalcium aluminate (C_3A) is formed at 1400 °C. The quicklime, which is found in excess, reacts with the part of dicalcium silicate (C_2S) to form tricalcium silicate (C_3S).
- VI. **Cooling:** Clinker cooling begins in the pre-cooling area of the kiln. The length of this area and cooling speed depend on several factors, such as the position of the primary burner and the type of cooler. The clinker leaves the kiln from temperatures of 1,350 °C (sinterising zone near the kiln outlet) at 1,150 °C (cooling zone with planetary —satellite— coolers). Optimisation of cooling via new techniques improves the overall efficiency of the kiln system. Moreover, the

clinker and the characteristics of the cement may be influenced positively by high cooling speed, especially in the pre-cooling area of the kiln. This phase sees the complete formation of the definitive structure and composition of the clinker, in which C_3S , C_2S , C_3A , $C_4(AF)$ the vitreous phase and secondary components are present.



Source: Ullmann's

Figure 3.2.32. Composition in kiln according to temperature.

In the clinkering process, the kiln load should reach temperatures of 1,400 – 1,500 °C, with gas peak temperature of 2,000 °C. The process should take place under oxidising conditions, thus an excess of air is needed in the sintering zone; these conditions are essential to form the clinker phases and the quality of the cement produced.

From the point of view of the physical-chemical processes, the burning process is usually divided into the following five stages:

- I. Drying.
- II. Preheating (up to 500 °C).
- III. Decarbonation or precalcining (700-1,000 °C)
- IV. Clinkering (1,000-1,450 °C)
- V. Cooling (1.450-80 °C)

3.2.4.3. Rotary kilns

Since the introduction of the rotary kiln in 1895, it has become the heart of modern cement production facilities. The first rotary kilns were long, with length to diameter ratios of up to 35-40, and today's modern ones have length to diameter ratios of 10. Vertical kilns are still used for the production of lime, but only in very few countries are they in use for the production of cement clinker, and in these cases, the plants are small scale.

The kiln systems most commonly used, therefore, are rotary kilns with, or without, additional (preheating and precalcining) systems that will be analysed later on depending on the design of the main process chosen.

The rotary kiln consists of a metal cylinder which is coated inside with a refractory material. It can exceed 150 metres in length, with a diameter of up to 4.5 metres. It is at a slight angle (2 to 5 %) and it turns at slow speed (100 to 180 revolutions per hour, depending on diameter and angle). The kiln is fed continuously and takes place at the top in the form of slurry, when the wet process is utilised, or in the form of powder, when the dry process is chosen. The product moves inside the cylinder due to gravity, due to the angle of the kiln and is eased by its rotation in such a way that the material moves along the kiln from the entry point to the exit point at the bottom, passing all of the zones of the kiln and therefore being exposed to all of the phases that take place along it.



Figure 3.2.33. Rotary kiln.

The flow of raw meal in the kiln takes place countercurrent to the hot gases coming from combustion. After the kiln is a cooled in such a way that the clinker cools with the air that enters, which in turn heats in such a way that it can be used to intensify combustion, bringing the necessary air for it to take place. When this air, which is at high temperature, reaches the top of the kiln, it is used to preheat and dry the raw meal entering at the top end of the kiln. Finally, the air leaves the kiln through a stack at a considerable temperature, accompanied by raw meal dust, and hence some kind of filter system is necessary in order to avoid dust emission into the ambient air.

Product load usually only covers 10-12 % of the interior section of the kiln. The fuel is injected from the bottom of the kiln via a nozzle or burner which is fed with pulverised coal or fuel-oil.

In the case of wet processing, kilns are longer since they must have a drying area where the water is eliminated from the slurry. This is the weak point of the wet process since the drying zone requires more space, as well as high fuel consumption.

In the clinker kiln, combustion takes place in one or two zones, depending on the technology used:

- In the main burner, which is present in all kilns and located at the lowest part of the rotary kiln, the flame reaches a temperature of close to 2,000 °C. Exhaust gas remains at over 1,200 °C for less than 5 seconds, in an oxidising atmosphere (excess oxygen).
- In the area of the kiln where limestone decarbonation (calcining) occurs, where combustion takes place at temperatures close to 1,200 °C, the gases remain at a temperature of over 850 °C for 3 seconds.

The specific location of the second combustion zone varies for different types of kilns. Most modern kilns have combustion chambers at the lower part of the cyclone tower (precalciner), where

combustion takes place with the contribution of air coming from the clinker cooler. Some kilns have a precalciner without the provision of tertiary air, and so combustion is carried out with the excess oxygen coming from the main burner.

In dry process kilns with no precalciner, or in semi-wet or semi-dry process kilns, combustion may take place in the first zone of the rotary kiln. This system is especially suitable for dense fuels fed in relatively large sizes (such as, for example, whole or shredded tyres).

In wet process or long kilns, alternative fuels can be fed into a special part of the kiln adapted for this purpose (patented 'Mid Kiln' system). The opening in the rotary kiln and the system of lockgates means that fuel can be fed in with each turn of the kiln.

Table 3.2.5. Combustion conditions in rotary kilns.

Parameter	Ranges
Combustion temperature	1,800-2,000 °C (Main burner)
Retention time	5-10 sec. at T>1,200 °C
Oxygen content	2-3 %

Source Cembureau

If the raw materials entering the kiln are high in alkali content and a cement is required with a lower or low content thereof, a by-pass can be added to remove them. In the sintering zone of the clinker burning process, where temperatures reach 1,450 °C, some alkalis volatilise, especially if presented in the form of sulphates. Volatilised alkalis are dragged with the flow of hot gases which, in the case of a kiln with preheaters, will be reintroduced into the system. In order to reduce the content of alkalis, a by-pass is installed to extract part of the hot gases from the system; these will later be passed through a filter system to remove the particles that are rich in alkaline compounds. The amount of gases that must be diverted to the by-pass depends on the quantity of alkalis to be removed: 10-20 % is normally enough to obtain an acceptable level.

Long rotary kilns

Long kilns are the oldest type of rotary kilns used in the production of cement clinker.

The largest long kilns have a length to diameter ratio of 38:1 and can be over 200 m in length. They are designed to carry out all of the stages of the process ranging from drying to clinkering (drying, preheating, precalcining and clinkering), in such a way that only the feed system and the cooler need be added. The first part of long kilns is equipped with chains in order to improve heat transfer.

These kilns (Figure 3.2.34.) can be fed with slurry, ground filter cakes, nodules or dry raw meal and hence, they are suitable for all types of process. Nevertheless, nowadays, long kilns are only used when dealing with wet raw materials, since if the moisture content of the raw materials is low enough to allow the dry process to be carried out, new cement works prefer to shortern kilns with several heat exchange stages, as they are more efficient energy consumers.

The wet process with long kilns was developed for cases of having very moist raw materials, which are easier to homogenise when diluted with water. Once they are crushed, mixed and blended in the form of slurry, they are introduced directly into the rotary kiln at 32 to 40 % water content to increase their fluidity. The water evaporates in the drying zone, at the inlet section.

Long wet process kilns are characterised by their large dimensions compared to their production capacity (maximum 3,600 t/d). This can be appreciated in the curves showing the ratios between production and the internal diameter of briquetting (Figure 3.2.35.), on the one hand, and between production and the internal volume of briquetting (Figure 3.2.36.) on the other.

The volume of production of wet process kilns varies from 0.3 to 0.9 t/d*m³ with an average of 0.6 t/d*m³. A tendency towards a decrease in this quotient has been noted, parallel with the increase in kiln diameter.

The thermal load in the burning zone (for the transversal section of this zone measured inside the briquetting), varies from 14.2 to 29.7 GJ/m²*h, with an average value of 19.6 GJ/m²*h. Thermal load tends to increase as the diameter of the kiln increases. Quite a good correlation ($R^2 = 0.91$) is obtained between thermal load and production (figure 3.2.37.).

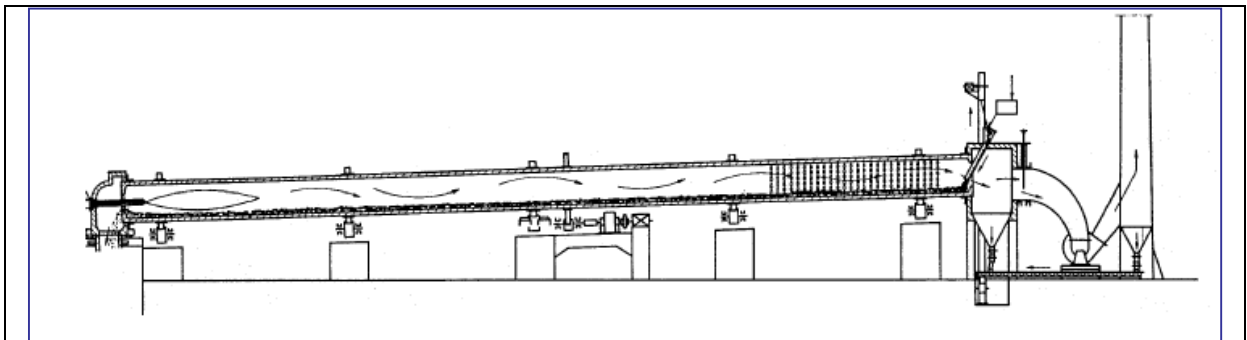
Wet process kilns have very high energy consumption, which may range between 4,500 and 7,000 kJ/kg of clinker. This was —and still is— the reason why these kilns are no longer in use, except for a few special cases where the aptitude for the consumption of replacement fuels allowed compensating this high consumption by the slight reduction in the unit cost of thermal energy.

The advantages of a wet process plant are essentially:

- A saving in electrical energy consumption of approximately 15 to 20 % compared to the dry process (for the facility as a whole).
- The possibility of consuming up to 100 % substitute fuels or industrial waste.
- Greater tolerance than the dry process with regard to minor elements (chlorides and alkali sulphates).
- High mechanical reliability linked to its simplicity.

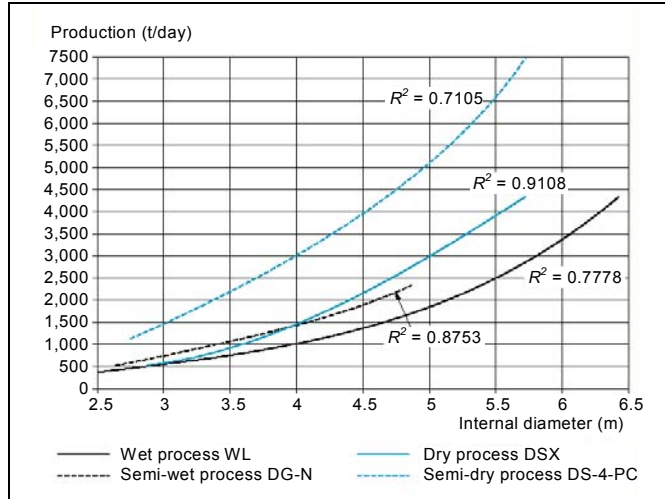
Conversely, the main setbacks are:

- Thermal energy consumption may reach 2 to 2.4 times that consumed in the dry process method.
- Unit production capacity is limited at 3,600 t/d whereas dry process kilns exist which can produce 7,500 t/d.



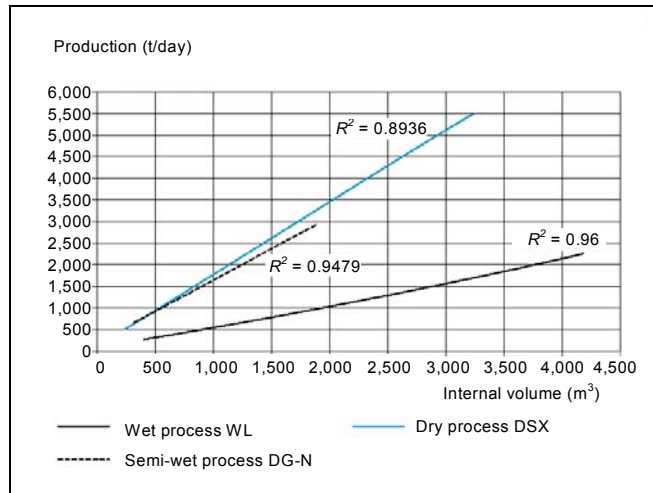
Source: Cembureau

Figure 3.2.34. Wet process long kiln.



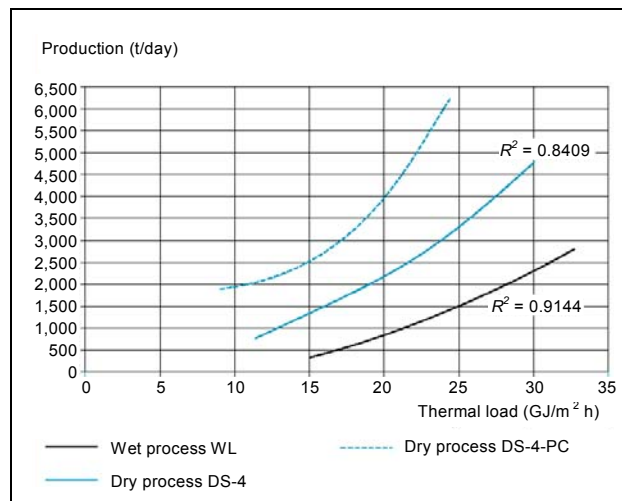
Source: Techniques de l'Ingénieur

Figure 3.2.35. Ratio between production and internal diameter.



Source: Techniques de l'Ingénieur

Figure 3.2.36. Ratio between production and kiln interior volume.



Source: Techniques de l'Ingénieur

Figure 3.2.37. Ratio between production and thermal load.

Rotary kilns equipped with preheaters

Rotary kilns equipped with preheaters have a typical length to diameter ratio of between 10:1 and 17:1. There are two kinds of preheaters: grate and suspension preheaters.

Grate preheater technology

The technology of the grate preheater, better known as a Lepol kiln, was invented in 1928. It was the first approach in which part of the burning process (drying and part of the decarbonation) took place in a stationary facility outside the kiln, on a moving grate. The end of the decarbonation and clinkering is carried out in the rotary part of the burning system. This allows the rotary kiln to be shorter, and thus reduces heat loss and increases the energy efficiency of the whole installation.

This method was developed as an alternative to the wet process method and, in comparison, offers an interesting, marked (20 to 30 %) reduction in specific thermal consumption by the burning system.

In Lepol kilns, the burning operation is preceded by granulation, in such a way that the raw material is transformed into pellets suitable for the grate. In the grate preheater (see Figure 3.2.39.) the pellets made with raw mix and water (semi-dry process) or the cakes whose wet slurry has been filtered (semi-wet process) are fed to a moving horizontal grate that passes along a closed tunnel. The grate plates allow air to pass through them. The tunnel is divided into a hot gas chamber and a drying chamber separated by a partition crossed by the grate. The partition enables avoiding, in so far as possible, the direct passage of hot fumes towards the drying chamber.

Gases exiting the rotary kiln, at a temperature of approximately 1,000 °C, blown by a fan, cross the bed of pellets on two occasions:

- Firstly through the layers of pellets in a chamber of hot gas, ceding much of the heat to leave the grate at 100-120 °C and then through the cyclones of the intermediate dust collector, where the large dust particles, which may cause wear to the fan, are removed.
- Later, a second fan draws the gas to the upper part of the drying chamber, crossing the wet layers of pellets, finally taking it to the dust collector.

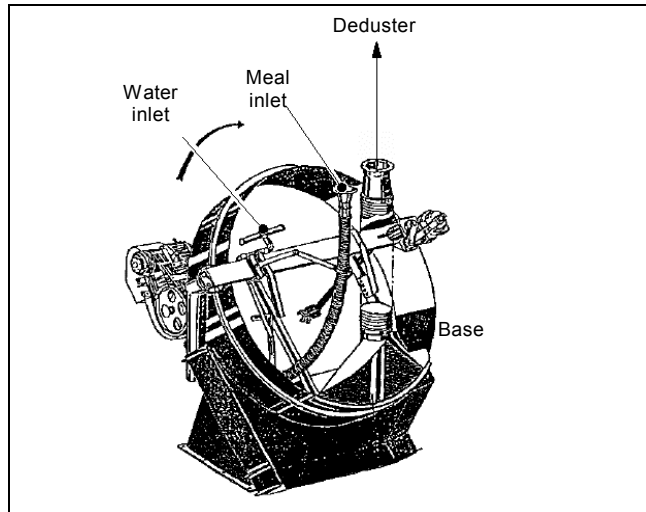
During this exchange, the dried, partially decarbonated pellets (20 to 30 %), enter the kiln at a temperature of 840 °C.

The Lepol grate consists of a set of continuous plates with a width of between 4 and 5.6 m and length between axes of 20 to 62 m. The thickness of the pellet layer can be adjusted to between 150 and 200 mm. The speed of the grate can vary between 25 and 50 m/h.

In order to increase plant production above nominal production, an auxiliary precalciner heater is used in the hot chamber, with the aim of having room for manoeuvre in terms of ventilation, to increase the quantity of oxygen at the kiln outlet from 1.5 to between 3.5 and 4.5 %. Therefore, the air necessary for precalciner fuel combustion is contributed by the kiln fumes. Between 20 and 25 % of the total heat may be contributed by the precalciner burner in such a way that the decarbonation of the mix on the grate may reach 55 to 60 %, instead of 20 to 30 % without precalcining.

The conditions of exploitation of the Lepol kiln, as well as those of the refrigerator, are determined by the previous granulation of the raw material prior to being introduced into the rotary part; this aspect is specified by the volume of production. This value is approximately 30 % higher than in the case of dry kilns without precalcining. The production capacity of Lepol kilns varies from between 1.5 and 3.2 t/d*m³ with an average value of 2.1 t/d*m³. As for wet kilns, there is a tendency for the production volume to decrease as kiln diameter increases.

The thermal load in the burning area varies between 10.2 and 19.2 GJ/m²*h with an average of 14.5 GJ/m²*h, with no correlation with production. Thermal consumption of the semi-dry method is lower than for the semi-wet method. It is noted that variation can be quite broad, from 3,200 to 5,000 kJ/kg of clinker, depending on operative conditions.



Source: *Techniques de l'Ingénieur*

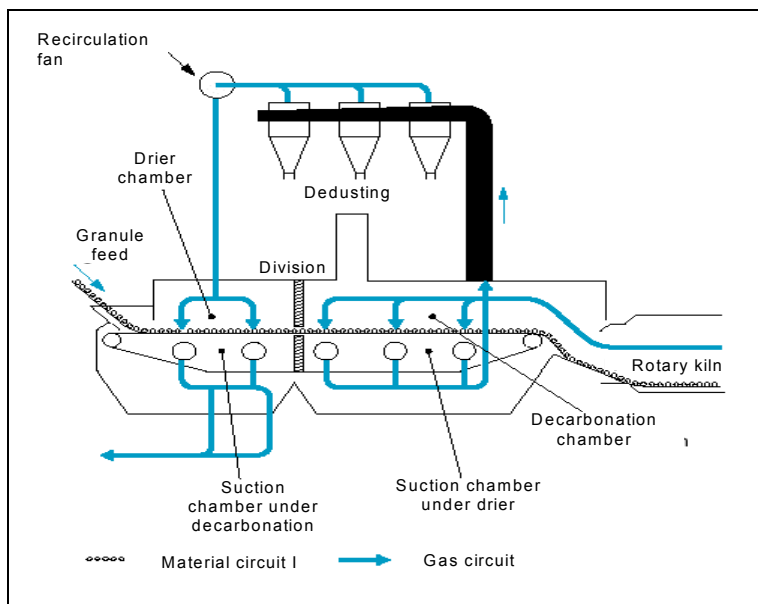
Figure: 3.2.38. Granulator.

The advantages of the Lepol method are:

- thermal energy consumption is lower than for the dry kiln.
- the good particle size of the clinker.
- the simplicity of the process.
- well controlled internal recirculation.

Its disadvantages are:

- the need for a raw material that is suitable for granulation.
- the impossibility to recover the sensitive heat of the fumes due to their low temperature.
- limited unit production capacity.
- the difficulty to control air inlets (20 %) and the pressure profiles in grate chambers.



Source: *Techniques de l'Ingénieur*

Figure 3.2.39. Lepol Grate.

X-stage technology suspension preheater kiln: DS-X (Dry Short X)

The invention of the suspension preheater or cyclone heat exchanger at the beginning of the 1930s was a great innovation in the cement making process.

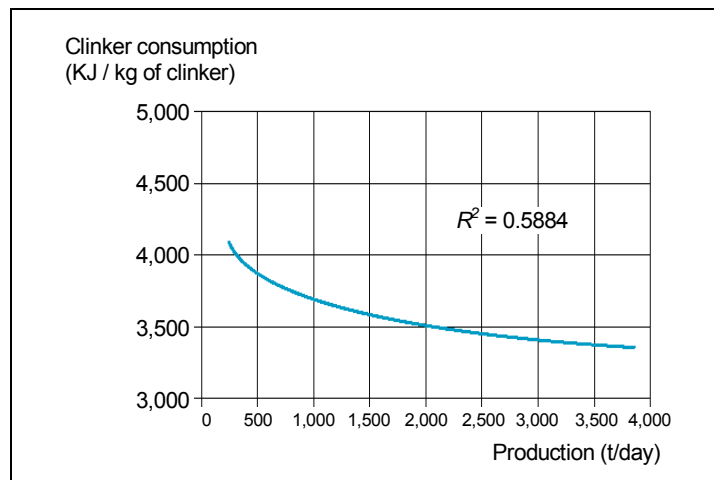
This type of preheater requires the raw meal to be dry (dry kiln process) in such a way that the preheating and even the partial calcining of the dry raw meal takes place due to maintaining the raw mix in suspension with the hot gases exiting the rotary kiln.

Use of this preheating system leads to a significant decrease in specific energy consumption and so the wet process has been replaced by the dry process with suspension preheater technology. Currently, practically all working kilns in the cement industry in the countries of the Mediterranean Action Plan use this type of process.

On the other hand, this method made it possible to reach larger unit production capacities, up to 4,500 or 5,000 t/d, without resorting to precalcining. The largest kiln of this type was built in 1974, and has a diameter of 6.2 m and production of 5,000 t/d.

Production volume varies between 1.2 and 2.9 t/d*m³ with an average of 1.7 t/d*m³. The thermal load in the burning zone ranges from 11.3 to 30.9 GJ/m²*h, with an average of 17.1 GJ/m²*h. A correlation (0.84) exists between production and thermal load (Figure 3.2.37.).

Thermal consumption by the dry method is theoretically the lowest of the four processes considered (wet, semi-wet, semi-dry, dry), although it has been noted that it may vary across quite a broad range, from 3,150 to 4,150 kJ/kg of clinker depending on the operative conditions (Figure 3.2.40). The effect of kiln size, due to the reduction of losses through the walls, achieves an improvement in comparison with large-sized facilities, and may reach 300 kJ/kg to 400 kJ/kg of clinker.



Source: *Techniques de l'Ingénieur*

Figure 3.2.40. Ratio between thermal consumption and production.

Clinker burning in dry kilns with suspension preheaters involves two stages:

- preheating and partial decarbonation (from 20 to 50 %) are carried out in the static part of the facility: cyclone exchanger;
- the end of decarbonation and clinkering are carried out in the rotary kiln.

Several suspension preheater systems may be implemented. Generally they have between four and six cyclone stages in set-ups where the raw materials are relatively dry and do not require a large thermal contribution to perform their drying.

The cyclones are positioned one on top of the other in a tower standing some 50-120 m in height. The highest stage may have two parallel cyclones to separate the dust better. The exhaust gases from the rotary kiln flow through the stages of the cyclones from the lower to the upper part. The mixture of dry, powdery, raw materials is added to the exhaust gas before the last upper cyclone stage. It is separated from the gas in the cyclones and is fed in prior to the next cyclone step. This procedure is repeated at all stages until the material is finally discharged from the last stage into the rotary kiln. This alternating blending, separation and re-blending at increasingly high temperatures enables optimal heat transfer between the heat of the exhaust gases and the raw mix.

Suspension preheaters encounter problems of incrustation on the walls of the cyclones and ducts, in cases in which the raw materials, and/or the fuel, contain high amounts of materials such as chlorides, sulphates and alkalis. Such incrustation frequently causes blockages and subsequent kiln shut-downs for several days at a time. One possible solution to this problem is to divert the gas from the kiln; i.e. to extract and purify a part of the kiln exhaust gas flow. This gas is cooled to condense the alkalis and is then treated in a dust collector prior to being expelled into the atmosphere.



Figure 3.2.41. Preheater.

The standard design of the 1970s was the four-stage cyclone preheater (see figure 3.2.42). This was a period when a great many plants with a range of 1,000 to 3,000 t/day were built.

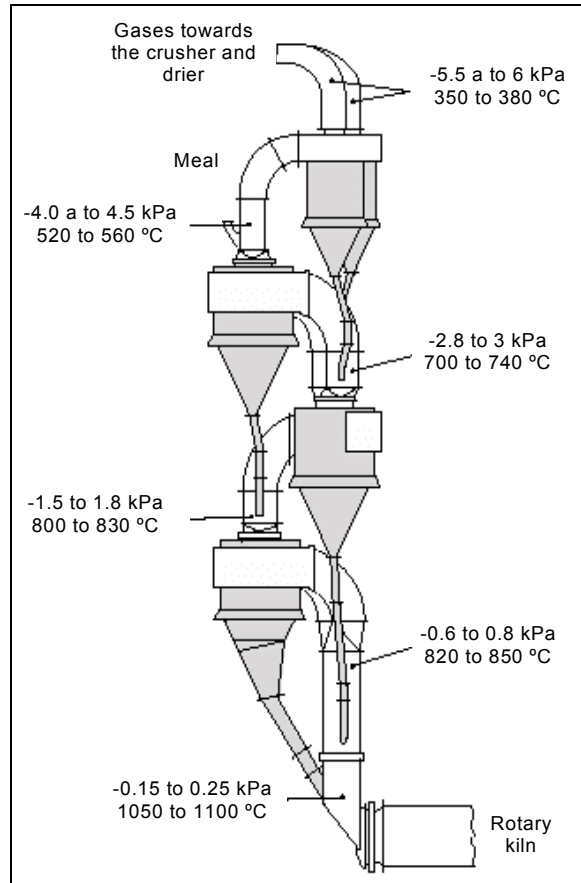
Almost all four-stage suspension preheaters operate with rotary kilns with three supports. The kilns, whose diameters range between 3.5 and 6 metres, have length to diameter ratios of 13:1 to 16:1. These kilns, which are mechanically simpler than long dry and wet kilns, are the most widely used kilns today.

The four-stage exchanger allows a balance between the heat available in the exiting gases (between 350 and 380 °C) and the need for heat to evaporate the moisture present in the raw materials with a water content of 8 or 9 %. In the upper stage of the cyclones, the main objective is to separate and thus limit the recirculation of materials (mix). Normally, values of close to 50 g/Nm³ are recorded, which represents around 8 % of kiln production.

Manufacturers propose different set-ups (figure 3.2.43.) of cyclone exchangers. The most recent improvements to the exchanger consist of an important reduction in cyclone load losses without deteriorating the separation function. Such changes may be:

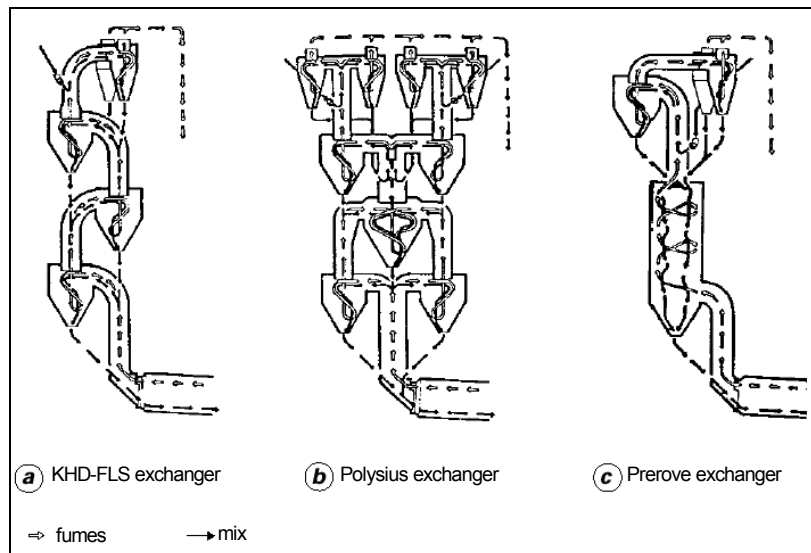
- Changing the design of the input pipe to the cyclone.
- Changing the aspect ratio in order to achieve greater acceleration.
- An improvement in the performance of the pipes inside the cyclones.

It is possible to obtain a total exchanger load loss of 3 kPa whereas the initial configurations were approximately 5.50 kPa for a four-stage exchanger. Hence, it has been possible to reduce specific electrical energy consumption, for the facility as a whole, of between 25 and 16 kWh/t of clinker.



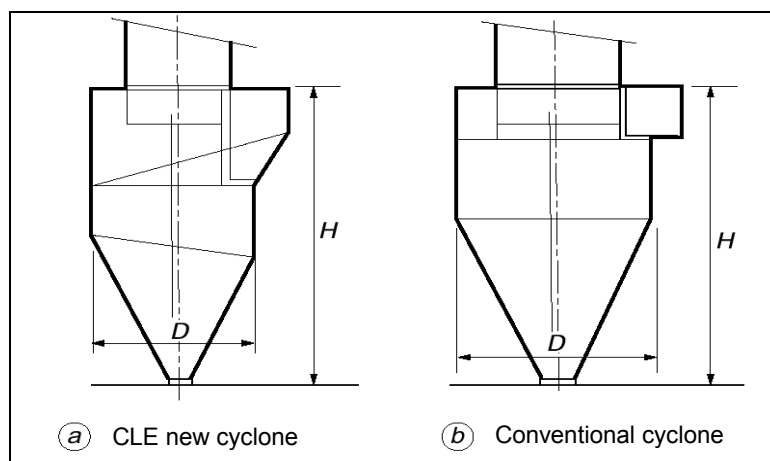
Source: *Techniques de l'Ingénieur*

Figure 3.2.42. Four-stage cyclone preheater.



Source: *Techniques de l'Ingénieur*

Figure 3.2.43. Cyclone exchangers.



Source: *Techniques de l'Ingénieur*

Figure 3.2.44. Diagram of a cyclone.

The advantages of the dry process burning system using suspension preheating are essentially:

- Optimal recovery of the sensitive heat from the gases.
- Scarce specific thermal consumption.
- Great ease of operation.
- The possibility of reaching high production capacities.

Its main setbacks are as follows:

- High sensitivity to the presence of minor elements (alkalis, chlorine, sulphur, etc.).
- Strong heterogeneity of clinker particle size.

X-stage rotary kilns with preheater and precalciner: DS-X-SF and DS-X-PC

Japanese industry, in response to the strong growth in cement consumption between 1963 and 1973 (with a 10 % annual increase) developed precalciner technology.

Precalcining consists of transfer towards the cyclone exchanger the fundamental part of the decarbonation phase (90 %) which was carried out in the rotary kiln.

Precalcining was developed in order to respond to the following objectives:

- To increase the unit capacity of the new production tools limited at 4,500-5,000 t/d in the classic dry method.
- To increase the production capacity of existing dry kiln plants or the conversion of other methods.
- To reduce the investment cost, as expressed as monetary unit per tonne of annual production.
- To improve the reliability of the facilities due to the reduction in rotary kiln diameter (as of 5.50 m diameter kilns require operations to repair the refractory material in the burning zone approximately every 3 months instead of every 12).
- To improve specific consumptions thanks to the effect of the reduction in size and the improvement in the quality of heat exchange.
- To reduce NO_x emissions.
- To enable integrating bypass systems in an economical fashion.

In this way, precalcining was developed (precalciner in figure 4.2.45.) by means of an auxiliary furnace, in which:

- Material can be fed in from levels 3 or 4 of the cyclone exchanger.
- Fuel fed in can be in the form of coal, fuel, or petcoke.
- The contribution of oxygen necessary for combustion can be provided either by the kiln gases, or by the refrigerator.
- The exit of materials to the rotary kiln can take place from the level of the lower cyclones (4, 5 or 6).

With the hypothesis of identical rotary kiln dimensions, the addition of a precalciner enables increasing plant capacity by a factor of 2 to 2.3.

General principles

The precalciner originates from observations as to the following principles:

- The rotary kiln is an excellent heat exchanger at its hottest part, the clinkering zone, where exchange takes place by radiation. This zone constitutes nearly 1/3 of kiln length (Figure 3.2.46.).
- In a plant with a preheater without precalcining, the basic part of decarbonation (from 80 to 90 %) takes place in the rotary kiln. This stage is considered to occupy 2/3 of the kiln length where the conditions of heat exchange are from 12 to 17 kJ/kg of clinker per metre of kiln. Figure 3.2.46. shows the mean temperature change of the material in an industrial facility.
- The decarbonation stage demands the most important heat requirements with regard to the set of stages employed in the method (1,965 kJ/kg of clinker). Figure 4.2.47. shows the evolution of a small amount of materials, in the laboratory, according to the heat cycle "Q", temperature "T" of the processes. At an industrial facility, where temperatures are not homogeneous, (Figure 3.2.46) the start of decarbonation prior to the average temperature of 900 °C and total decarbonation beyond 900 °C are noted.
- The exchange of heat between material and gases by convection is improved by the suspension of the material, although there is scarce temperature divergence (figure 3.2.46.).

In part, on the basis of these observations, at the beginning of the 1970s, Japanese company IHI developed the precalciner under the name of the SF process (Suspension Kiln), thanks to which the decarbonation of the raw meal reaches 80 to 90 % prior to being introduced to the rotary kiln, from 50 to 60 % of the fuel is used in the precalciner furnace.

Depending on the proportion of fuel injected in precalcining, the following proportions of decarbonation are achieved:

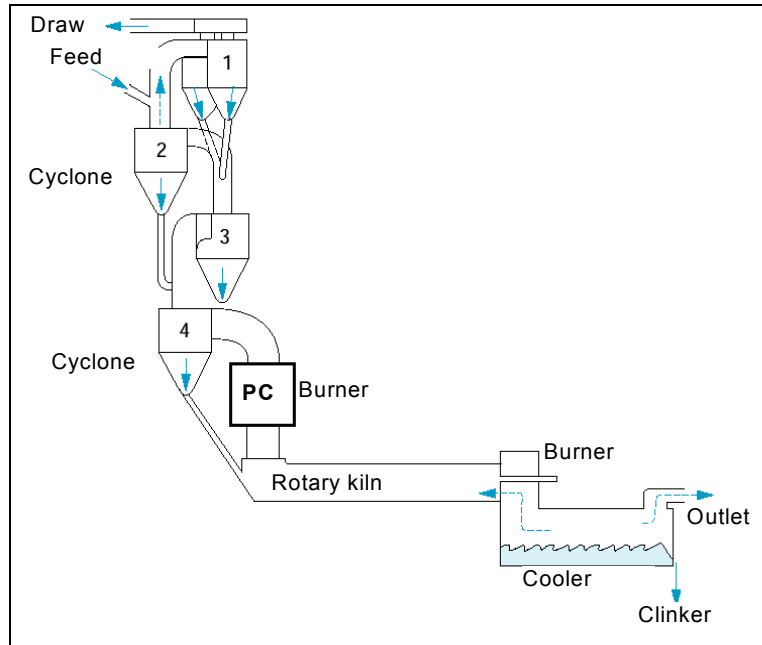
Table 3.2.6. Proportion of decarbonation.

Ratio of fuel injected in precalcining	Ratio of decarbonation
10 %	20 %
55 %	80 %

Source: *Techniques de l'Ingénieur*

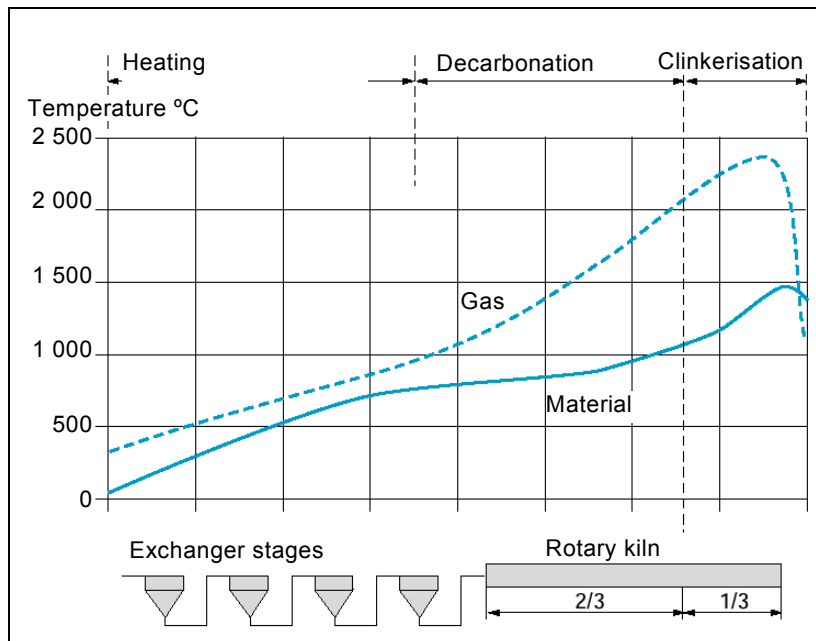
Two precalciner systems can be distinguished according to the method of combustion air feed:

- Without a tertiary air duct.
- With a tertiary air duct.



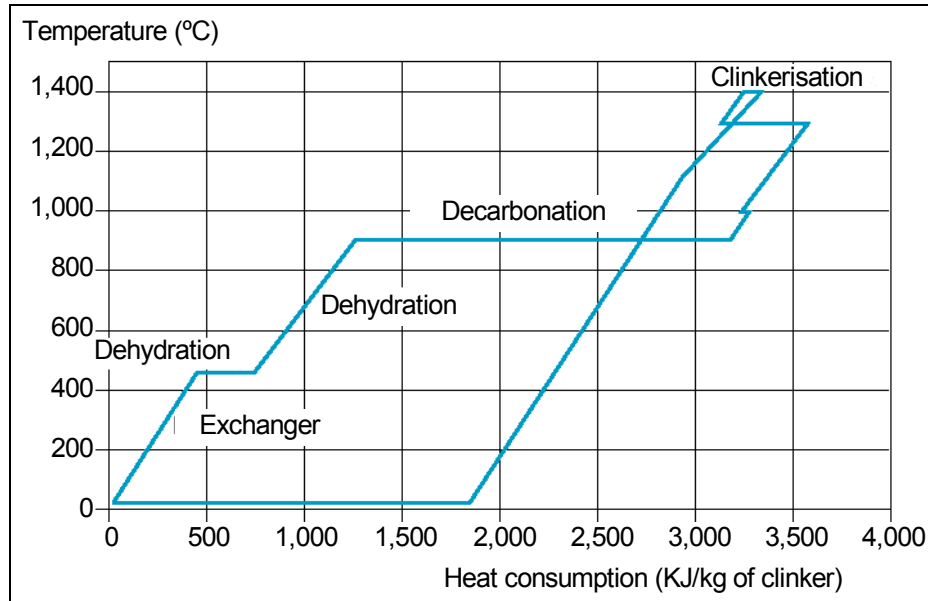
Source: Techniques de l'Ingénieur

Figure 3.2.45. Preheater kiln and precalciner.



Source: Techniques de l'Ingénieur

Figure 3.2.46. Gas temperature profile in the burning process.

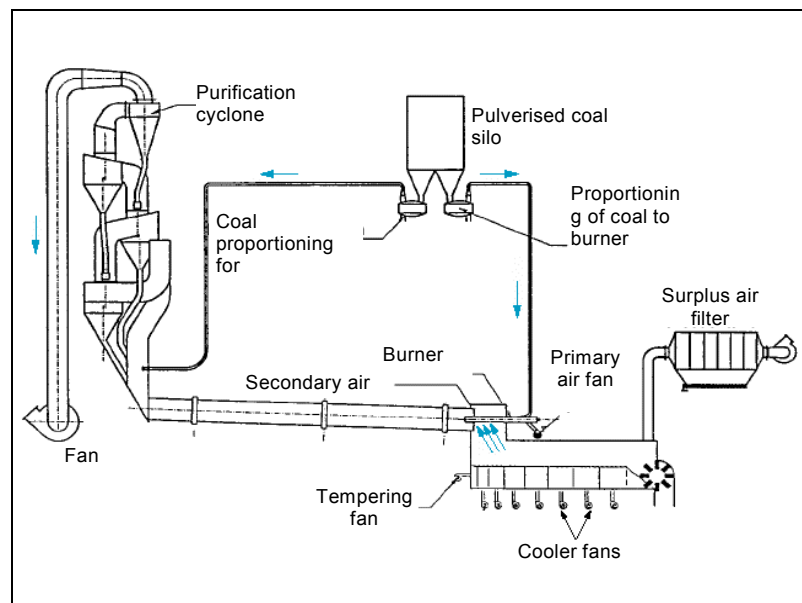


Source: *Techniques de l'Ingénieur*

Figure 3.2.47. Burning process.

Precalcining without tertiary air

In precalcining without tertiary air (figure 3.2.48.), combustion air is provided by the excess air of the rotary kiln burner.



Source: *Techniques de l'Ingénieur*

Figure 3.2.48. Precalcining without tertiary air.

In Figure 3.2.49, the curves make it possible to determine, for an excess of air defined in precalcining, the excess of air necessary in the main burner in order to achieve a chosen precalcining rate.

This causes a decrease in flame temperature T of more than 100 °C, since it implies a strong decrease in thermal changes in the burning zone where the changes are brought about by radiation (proportional to T^4).

Figure 3.2.48. makes it possible to evaluate the adiabatic temperature variation of the main burner flame depending on the excess air. Above a precalcining rate of approximately 15 to 20 %, the flame is not hot enough to ensure proper clinkering, this being the main setback of this technique.

The curves of the figures are established for a coal of 31 MJ/kg LHV (lower heating value).

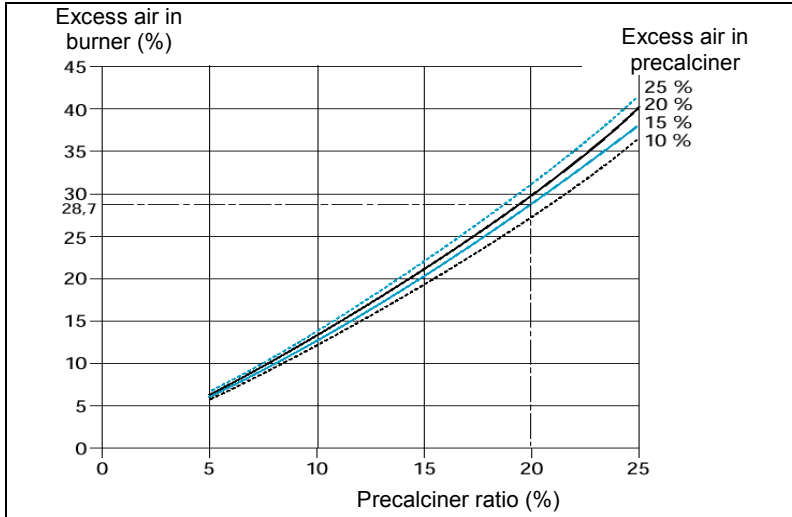
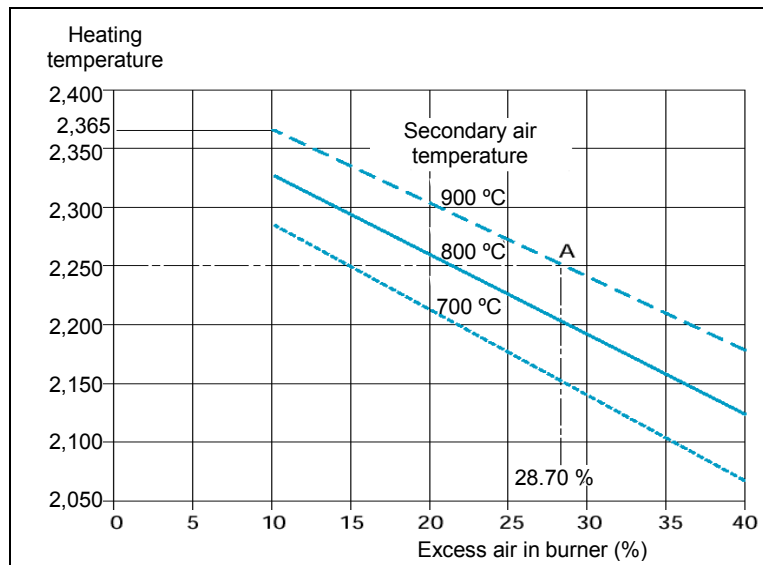


Figure 3.2.49. Ratio between excess burner air and the precalcining ratio.



Source: *Techniques de l'Ingénieur*

Figure 3.2.50. Ratio between flame temperature and excess air.

This type of precalcining is not foreseen in the framework of new facilities, but its use is implemented in existing facilities when the aim is:

- To perform a small increase in production capacity without the need for significant modification.
- To reduce the thermal load in the burning zone for equal production capacity.

Kiln exhaust gases are sent to precalcining via a vertical duct. This duct can be lengthened and transformed into an elbow shape in such a way that sufficient time is available to ensure combustion. In practice, combustion is rarely completed and a CO content of approximately 0.1 to 0.2 % is observed.

The production precalciner kilns without tertiary (or partial) air is on average $2.49 \text{ t/d}\cdot\text{m}^3$; the thermal load in the burning zone is, on average, $19.6 \text{ GJ/m}^2\cdot\text{h}$.

Comparing these data with those of the dry kiln process without precalcining, it becomes clear that precalcining without tertiary or partial air leads to an increase in specific production of 20% approximately, at the cost of a significant increase in thermal load, which becomes of the same order of magnitude as that of the wet kiln process.

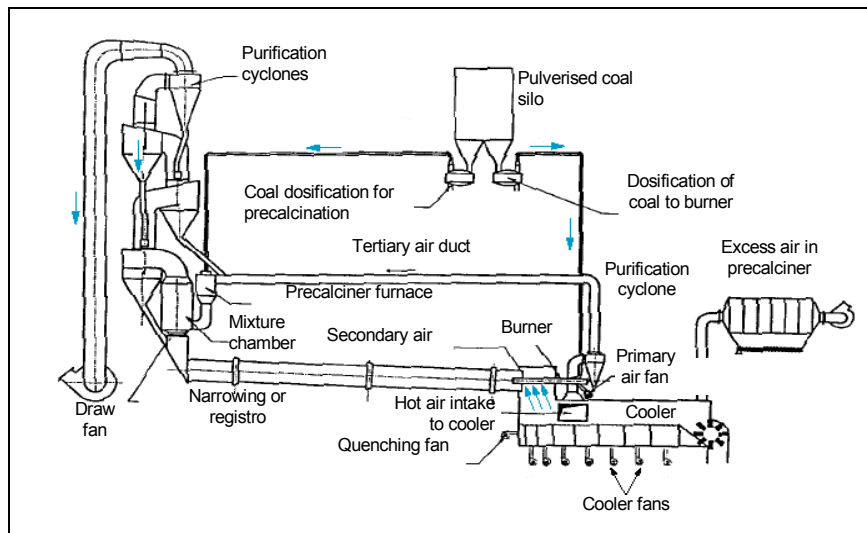
Precalcining with tertiary air

In precalcining with tertiary air, the combustion air of the precalciner furnace is delivered by an independent duct. This enables achieving levels of precalcining of greater than 20 %, reaching as high as 95 %. Figure 3.2.51. shows a diagram of the general principle. The most complete system includes:

- A furnace installed at the lower end of the preheater, which receives the air coming from the kiln or from the clinker cooler, through a duct of tertiary air that skirts the kiln. The tertiary air is cleaned, removing the powder, by means of a cyclone or a decantation chamber.
- A mixer chamber, whose purpose is to mix the gases coming from the rotary kiln with those coming from the precalcining furnace.
- A narrowing or a regulator for adjusting the proportions of gas.
- Two fuel gauging systems, one for the burner at the kiln head, and another for the precalciner.

In this case, precalcining with tertiary air, the main disadvantage of the precalciner without tertiary air disappears, since the excess air in the burner is identical to that of a kiln without precalcining.

The volume of production in kilns in which precalcining with tertiary air takes place is on average $3.5 \text{ t/d}\cdot\text{m}^3$; the thermal load in the burning zone is $16 \text{ GJ/m}^2\cdot\text{h}$. Compared with the dry process without precalcining, increased production is on average 2.1 times, whereas the thermal load in the burning zone is approximately at the same level.



Source: *Techniques de l'Ingénieur*

Figure 3.2.51. Precalcining with tertiary air.

Classification

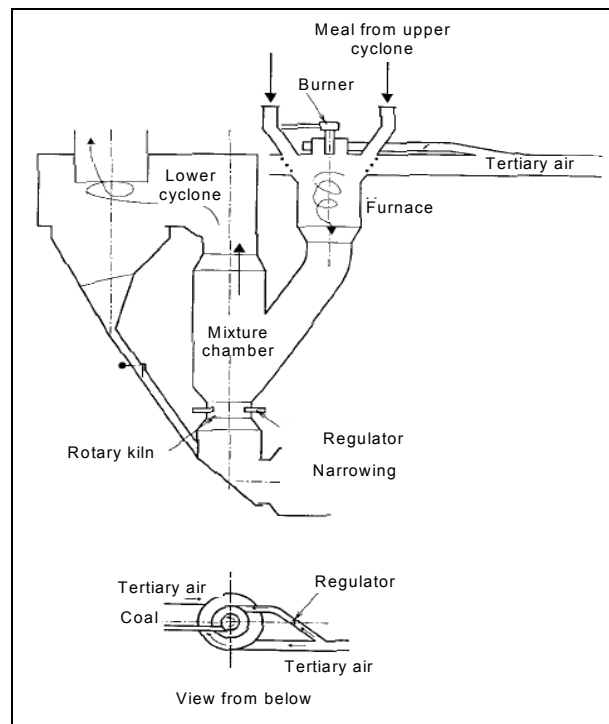
Precalciner systems can be grouped according to three kinds:

- *Class 1.* Includes systems in which the material is suspended in a tubular duct where the material and gases come into contact. The length of the duct is adapted to obtain sufficient contact time. This group represents the simplest systems and do not have a tertiary air duct.
- *Class 2.* Includes systems in which the suspension of material is not linear but is accelerated spirally in a vortex in which the turbulence must activate the exchanges. Most of the systems proposed belong to this class.
- *Class 3.* In this class, the material remains for much longer in the precalcining furnace. It is currently being developed but is not commonly implemented in industry.

Industrial applications

The undeniable advantages of precalcining led suppliers to propose a great diversity of industrial technological solutions. Here are a few examples.

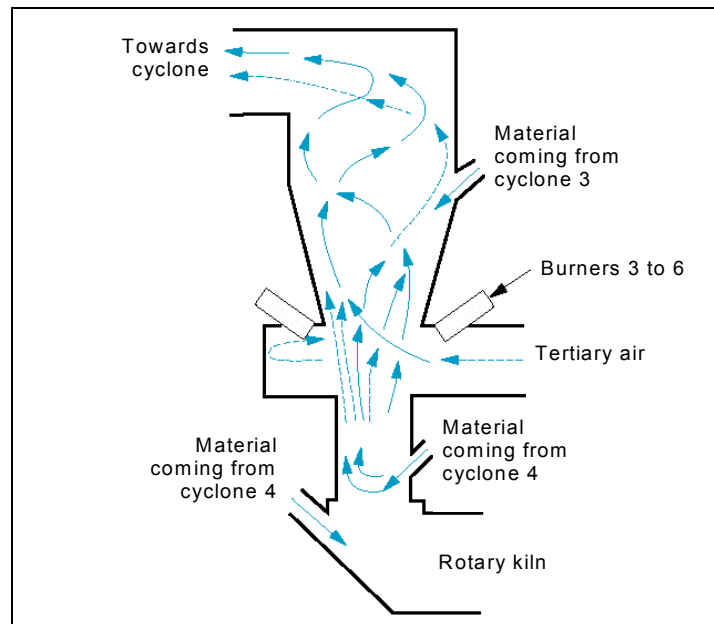
The *RSP System* (Reinforced Suspension Preheater), by Onoda Cement Co., was the first industrial application, dating from 1972 (Tahara, Japan). This system, which can be seen in figure 3.2.52., involves a furnace, a mixing chamber, a narrowing, a regulator; it belongs to *Class 2*.



Source: *Techniques de l'Ingénieur*

Figure 3.2.52. RSP System.

NSF System, by IHI Co., was the first industrial application, dating from 1971 (Chichibu, Japan). Two successive versions were made: the SF and the NSF (figure 4.2.53.). They differ in the position of the burners and the introduction of the material into the furnace. They belong to *Class 2*.

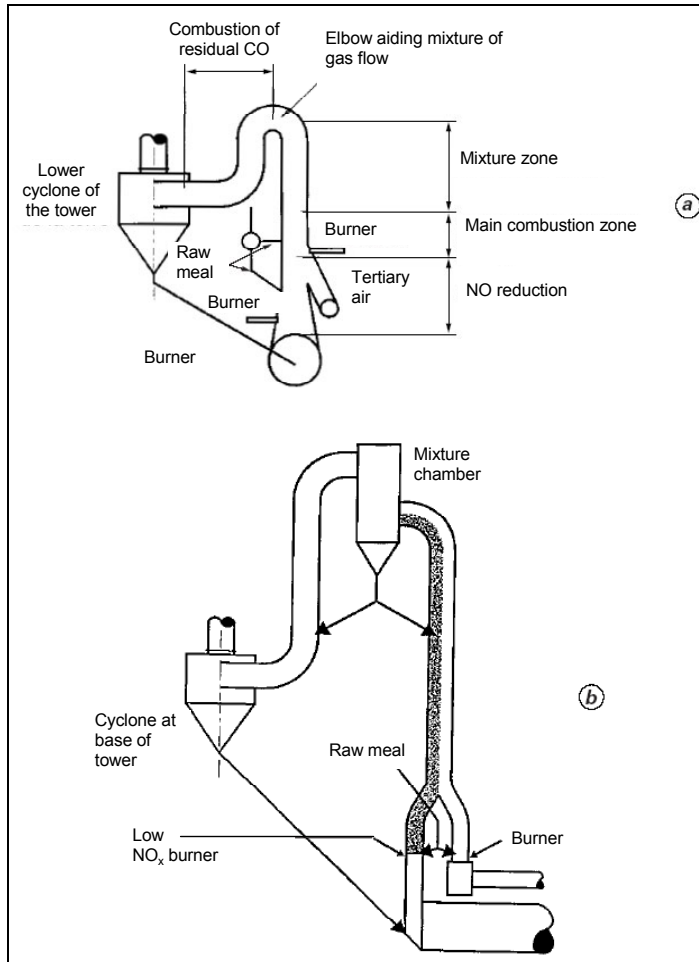


Source: *Techniques de l'Ingénieur*

Figure 3.2.53. NSF System.

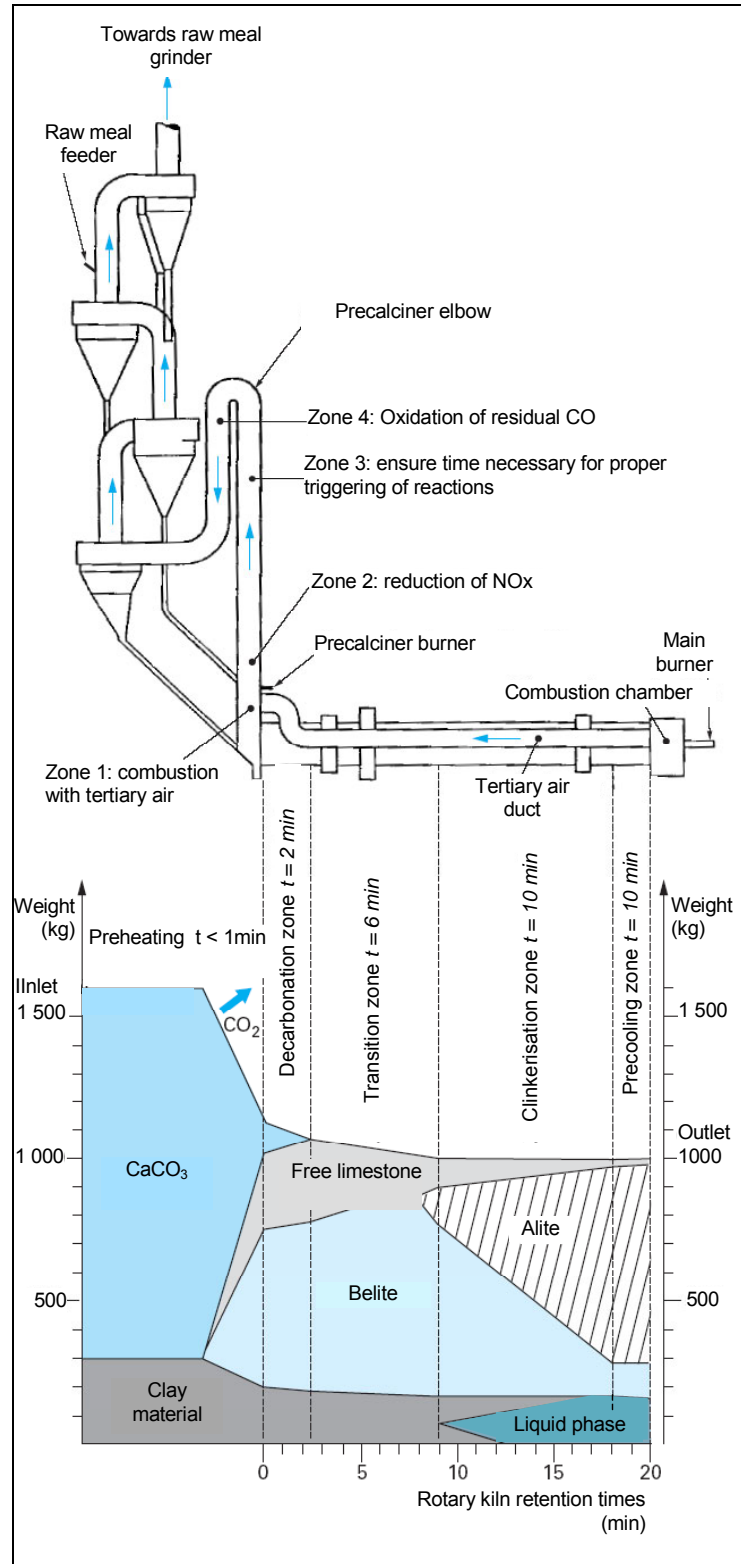
KHD Pyroclon System (Cologne, Germany)

- Pyroclon S: The first Pyroclon S (Special) system uses the precalcining technique without tertiary air and belongs to *Class 1*.
- Pyroclon R and RP: The following systems, Pyroclon R (Regular) (Figure 3.2.54.) and RP (Regular-Pyrorapid) either use, or not, the fumes from the kiln in a precalcining duct supplied with tertiary air (*Class 2*). A mixing chamber is installed tangentially at the inlet and outlet, at the upper part of the precalcining chamber. The precalciner is divided into 4 sections.
- Pyrorapid: R, RP and RP *low NO_x* precalcining systems can be associated with a rotary kiln denominated Pyrorapid (Figure 3.2.55.).



Source: *Techniques de l'Ingénieur*

Figure 3.2.54. Pyroclon R System.



Source: *Techniques de l'Ingénieur*

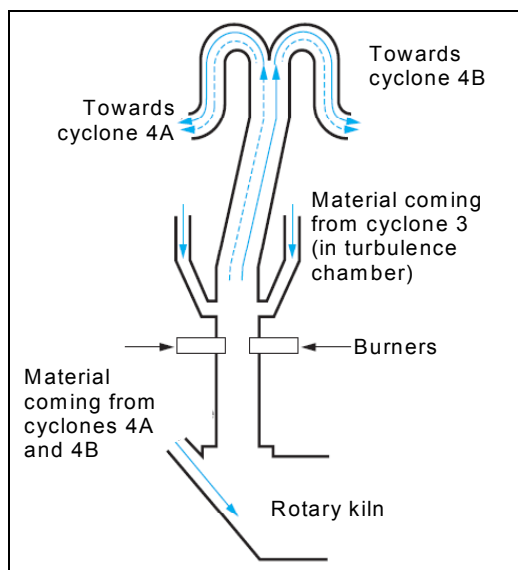
Figure 3.2.55. Pyroclon system associated with a Pyrorapid kiln. Evolution of the weight of solid materials.

Prepol Systems by Polysius

- AT (Air Through) precalcining is carried out without tertiary air (*Class 1*) in a rectangular housing which connects the kiln to the cyclones of the lower level. In this duct, the kiln fumes

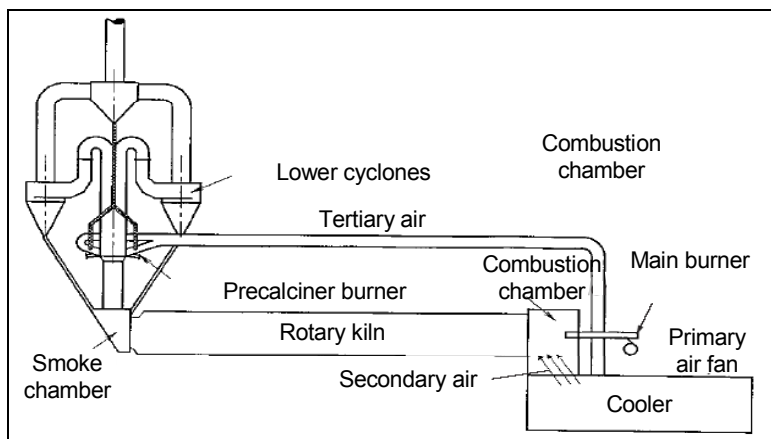
meet the material coming from the turbulence chamber (level 3) at approximately 700 °C and the fuel injected from either side (figure 3.2.56.).

- AS and AS-LC Precalciners. The AS (Air Separate) precalciner consists of a vertical tube followed by an upper elbow prior to the lower cyclones of the preheater (Figure 3.2.57.). The LC (low calories) alternative (class 1) permits the combustion of a medium quality fuel, of little heating value – with high ash content.
- AS- C.C. Precalciner. This class 2, Air Separate, Low Calorie precalciner includes a combustion chamber and a mixer chamber, as can be seen in Figure 3.2.58.
- AS- MSC Precalciner. This system, whose initials stand for "Multi-Stage Calciner", was studied with a view to obtaining a reduction in NO_x emissions. Its principle is gradual combustion (Figure 3.2.59.).
- AS systems AS (Class 2) offer the possibility of installing an ammonia injector if there is a need to further reduce NO_x. In effect, they offer a temperature range that enables such injection in the framework of the SNCR (Selective Non-Catalytic Reduction) method.



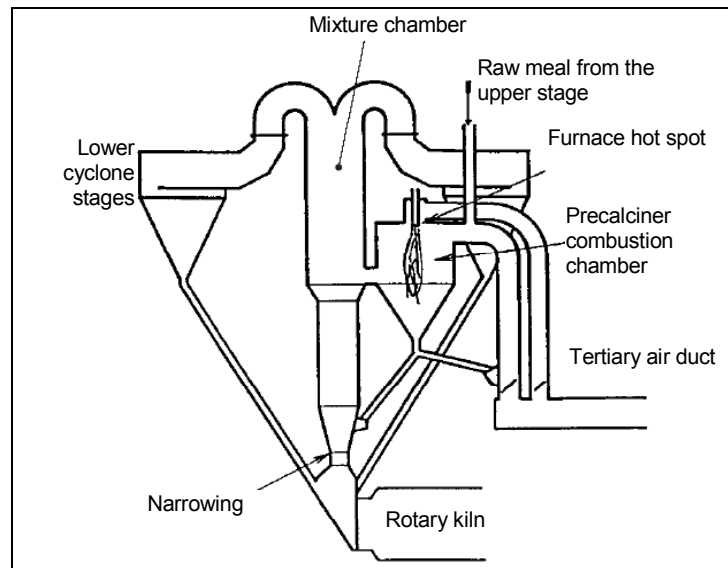
Source: *Techniques de l'Ingénieur*

Figure 3.2.56. Prepol AT System.



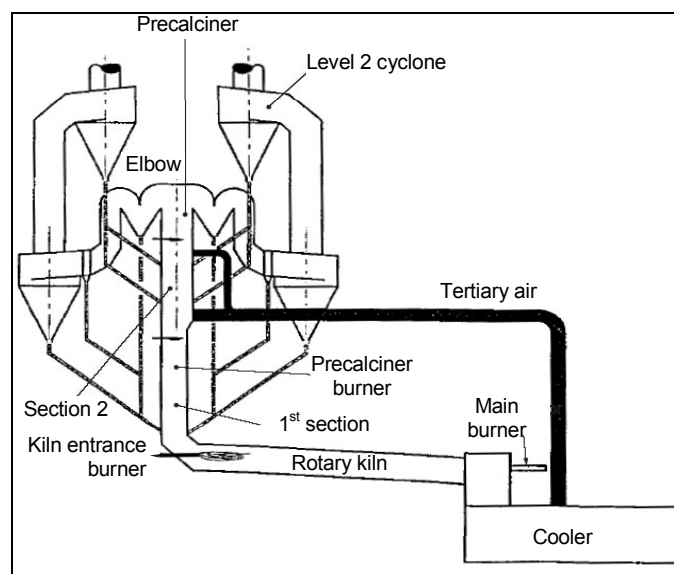
Source: *Techniques de l'Ingénieur*

Figure 3.2.57. Prepol AS System.



Source: *Techniques de l'Ingénieur*

Figure 3.2.58. Prepol AS-CC System.



Source: *Techniques de l'Ingénieur*

Figure 3.2.59. Prepol AS-MS System.

Ciments français FCB System.

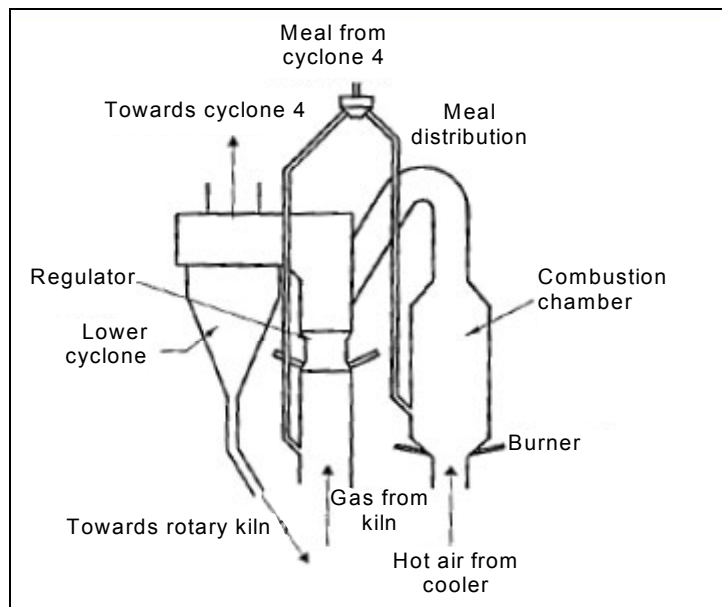
In the kiln of this Class 2 *Five Cail Babcock (FCB)* precalciner, there is no flow rotation.

FL Smidth Systems

The first developments date from 1974. The Danish company proposes the following (class 2) systems:

- The ILC (In line calciner) System. This system is used with a single revolution. The precalciner is in the vertical tube of the rotary kiln. The manufacturer envisages use of this system for production levels ranging from 1,500 and 4,000 t/d. The precalcining quotient admitted is 55 to 65 % enables up to 100 % transfer of gas.

- The SLC-S (separate line calciner - special) system. This set up, which is similar to the previous one (figure 3.2.60.), is used with a single or a double revolution. The combustion chamber is located parallel to the vertical tube of the kiln. This set up is recommended for production of between 1,500 and 5,500 t/d. The precalcining percentage reaches 55 to 60 %.
- The SLC (Separate line calciner) system. The SLC device adapts to the double string cyclone preheater systems. The precalciner is placed parallel with the vertical tube of the rotary kiln. As in the system above, combustion takes place in hot, pure air. The manufacturer's recommendations are:
 - Production: as of 3,000 t/d;
 - Precalcining quotient: from 55 to 65 %;
 - Possible deviation: up to 30 %.

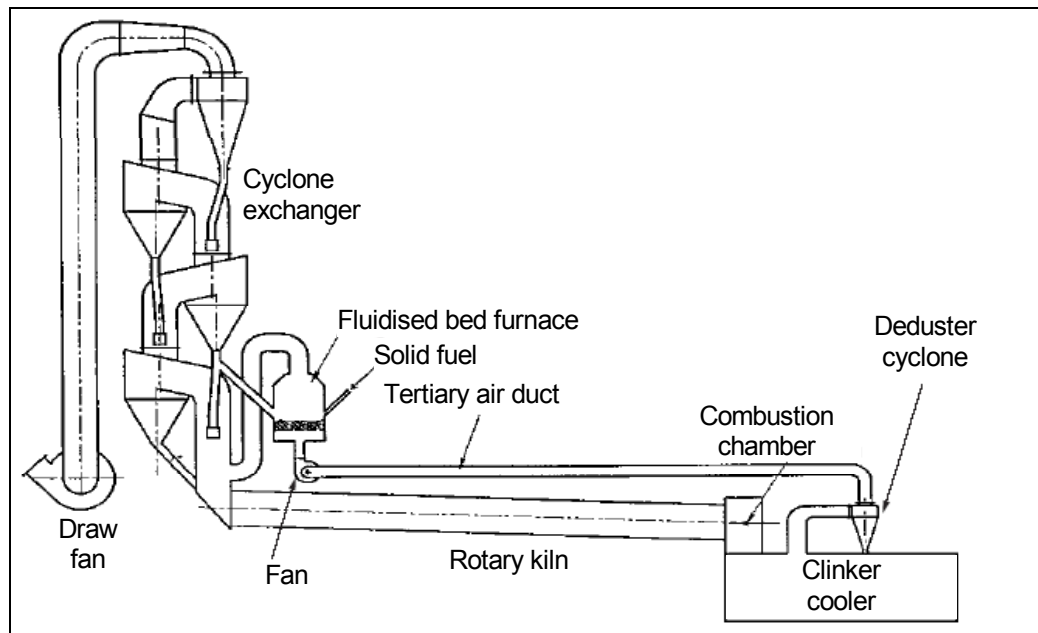


Source: *Techniques de l'Ingénieur*

Figure 3.2.60. SLC System.

MFC System by Mitsubishi

Initial industrial development dates from 1972. The Japanese company conceived a precalcining kiln that worked in a fluidised bed. The two types, MFCa "carry-over" and MFCb "over flow", are slightly different. To illustrate this, Figure 3.2.61 shows the former. In theory, the use of a fluidised bed allows the use of low quality fuels. Despite this advantage, this type of furnace has not spread to the countries of the Mediterranean Action Plan.



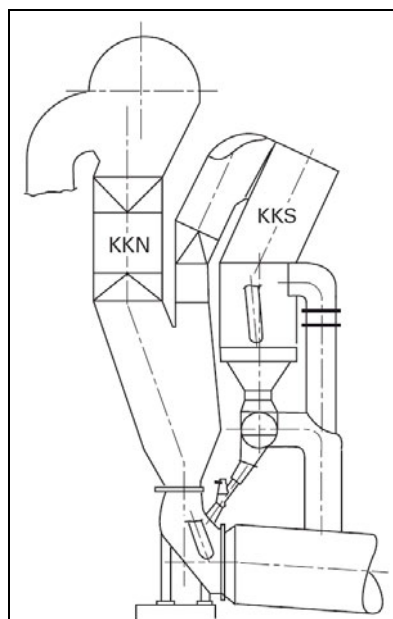
Source: *Techniques de l'Ingénieur*

Figure 3.2.61. MFC System by Mitsubishi.

Prerov Precalciner

The Prerov precalciner (Figure 3.2.62.) includes two parts:

- The precalciner (KKS) itself, into whose lower part the mix of cyclones N-1 and fuel are introduced.
- The broad-sectioned post-combustion chamber (KKN) provided with an elbow, guarantees a residence time of several seconds without burning the mix coming from the precalciner (KKS). The gases from the precalciner and the kiln are mixed before entering the level of lower cyclone N.



Source: *Techniques de l'Ingénieur*

Figure 3.2.62. Prerov Precalciner.

3.2.4.4. Vertical kilns

The first kilns used were intermittent vertical kilns, similar to those used in burning lime, in which the raw material was loaded in the form of briquettes, mixed with the fuel. Their use in the countries of the Mediterranean Action Plan has been reduced to just a few kilns, given that the clinker resulting from a rotary kiln is of higher quality and is more regular in its characteristics, in addition to yielding a higher production, which has led to the rotary kiln being the most commonly used procedure today, in spite of its higher cost and the need for more complex, larger-sized facilities. Currently, the use of vertical kilns is practically limited to developing countries such as China (80 % of its capacity) and India.

This type of kiln consists of a vertical cylinder of 2 to 3 metres in diameter and 8 to 10 metres in height, clad with a refractory material.

The raw meal, once homogenised, is mixed with the fuel to the correct proportions and is taken to a blender which feeds a granulator, where a small quantity of water is added to the ground powder. Due to the rotary effect of the granulator plate, the raw meal adopts the form of pellets. These pellets fall into the upper part of the kiln where they are regularly distributed over the surface by means of a rotary hopper. The upper part of the kiln is conical in order to keep the degree of compactness due to the retraction effect of the grains when the dry, since as they lose moisture they take up less volume. As these pellets descend the kiln barrel, the pellet drying, preheating, calcining, clinkering and cooling phases take place. Thus, during burning, the material first passes through a short sintering zone in the upper part of the kiln, a zone which is slightly enlarged. It is then cooled by the fuel air injected from below and falls through the bottom part of the kiln onto a grate, now in the form of clinker. Vertical kilns produce less than 300 t/day of clinker. They are only economical for small factories, which is why their numbers have fallen.

In theory, vertical kilns can achieve the energy efficiency of rotary kilns, but in practice, their energy consumption varies between 3.7 GJ/t and 6.6 GJ/t.

3.2.4.5. Clinker coolers

The clinker cooler is an integral part of the kiln system and has a decisive influence on the development and economy of the plant's energy performance.

The cooler performs two tasks: to recover as much heat as possible from the hot clinker (the clinker leaves the kiln at around 1,450 °C) to return it to the process; and to reduce the temperature of the clinker to the suitable level for the equipment downstream.

Heat is recovered by preheating the air used for combustion in the main burner, as close as possible to the thermodynamic limit. However, this recovery is hindered by such circumstances as the high temperatures, the extreme abrasiveness of the clinker and its broad range of particle size.

Rapid cooling benefits the clinker, improving its grindability and optimising the reactivity of the cement.

Typical problems for clinker coolers are: thermal expansion, wear, incorrect air flows and low yield.

There are three main types of coolers: rotary, planetary and grate, which will be described below. Other coolers exist, such as in the case of white clinker, which differ from the usual ones due to the need to maintain the reducing conditions to 600 °C in order to conserve the colour of the end product.

In the 1970s, the planetary (satellite) cooler predominated over the grate cooler due to reasons of reliability, maintenance costs, ease of operation and initial outlay (absence of powder removal). Nevertheless, a series of circumstances arose:

- Poor results for planetary coolers in larger kilns (4,000 t/d).
- Decisive improvements in grate-cooler technology.
- The need to produce tertiary air at 800-900 °C for the precalciner, which the planetary cooler was incapable of providing.

These circumstances brought about a change in the philosophy of the technology, and grate coolers began to dominate. Moreover, this turnaround in trend came about as a result of the following:

- A new technical-economic opportunity.
- A change in the technology of the plates of conventional grate coolers.
- The new grate coolers were the only ones to allow an increase in production capacities.

Rotary (tube) coolers

The tube cooler uses the same principle as the rotary kiln, but with reversed heat exchange. It is positioned at the outlet of the kiln, often in reverse configuration, i.e., below the kiln a second rotary tube is installed with its own drive system. At the kiln outlet, the clinker goes to a transition hopper prior to entering the cooler, which is fitted with lifter plates to disperse the clinker into the air flow.

Cooling air flow rate is determined in accordance with the air required for fuel combustion. Playing a role in the yield of the cooler are speed of passage and internal design. The design of the turners must take heat exchange into account and control the return cycle of the powder to the kiln. There is no hardening effect in this kind of cooler, just as in the planetary cooler, as we shall see in the next section.

This kind of cooler is mechanically quite simple (Figure 3.2.63.); however, it presents two process difficulties if used on high capacity kilns:

- The formation or build-up in falling clinker at the input part.
- The fluctuation in air speed in the zone equipped with elevators.

The former problem may be solved by means of an automatic cleaning system, and the latter by increasing tube diameter.

The tube, whose length/diameter ratio is approximately 10:1, rotates at a velocity of between 2.5 and 3.0 rpm.

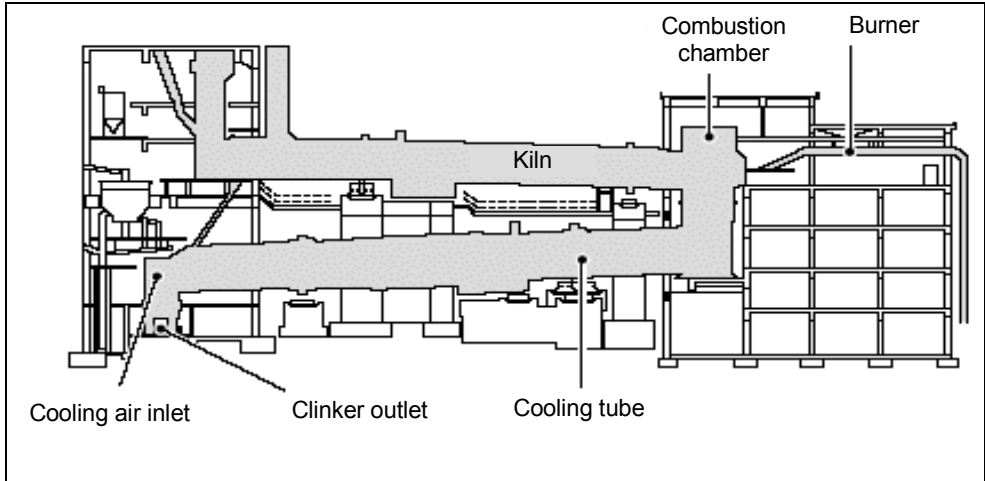
The inside of the tube (Figure 3.2.64.) is fitted with concrete or refractory briquette along 60 % of its length.

The main dimensions for a rotary cooler are presented in Table 3.2.7.

Table 3.2.7. Theoretical dimensional characteristics of rotary coolers

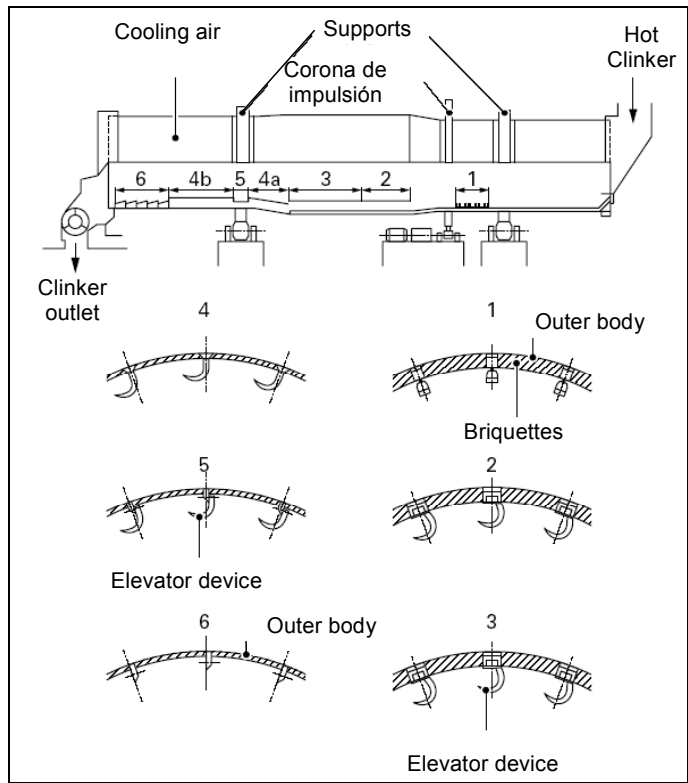
Characteristics	Production	
	2,300 t/d	3,200 t/d
Diameter (m)	4.4-4.8	5.2-5.6
Length (m)	46	54

Source: *Techniques de l'Ingénieur*



Source: *Techniques de l'Ingénieur*

Figure 3.2.63. Rotary or tube cooler.



Source: *Techniques de l'Ingénieur*

Figure 3.2.64. Tube cooler. Interior clinker lifting devices.

Planetary (satellite) cooler

The planetary, or satellite cooler (Figures 3.2.65. and 3.2.66.), consists of several tubes, typically from 9 to 11, fixed to the kiln at the discharge end.

The coolers are joined to the kiln throughout a perimeter circumference and the material passes to them through some openings in the kiln casing. The amount of cooling air is determined by the air required to burn the fuel. Air enters each of the tubes from the discharge end allowing countercurrent heat exchange. As for the tube cooler, the interior devices for clinker lifting and dispersion are essential.

Each tube, whose length/diameter ratio is approximately 10:1, is held by two supports, one of which is fixed and the other sliding, the latter in the part at the clinker outlet. The internal tube coating is made up of concrete or refractory briquettes along 20% of its length as of the pipe connection flange, and the rest, of lifters and elevators to improve thermal exchange.

This type of cooler has no variable operative parameters. High wear and thermal shock in conjunction with dust cycles inside the tubes, leads to the clinker leaving at high temperatures and hence the heat recovery ratio is low. The temperature at which the clinker exits can only be further reduced by the injection of water inside the cooler tubes or on the casing.

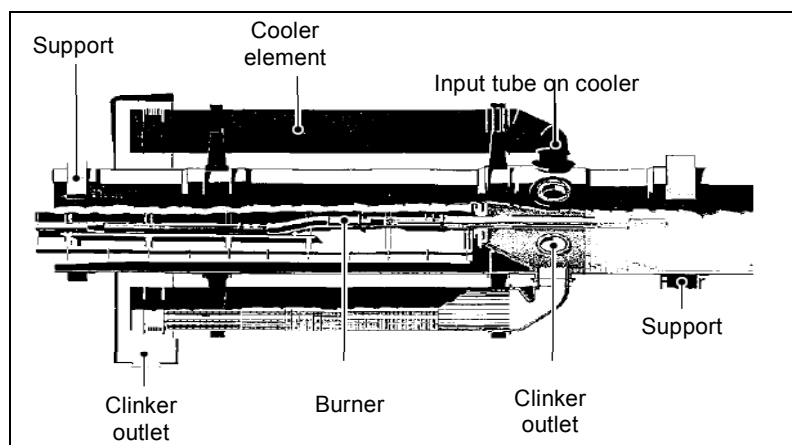
The planetary cooler is not suitable for precalcining, since it is practically impossible to extract tertiary air with this system. However, it is possible to install an auxiliary burner at the kiln inlet part, at the bottom of the preheating tower. Up to 25 % of the fuel can be burnt in this secondary burner (most typically it is around 10 %).

Integrating a satellite cooler into a burning line provides numerous simplifications both on a mechanical and an operative level, provided kiln capacity remains at average values (< 2,500 t/d).

The clearest advantage is the absence of surplus air; this leads to the suppression of all purification devices that are necessary in the case of grate coolers.

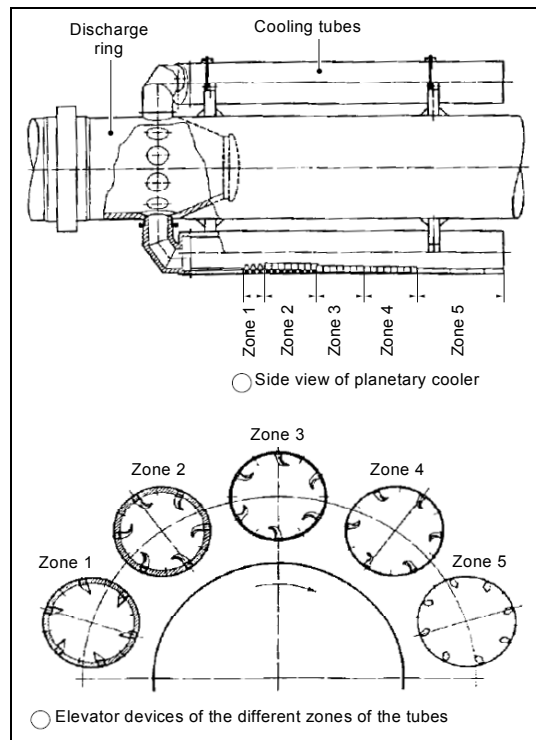
On the other hand, some drawbacks exist, such as:

- The high maintenance costs and the lack of reliability, over 2,000 to 2,500 t/d.
- The high levels of noise associated with the falling of clinker in the parts equipped with elevators.
- The impossibility of increasing production beyond nominal production.
- The high temperature (150 to 300 °C) of the exiting clinker.
- The absence of the clinker-hardening effect.
- The tendency to move burning away from the entrance, to avoid build-ups and obstructions in the tubes, but creating less reactive crystals.
- Average yield (55 to 65 %) is lower the further away the cooler is from the burning zone.
- The main disadvantage lies in the impossibility to provide the tertiary air needed for the precalciner, the stage which has become generalised in new kilns.



Source: *Techniques de l'Ingénieur*

Figure 3.2.65. Planetary or satellite cooler.



Source: *Techniques de l'Ingénieur*

Figure 3.2.66. Location of coolers.

Grate coolers

Exchange in grate coolers takes place due to the passage of a flow of ascending air through a layer of clinker (clinker bed) lying on an air-permeable grate. The coolers are classified in accordance with the form of transport of the clinker along them, into: travelling grate and reciprocating grate.

The air that is not used in combustion is used for the purpose of drying, for example: raw materials, cement or coal additives. If not used for drying, this air must be purified prior to being emitted into the atmosphere.

Travelling grate coolers

In this type of cooler, the clinker is transported along a travelling grate. This grate has the same design characteristics as the preheater (Lepol) grate. Cooling air is insufflated via compartments beneath the grate by means of fans. The advantages of this design include a homogeneous layer of clinker (without any steps) and the possibility of changing plates without shutting down the kiln. Due to its mechanical complexity and poor recovery, resulting from the limited thickness of the bed (caused by the difficulty of achieving effective seal between the grate and the walls), this design ceased to be used in new facilities built as of 1980.

Conventional reciprocating grate coolers

The transport of the clinker in the reciprocating grate cooler takes place by the progressive pushing on the clinker bed of the front edges of alternate rows of plates. Relative movement of front edges is generated by hydraulic or mechanical (crankshaft) drives connected to every second row. The clinker travels from the inlet end to the outlet end, but the grate is fixed (Figures 3.2.67. and 3.2.68.).

The grate plates are made from heat-resistant cast steel, and are typically 300 mm wide. Each plate is drilled to allow air to pass through it.

Cooling air is also insufflated via compartments located beneath the grate by means of fans at 300-1,000 mm of water column pressure. These compartments are partitioned from one another to maintain pressure profile. Two cooling zones may be distinguished:

- The recuperation zone. The hot cooling air produced in this zone is used for combustion in the main burner (secondary air) and in the precalciner (tertiary air).
- The aftercooling zone, where the additional cooling air cools the clinker to lower temperatures.

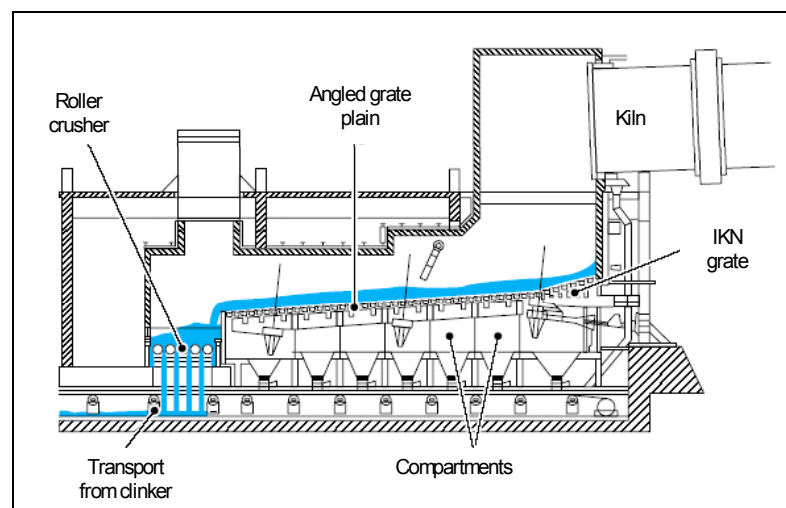
The largest units in operation have an active surface of some 280 m² and a capacity to cool 10,000 t/day of clinker. The typical problems of these coolers are segregation and uneven distribution of the clinker, leading to air-clinker imbalance, fluidisation of fine clinker, incrustation, and a low plate service life.

Modern reciprocating grate coolers

The introduction and development of modern technology grate coolers began around 1983 (Figure 3.2.69.). The design aimed to eliminate the problems with conventional coolers obtaining closer to optimum heat exchange as well as more compact coolers using less cooling air and smaller dedusting systems.

Modern reciprocating grate coolers cover the 1,900 t/d to 9,100 t/d production range. The key characteristics of this technology (depending in the supplier) included the following:

- New permanent or variable plate designs, with less loss of load, permeable to air but not clinker.
- Forced plate aeration.
- Individually adjustable aeration zones.
- Fixed inlet.
- Fewer, wider grates.
- Roller crusher.
- Heat shields.



Source: *Techniques de l'Ingénieur*

Figure 3.2.67. Conventional angled reciprocating grate cooler.

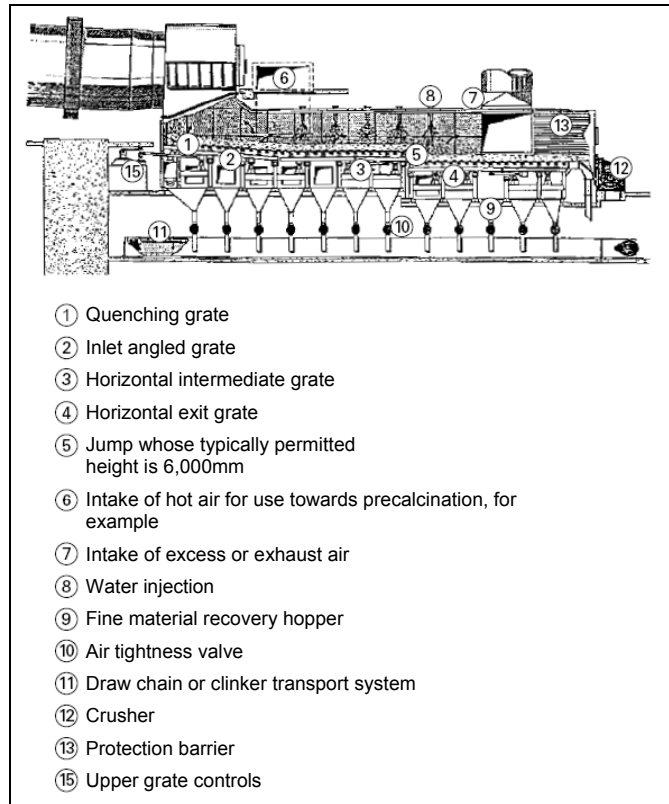
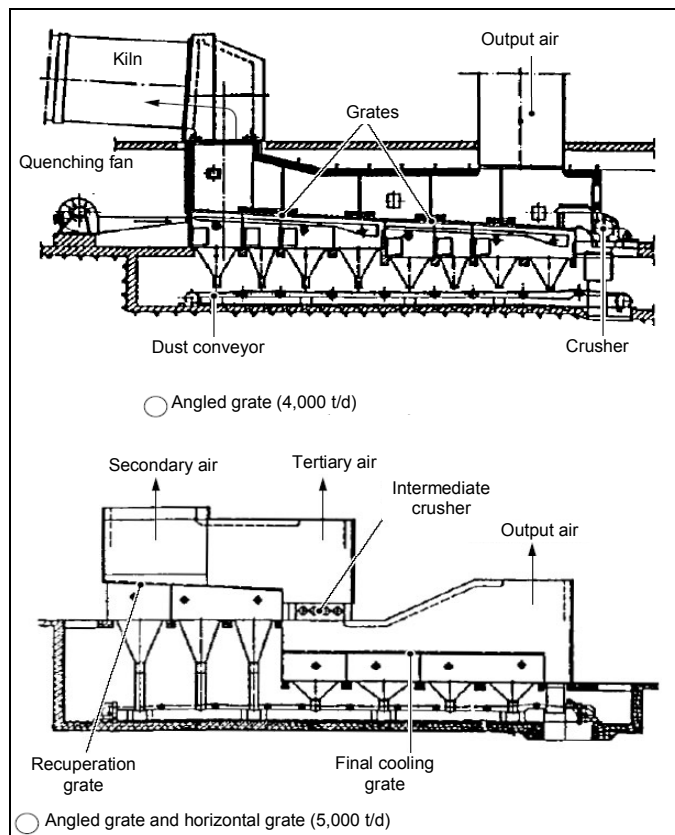


Figure 3.2.68. Longitudinal section of a conventional reciprocating grate cooler.



Source: *Techniques de l'Ingénieur*

Figure 3.2.69. Modern reciprocating grate cooler.

Other coolers (vertical)

Other coolers have been designed, such as, for example, a cooler known as a gravity or G cooler for installation after a planetary cooler or a short grate cooler/recoverer. The cooler air never comes into contact with the clinker, since the heat exchange takes place between the clinker which descends over transverse steel tubes, which, in turn, are cooled by air blown through them.

Comparison of clinker coolers

For the three main types of coolers (grate, satellite and rotary), Table 3.2.8. compares the following features:

- Conditions of exploitation.
- Exploitation costs.
- Process.
- Initial outlay.

Regarding maintenance costs, the ranges shown are very extensive. Indeed, for the grate cooler, depending on whether one is dealing with the old or the recent conception, direct costs may vary by as much as double; indirect costs (related with the lack of reliability) may also vary greatly. For the planetary cooler, conditions of exploitation are highly significant; the stability of a satellite cooler overloaded beyond its nominal capacity (by 15 to 20 %) will be greatly reduced and may lead to high direct and indirect maintenance costs.

Table 3.2.8. Comparison of the three types of cooler.

Elements for comparison		Grate coolers	Planetary coolers	Rotary coolers
Conditions of exploitation	Production capacity (t/day)	from 0 to 10000	from 0 to 2000	from 0 to 2000
	Dust emission through surplus air	Possible	Nil	Nil
	Noise	Low	High	High
Exploitation costs	Yield (%)	from 65 to 85	from 55 to 65	from 55 to 70
	Electricity consumption (kWh/t of clinker)	from 6 to 8	from 2 to 3	from 2 to 3
	Maintenance	from 3 to 6	from 3 to 5	from 2 to 4
Process	Flexibility of capacity	yes	no	no
	Clinker quality (quenching)	Yes	no	no
	Recuperation of gas heat (other equipment)	Possible	Limited	Limited
	Recuperation of precalciner gas heat	Possible	Impossible	Possible
Outlay	Investment costs	1	0.6	

Source: *Techniques de l'ingénieur, Fuors de cimentiere*

3.2.5. Grinding and storage of cement

In this stage, the clinker is mixed with the setting regulator (gypsum) and any possible additives (blast-furnace slag, silica fume, pozzolan, limestone, fly ash, etc.) and fed into the mills for grinding. Once

the desired fineness has been reached, the product finally obtained is cement. The proportion of each component depends of the type of cement being manufactured

3.2.5.1. Clinker storage

Clinker and other cement components are stored in silos or closed bays.

The most common clinker storage systems are the following:

- Longitudinal tank with gravity discharge (Figure 3.2.70.).
- Circular tank with gravity discharge (Figure 3.2.71.).
- Clinker storage silo (Figure 3.2.72.).
- Dome-type spherical silo (Figure 3.2.73.).

CLINKER STORAGE METHODS

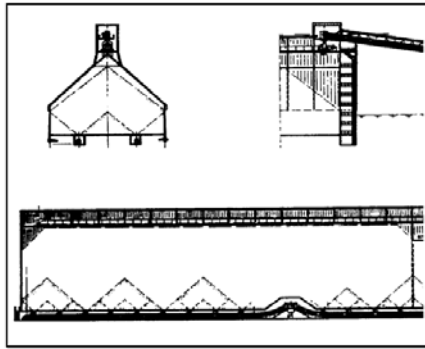


Figure 3.2.70 Longitudinal tank with gravity discharge.

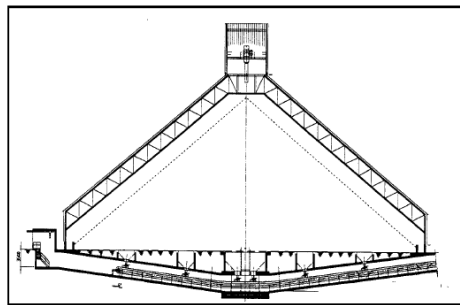


Figure 3.2.71 Circular tank with gravity discharge.

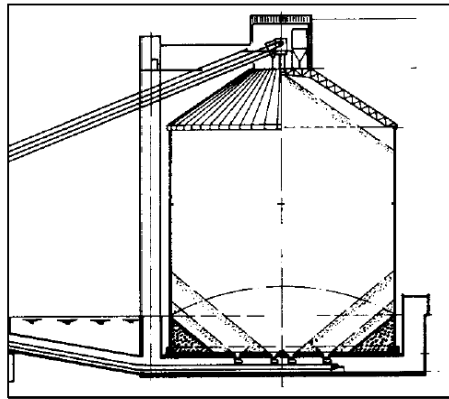


Figure 3.2.72 Clinker storage silo.

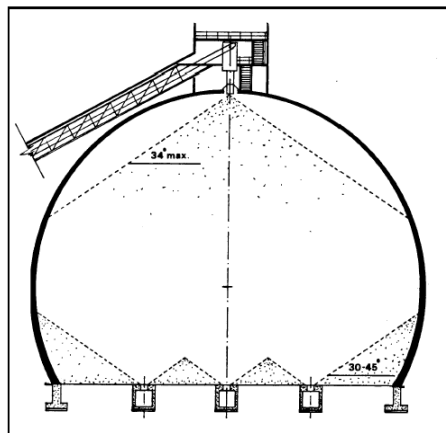


Figure 3.2.73 Dome-type spherical silo.



Figure 3.2.74 Clinker storage silo.

The different components are stored in separate areas, they are metered by means of scales and are added jointly and continuously to the cement mill.

3.2.5.2. Cement Mill

In the grinding process (Figure 3.2.75.), the components are ground, tightly mixed, and the material is then passed through separators (the components added may be ground along with the clinker, or may need to be dried and ground separately). If the cement has the required physicochemical characteristics, it can be stored in airtight silos; otherwise, it is sent back to the mill for further grinding.

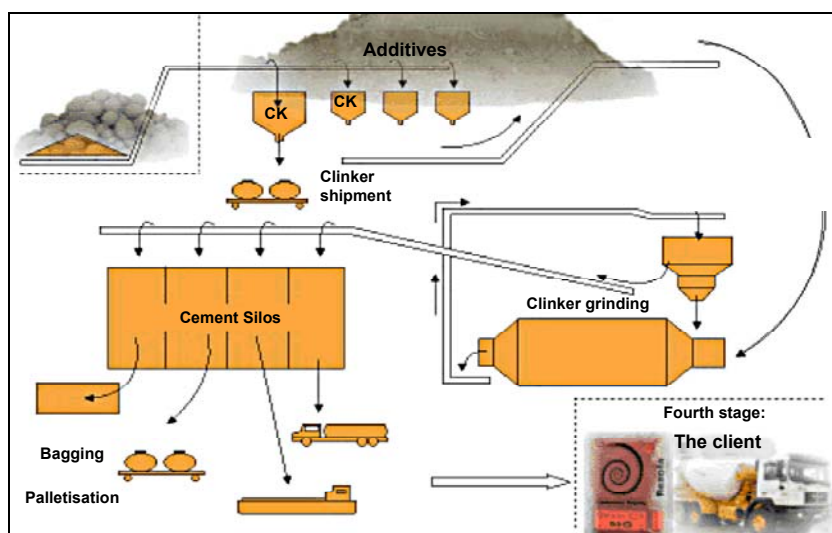


Figure 3.2.75. Process of grinding clinker to obtain cement.

Grinding plants can be located apart from clinker production plants. The type of cement, grinding and the design and installation depend on the type of cement to be produced. The grindability, humidity and abrasion of the cement components produced are highly important.

The majority of mills work in a closed circuit, i.e., they can separate the cement to the fineness required and return the coarse material to the mill.

Weighing and metering of mill feed

Accuracy is highly important for attaining and maintaining high energy efficiency within the mill. The most frequently used weighing and metering equipment is the belt weigh feeder.

Clinker grinding

Owing to the wide variety of types of cement required on the market, nowadays the latest generation of milling systems tend to be fitted with dynamic air separators.

The most common milling systems are the following:

- Closed-circuit ball mill (the percentage of additives is fairly limited if they are not dry or pre-dried).
- Vertical roller mill (better adapted to higher percentages of additives, due to its drying capacity, and more suited to the separate grinding of additives).
- Roller press (the percentage of additives is fairly limited if they are not dry or pre-dried).

Other grinding systems include the following:

- Open circuit ball mill.
- Closed-circuit ball mill with mechanical air separator or cyclone air separator in the older generation.

- Horizontal roller mill.

The principle of working with vertical roller mills is based on the action of 2 - 4 grinding rollers, supported on articulated arms and mounted over a horizontal grinding table or rolling track. It is especially suitable for the simultaneous milling and drying of raw materials for cement or slag, as vertical roller mills can handle relatively high humidity contents in the mill feed. The retention time for the material in the mill is fairly short in order to prevent the pre-hydration of the clinker, for example, in the case of grinding cement with slag.

The high-pressure roller mill requires comparatively high levels of maintenance. Horizontal roller mills often operate in series with ball mills.



Figure 3.2.76 Cement grinding. Holcim Cement Plant, Spain.

A more recent development in cement grinding is the horizontal roller mill. This has a short, large-diameter ring-shaped body and is mounted over hydrostatic or hydrodynamic bearings. The cylindrical ring rotates, driven by the circumferential gearwheel. Within the ring there is a horizontal free-turning roller which can be pressed hydraulically against the cylinder body. The material to be ground is fed in through one of two points over the roller, and is then ground between the roller and the cylinder body. The ground material discharged from the mill is sent to a separator, and the coarse fraction is returned to the mill.

Grinding of additives

The materials used as components in cement grinding (as additives to the clinker) have characteristics which improve its properties, such as workability, water retention, durability, mechanical resistance, sulphate resistance, cold resistance, etc. These materials may be natural or by-products from other industrial processes such as:

- Industrial pozzolans.
- Power station fly ash.
- Blast-furnace slag.
- Silica fume from the ferro-alloy industry.
- Calcined shale.
- Calcium sulphate from the desulphurisation of industrial gases.

Additives (natural or industrial mineral compounds) are generally ground along with the clinker and the gypsum.

The decision on whether additives should be ground separately depends basically on the following factors:

- The percentage of additives in the final product and in the total cement production.
- Whether a spare mill is available.
- Whether there is a considerable difference between the grindability of the clinker and that of the additives.
- The humidity content of the additives.

If additives require pre-drying, drying systems can be employed using kiln exhaust gases and/or the exhaust air from the cooler, as well as an independent hot air generator.

Combined grinding systems

Any of the aforementioned grinding systems for the dry/semi-dry grinding of raw materials can be used to grind additives along with clinker and gypsum. Nevertheless, the majority of systems are limited by the humidity content of the feed mixture - maximum 2%, or 4% if hot gases are used. For contents with higher levels of humidity, these systems require the pre-drying of additives in a dryer. One exception are vertical mills, which can handle humidity contents up to 20%, but which also require a supply of hot gases for the drying process.

A separate air-heating system is frequently required to maintain the dryness - especially in the case of slag having a higher humidity content - and to avoid any loss in quality arising from pre-hydration in the mill.

In the case of the production of compound Portland cement and blast-furnace cement, a closed-circuit grinding installation with an air separator is used. In general, open-circuit grinding is used primarily for the production of Portland cement with fineness under $3,500 \text{ cm}^2/\text{g}$.

Separate grinding systems

In order to mill additives separately, systems for the dry/semi-dry grinding of raw materials can be used. In any case, if there is a high humidity content in the mix, pre-drying will be necessary.

During the simultaneous grinding of a number of principal components, the distribution of cement particle size depends on the grindability of the individual components and the type and duration of grinding.

Two-stage grinding processes are characterised by a combination of two stages in which the grinding is configured in different ways. This system permits the grinding and drying of humid components, such as slag. Moreover, one of the components may be pre-ground to the required particle size distribution in the first stage, and thus optimised for the second stage.

One possible configuration is characterised by the grinding of the principal components, storage of the fine components and a mixing stage which allows the production of cement finished with the different required formulations, reactivities, fineness, size distribution, etc.

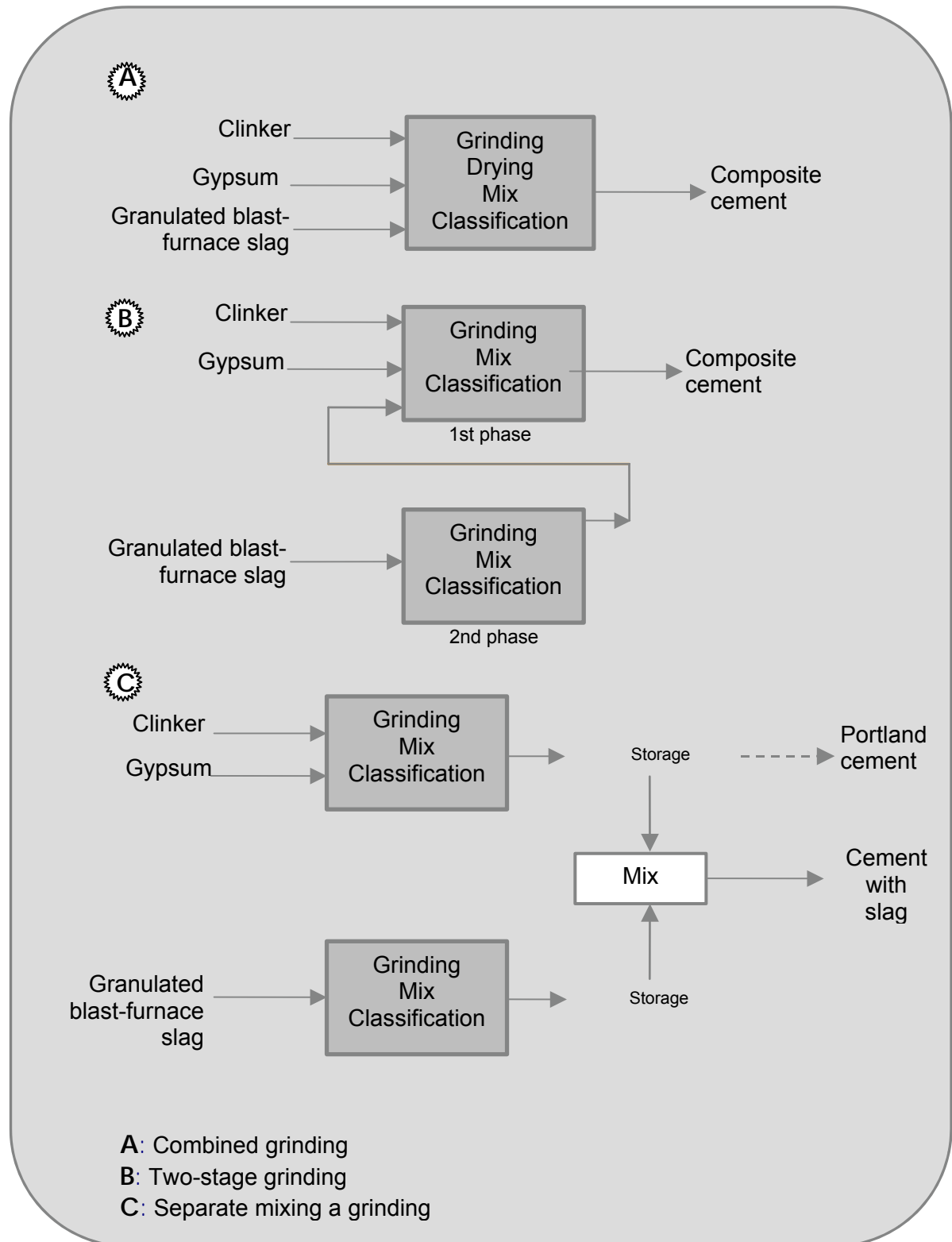


Figure 3.2.77. Principal technological processes in cement grinding.

Separation by particle size distribution

The particle size distribution of the product discharged from the cement mill is highly important for the quality of the cement. These parameters are regulated by adjusting the separator. The latest

generation squirrel-cage rotor separators include many advantages over previous designs, including the following:

- Low specific energy consumption (less over-grinding).
- Increased capacity (efficiency).
- Possibility of cooling the product.
- Greater flexibility in controlling the fineness of the product.
- Greater control in particle size distribution, and thus improved product uniformity.

3.2.5.3. Cement storage

The cement is sent to storages silos, whence it is extracted by means of mechanical and pneumatic systems, for transport to where it is to be packaged in paper sacks, or shipped directly in bulk. Mechanical systems usually involve high investment costs, but with lower operating costs than pneumatic transport.

The most commonly used system is a combination of fluidised or screw belts and scoop lifts.

Several silos are generally required for the storage of different cements. Nevertheless, new silo designs mean that more than one type of cement can be stored within the same silo.

The most common configurations for cement silos are as follows:

- Single-cell silo with discharge hopper.
- Single-cell silo with central cone.
- Multi-cell silo.
- Copula silo with central cone.

Compressed air is used to initiate and maintain the cement silo loading process, injecting the material into the silo through aeration units set in its base.

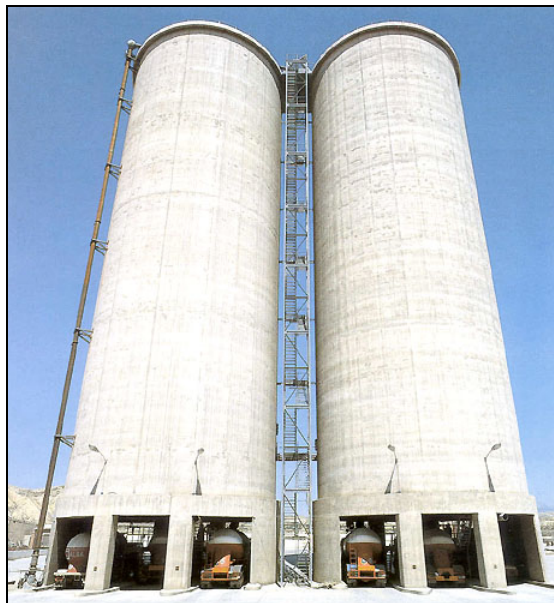


Figure 3.2 .78 Cement silos. Uniland Cement Plant. Spain.

3.2.6. Cement Products

3.2.6.1. Properties and types of cement

The cement industry produces the types and classes of cement—obtained by different mineral mixes—which are required in the market. Economic and industrial progress, sources of raw materials, and climatic conditions have given rise to a number of advances in building methods and types of construction materials and, thus, to different types of cement, depending on the physicochemical characteristics and final applications required.

Physicochemical characteristics

By way of a preliminary step to their description, we must establish the definition of what is referred to as the hydraulicity index. This index is a figure that is obtained from the ratio between the acid and basic components of the cement. $I = \text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3 + \text{SO}_3 \text{CaO} + \text{MgO} + \text{K}_2\text{O} + \text{Na}_2\text{O}$.

Values between 0.65 - 1.20 mean that the cement is quick setting (setting in under an hour); whereas values between 0.50 - 0.65 mean that it is slow setting (in excess of 8 hours).

The most important physical and mechanical characteristics are as follows:

Fineness of grinding

This characteristic is closely linked to the cement's hydraulicity value, since it plays a decisive role in the speed of the chemical reactions that take place during its setting and its initial hardening. When coming into contact with water the cement grains are only hydrated to a depth of 0.01 mm; hence, if these grains are very coarse, their efficiency will be very low, as inside the nucleus will be practically inert. If the cement is excessively fine, the shrinkage and heat given off during setting are very high (which is generally detrimental): the binder will be more susceptible to weathering (ageing) after prolonged storage; and its resistance to corrosive water is reduced.

Given that mechanical resistance increases with fineness, a compromise must be sought: the cement must be finely ground, but not excessively so. It is desirable for the cement to reach certain levels of resistance, at different ages, due more to the quality of the clinker than to the fineness of grinding.

Expansion

In the long term, this phenomenon is due to the existence of excessive amounts of free lime or magnesium. This condition should be measured in the cement prior to its use in construction in order to avoid any possible disasters.

Mechanical resistances

By the resistance of cement, we mean that of a mortar standardised in accordance with current legislation. This property is important, but usually a double-edged sword, as it tends to adversely affect durability.

Setting and hardening

This is without doubt the principal characteristic of cement, and is thus so important for its use in construction. Setting is brought about by the addition of water, which produces the hydrolysis of certain compounds and the subsequent hydrations and recombinations, after which the cement acquires the hardness of stone. The hydration of cement takes place in two stages:

1. Setting: during which the plastic mass acquires increasing rigidity (duration ranging from minutes to 18 hours)

2. Hardening: The hardness and mechanical resistance of the rigid mass increases (this may take 28 days, but cases of several years have been recorded). This phenomenon includes a series of complex reactions (see Section 3.2.8 Delivery of cement).

Common cements

Due to the large number of different types of cements, it is necessary to separate “common cements” from “cements with special characteristics”.

Common cements are those which are apt for structural applications and which can also be used for non-structural applications in construction. Part of the cement may consist of mineral additives from natural or industrial sources. These additional minerals may have different characteristics:

- Hydraulic (blast furnace slag).
- Pozzolanic (volcanic rocks, fly ash, micro silica, calcined clay).
- Filling (limestone).

In general, five principal types of common cement can be distinguished, depending on the characteristics of the added minerals:

- Portland cement.
- Portland-composite cement.
- Blast-furnace cement
- Pozzolanic cement.
- Composite (blended) cement.

Portland cement

Portland cement is a hydraulic cement produced by the mixing and grinding of clinker with a low percentage of gypsum and natural or industrial anhydrate (calcium sulphate), which acts as regulator for the hardening process and which generally contains one of more of the forms of calcium sulphate, as an additive during milling. This slow-setting type of cement is used in pre-fabricated construction and high-resistance concrete.

Portland-composite cement.

This is Portland cement with additives. It contains between 6 and 35 % of other principal components besides clinker. It is a type of intermediate cement between the previous one and pozzolanic Portland cement and blast-furnace cement (using blast-furnace slag), permitting a continuous grading between one and the other. It is used in the manufacture of reinforced concrete and mass concrete.

Blast-furnace cement

These are cements with a high percentage of blast-furnace slag which, along with the clinker, acts as a hydraulic binder. Granulated blast-furnace slag is a by-product of the treatment of ferrous minerals in a blast furnace which, for use in the manufacture of cement, must be obtained in a granular form by rapid cooling, and must also have a suitable chemical composition. It is inexpensive, but sets and hardens slowly.

It is a good cement for large blocks, but it is not recommend for use in settings with low temperatures which retard the setting even further, and should not be used at temperatures below 5 °C. It takes on a greenish hue, and this should be borne in mind for visible concrete. It requires humidity for approximately two weeks, heat and dryness being its principal enemies.

Pozzolan cement.

Cement containing pozzolan is obtained by the joint pulverisation of a mix of Portland clinker and pozzolan with the eventual addition of calcium sulphate. The pozzolan content should be between 15 and 50 % of the total weight. Pozzolan is a siliceous or aluminosilicate material, which, in itself may have little hydraulic activity, but in finely ground form and in the presence of humidity, reacts chemically with calcium hydroxide at common temperatures to form compounds with hydraulic properties.

Composite cement.

Composite cements are binders which, besides Portland cement clinker and gypsum, contain one or more of the following materials: latent hydraulic material, generally granulated blast-furnace slag, pozzolan components, such as natural pozzolan, volcanic ash, silica fume, calcined clay, etc., and/or inert additives, in most cases limestone. It gives rise to slow-setting, low-resistance concretes with few retractions that are not suitable for reinforced concrete.

Table 3.2.9. Principal types of cement.

Types	Name	Designation
CEM I	Portland cement	CEM I
CEM II	Portland cement with slag	CEM II/A-S
		CEM II/B-S
	Portland cement with slag fume	CEM II/A-D
	Portland cement with pozzolan	CEM II/A-P
		CEM II/B-P
		CEM II/A-Q
		CEM II/B-Q
	Portland cement with fly ash	CEM II/A-V
		CEM II/B-V
		CEM II/A-W
		CEM II/B-W
	Portland cement with calcined shales	CEM II/A-T
		CEM II/B-T
	Portland cement with limestone	CEM II/A-L
CEM II/B-L		
CEM II/A-LL		
CEM II/B-LL		
Portland-composite cement	CEM II/A-M	
	CEM II/B-M	
CEM III	Cement with blast furnace slag	CEM III/A
		CEM III/B
		CEM III/C
CEM IV	Pozzolan cement	CEM IV/A
		CEM IV/B
CEM V	Composite cement	CEM V/A
		CEM V/B

Cements with special characteristics

These are none other than the general cements seen above, which also incorporate specific properties which lend additional utility for specific applications.

Sulphate-resistant cements

These cements are used for concrete structures that are exposed to the action of soluble sulphates in subterranean water, surface water and soils. Portland cements with a low content of C_3A (under 3 %), and cements with blast-furnace slag with at least 65 % granulated slag, have been sufficiently tested in Europe and in other parts of the work, obtaining the required chemical resistance. The suitability of these cements depends on regional environmental conditions.

Low-heat cement

These cements are used in large concrete structures, and are characterised by their low heat generation during hydration.

Hydration heat leads to an increase in the temperature of the concrete and gives rise to tension and the formation of cracks. The fundamental characteristic of these cements is an initial lower development of resistance.

Low-alkaline cements

Low alkaline cements are used in the production of concrete which contains aggregates that can react with alkalis (aggregates containing SiO_2 , such as opal, chert, certain silicate minerals, volcanic fume, etc.). The reaction is known as an alkali-siliceous reaction and leads to expansion and eventually to cracking. It is used under humid atmospheric conditions. These cements are defined globally as cements with a total maximum alkali content lower than 0.6% (calculated as the equivalent of Na_2O), whilst in the composition of Portland cement, contents of 2% may be considered acceptable.

Calciumaluminate cements.

These are cements with an Al_2O_3 content between 36 and 55 %. This is a hydraulic binder which solidifies and hardens due to the hydration of the aluminates. The principal component is anhydrate monocalcium aluminate ($CaO Al_2O_3$, CA). The hydraulic characteristics are principally based on the hydration of CA. The rapid development of resistance (over N/mm^2 after 6 h, and over $40 N/mm^2$ after 24 h) coupled with normal hardening behaviour (> 60 minutes, similar to Portland cement) and the high chemical resistance of dense mortars and concretes are the principal characteristics of this cement. An increase in the Al_2O_3 content results in increased refractory resistance.

Short-term resistances are greater than those of Portland cement, although the long-term ones are lower as a consequence of the conversion effect (formation of hydrated calcium aluminate which results in greater porosity). This is more stable against corrosive waters and seawater than Portland cement. Much more care must be taken in the selection of aggregates and additives than for normal Portland cement. Coatings may be inferior, due to the greater protection against corrosion provided by the liberation of alkalis in this cement.

Other cements

There are many types of cement with specific characteristics, and which are often used for special purposes. In the majority of cases they are not standardised, nor can they be introduced into the market within a national legislation. A number of examples are given below:

Super-sulphate cements These are made up of blast-furnace slag with an anhydrate content ($CaSO_4$) lower than 5 %, and a maximum Portland cement clinker content of 5 %. The use of

waterproof cement is advantageous, for example, in the compacting of soils. Waterproof cement is its common Portland cement which contains small quantities of waterproof substances added during grinding at high temperatures.

Oil well cements. These are used to cement the steel coverings of the walls of drillings for gas and oil wells, forming a covering to seal porous formations. These are Portland and pozzolanic cements which, owing to their composition, set even at high temperatures and pressures.

Regulated setting cement. This cement sets and hardens very rapidly due to its high content of the compound $11 \text{ CaO} \cdot 7 \text{ Al}_2\text{O}_3 \cdot \text{CaFe}_2$.

Expansive cement. This generally contains high quantities of aluminates and sulphates. It expands on hardening due to the formation of ettringite.

Masonry cement. Masonry cement is a factory-produced finely ground hydraulic binder, and is formed essentially by the presence of Portland clinker cement to develop its mechanical resistance.

White cements. The whiteness of the cement is regulated in order to be catalogued as such.

3.2.7. Bagging and shipment

For a long time, cement has been supplied in paper sacks (Figure 3.2.79.). Nevertheless, the current trend is to supply it in bulk (Figure 3.2.80.), transporting it in tanker trucks. The cement can be sent to shipment destinations via land or maritime transport.



Figure 3.2.79. Transport of cement in sacks.



Figure 3.2.80. System for the bulk loading of cement.

Bulk transport

There are a number of advantages of acquiring cement in bulk, among them the following:

- Savings in purchasing the cement.
- Savings in loading, storage and handling.
- Savings in losses arising from damaged or wet sacks.
- Increased work productivity, as the cement is immediately available.
- Avoids the risk of robbery.

In any case, from a social economic perspective, it results in currency savings for the State by reducing the imports of consumables for manufacturing packaging.

The cement transport vehicle is a pressurised tank which is loaded at storage silos by gravity, and which is fitted with a compressor for discharging the material. The driver regulates the controls in order to obtain the required mixture of air and cement for transporting the material from the silo to the work site.

The first bulk carrying vehicles had a dual-cone design, with a central discharger and an aeration device running along the inside of the container. Due to the geometry of the cone, only those products which could be fluidised could be discharged.

Later, due to the need to increase capacity and obtain more versatile vehicles capable of carrying larger quantities of product, improvements were introduced into the design, making it possible to adapt them to various uses, including the transport of liquids (ranging from inflammable to solid granulated products), by converting the valve and ventilation systems of the container. Vehicles are categorised into tanks, trailers and a combination of both.

3.2.8. Delivery of cement

When the cement—or its mixes with sand (mortar) and stone (concrete)—is mixed with water the initially plastic slurry obtained starts to lose this property after a certain time (for example, an hour), and ends up being transformed after three or four hours into a mass that is totally rigid, although still not resistant.

This hydration phenomenon can be divided into two separate phases: setting and hardening. During the setting, which takes place within hours, those components of the cement which are more easily and rapidly soluble in water are dissolved into the liquid phase. During this process heat is given off and the slurry progressively loses plasticity and acquires rigidity, until at the end the slurry becomes totally solid. During the hardening which then occurs, and which take a long period of time (days, months and even years), the hydration and consolidation processes continue at constant but decreasing rates, with the rigidity, hardness and mechanical resistance of the slurry increasing gradually, and the heat from hydration being dissipated.

One effect which may appear when mixing cement with water is known as “false setting”, and this consists of the premature binding of the mass, which takes place some five minutes after the onset of mixing. It does not alter the properties of the cement, due to which it is harmless, and is solved by continuing to mix the cement.

The principal hydration reactions are as follows:

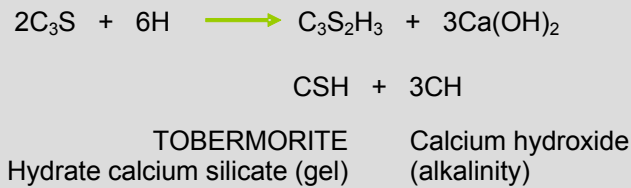
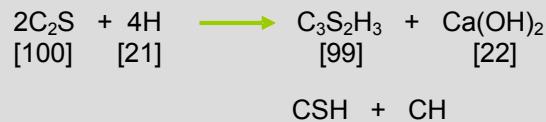
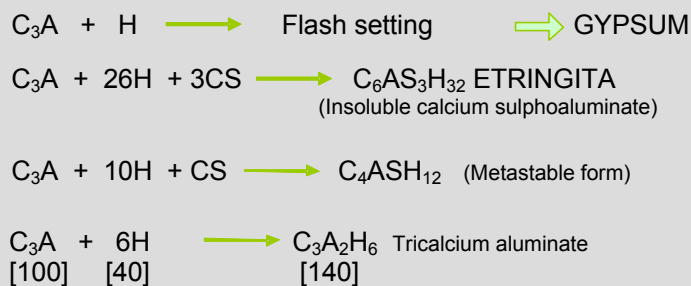
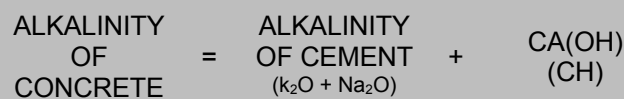
For C₃S**For C₂S****For C₃A****For C₄AF**

Figure 3.2.81. Cement hydration process.

The first reactions are those of the non-silicate components, and these are responsible for the setting behaviour. The phase that hardens is hydrate tricalcium disilicate, or tobermorite gel (discovered in Tobermory, Scotland). Its rigidity and final resistance depend on the quantity of water present and the temperature. As it forms a disperse colloid (gel), the tobermorite envelops the particles of calcium hydroxide, aluminium hydroxide and non-hydrolysed clinker grains, protecting them from the initial action of the water.

The reactions continue during the hardening process, and the reagents come together to form a compact mass of particles. In order for this stage of the reaction to take place, the water required is released by the gel, which then becomes hard and impermeable. The crystal particles that are formed interlock and fill the pores of tobermorite gel, thus ordering the structure.

3.2.9. Quality control

Quality control starts from the selection of raw materials, on the basis of the chemical composition, and continue with the metering and grinding to ensure the suitable preparation of the mix for calcining, where it must be verified that the chemical compounds needed for the manufacture of the required cement have been obtained. In the finish grinding, it must be checked that the product complies with quality parameters such as, compression resistance, workability, etc., thus conforming to that stipulated in the quality policy.

4. ENVIRONMENTAL PROBLEMS IN THE MANUFACTURE OF CEMENT: WASTE FLOW AND CONSUMPTION

There are a number of different environmental problems deriving from cement manufacturing processes, but these depend to a large extent on the raw materials and fuels used, as well as the processes carried out in this industry.

The environmental aspects associated to the cement industry can be separated into two distinct groups: those associated with the raw material extraction stage, and those associated with the clinker and cement production stages.

The environmental aspects associated with the extraction of raw materials are determined principally with the deterioration of the landscape and the natural setting, noise, vibrations and the dust produced by blasting along with the characteristic activities of quarries. With regard to these aspects, it should be pointed out that at this moment in time, the extraction of minerals is no longer limited to merely covering the needs of resources; rather it also aims to be accepted by society in general, from an environmental point of view. Another, indirect, environmental aspect of these operations is that associated with the transport of raw materials from the quarry working to the production plant (principally, energy consumption, emissions from vehicles, diffuse particle emissions to the atmosphere and noise), one reason for which, from both economic and environmental perspectives, it is of paramount importance that the production plant be as close as possible to the quarry.

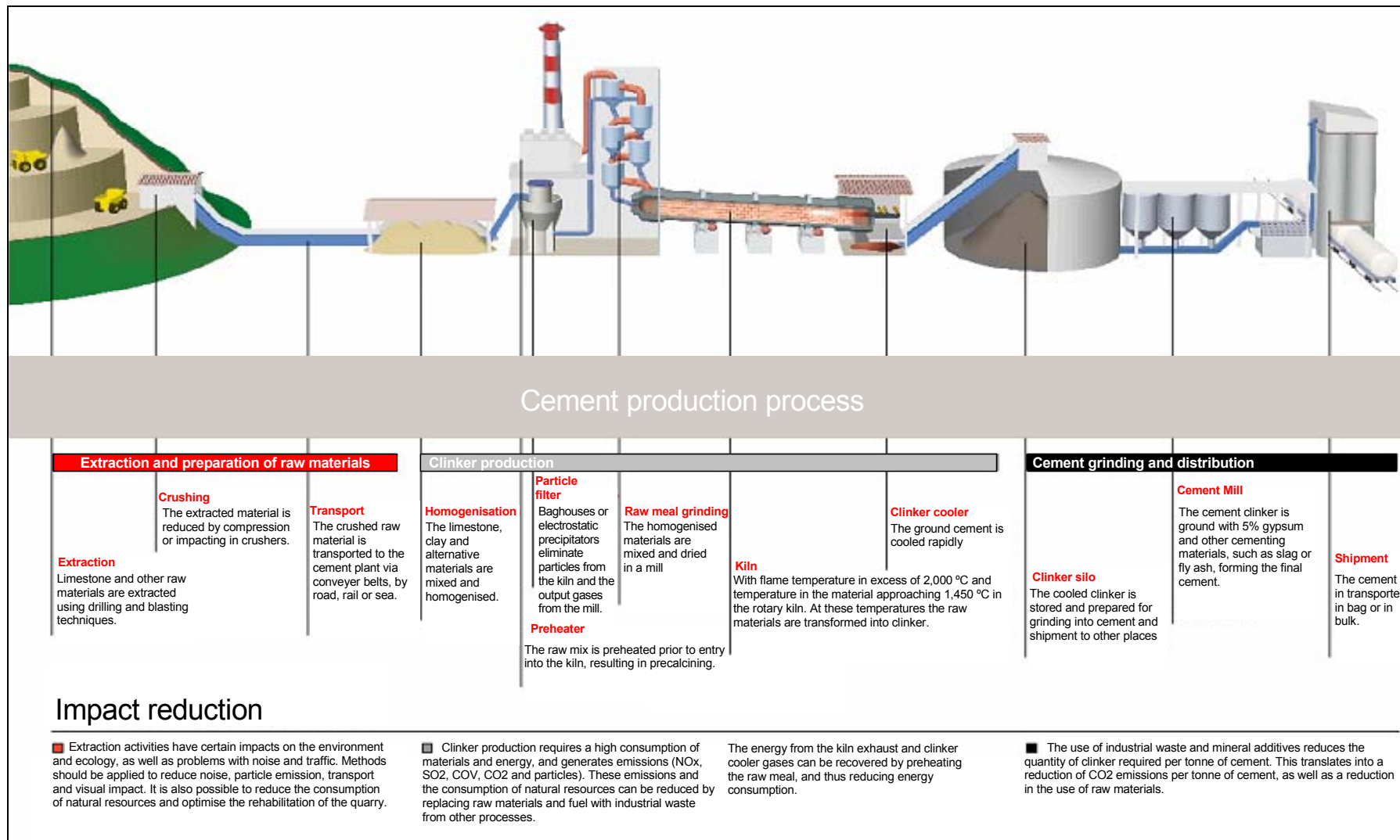
The principal environmental aspects associated with clinker and cement production are atmospheric emissions (dust, NO_x, SO₂, CO₂, COV, etc.) and energy consumption.

Water discharges are limited to rain run-off, the refrigeration of equipment (normally closed circuit) and sanitary water; the storage and handling of fuels are also potential sources of soil and ground water contamination.

This chapter gives a description of waste flows (atmospheric contamination, liquid discharges and waste) as well as energy and water consumption for the principal processes in the manufacture of cement.

In some instances, specific management options are proposed, which in any case must be contrasted specifically with the waste flow management obligations that have been established in each country, and for which compliance is obligatory.

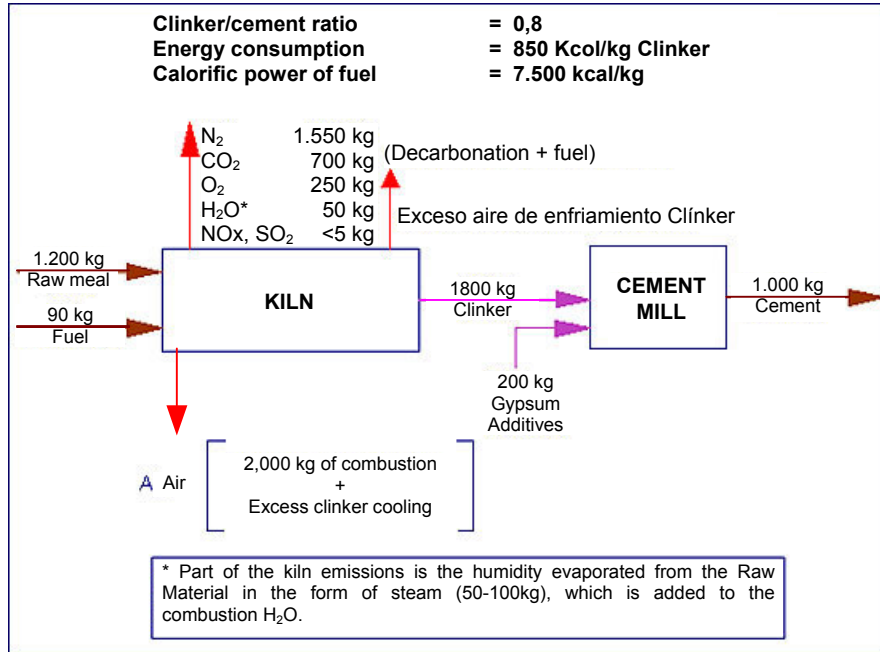
In order to facilitate the understanding of that described in the different sections of this chapter, below is a diagram of the cement manufacturing process with its associated environmental impacts:



Source: Adapted from an original diagram from Holcim.

Figure 4.0.1. Diagram of the cement manufacturing process and its associated environmental impacts.

We now go on to show a mass balance for a tonne of cement, and a summary table of the principal contaminants that are generated, depending on the stage of the production process:



Source: Oficemen

Figure 4.0.2. Mass balance for one tonne of cement

Table 4.0.1. Principal contaminants depending of stage of the production process.

Contamination source	Part	SOx	NOx	COx	COV	Metals	Halogens	Dioxins and furans	NH ₃	S.S.	pH
Preparation and storage of raw materials	A										
Preparation and storage of fuels	A										
Kiln	A	A	A	A	A	A	A	A			
Clinker cooler	A										
Cement grinding	A										
Cement storage	A										
Drainage										W	W

A: To air, W: To water, L: To land.

Source: Cembureau

4.1. POTENTIAL SOURCES OF ATMOSPHERIC CONTAMINATION

4.1.1. Principal atmospheric emissions

The cement industry emits a series of contaminants to the atmosphere, and these may originate from specific or diverse sources (Figure 4.1.1.).

Emissions from specific sources are generated during the production process (combustion, grinding and drying), and are characterised as being channelled through ducts and chimneys. The principal contaminating compounds that are generated include:

- Solid particles.
- Nitrogen oxides.
- Sulphur dioxide.

There are also other compounds which are emitted from the same sources, depending on the characteristics of the process:

- Carbon dioxide.
- Carbon monoxide.
- Volatile organic compounds.
- Hydrochloric acid.
- Hydrofluoric acid.
- Dioxins and furans.
- Heavy metals.

Emissions from diverse sources, however, are not channelled, and are not associated to combustion, grinding or drying processes, rather simply to operations such as the batch loading of lorries by excavating shovels, the piling of limestone, the transit of vehicles over unpaved roads or the erosive action of wind on those materials that are stored exposed to the elements.

These operations basically emit solid particles to the atmosphere as their only contaminant.

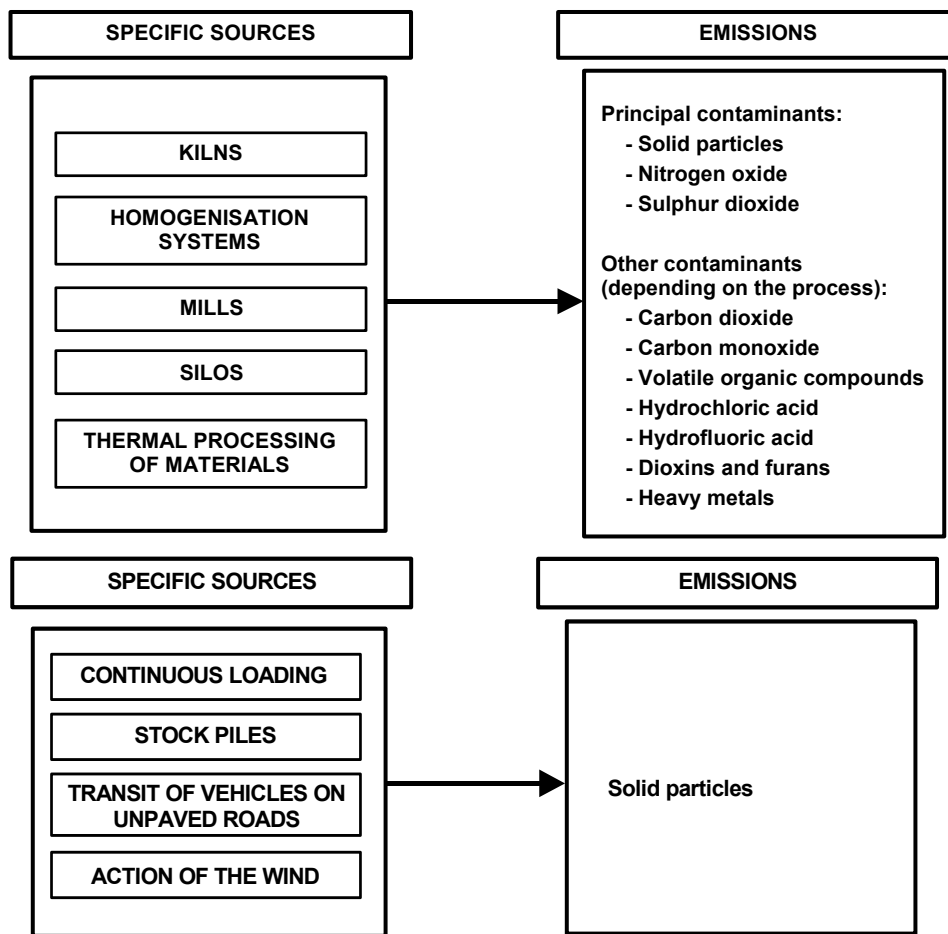
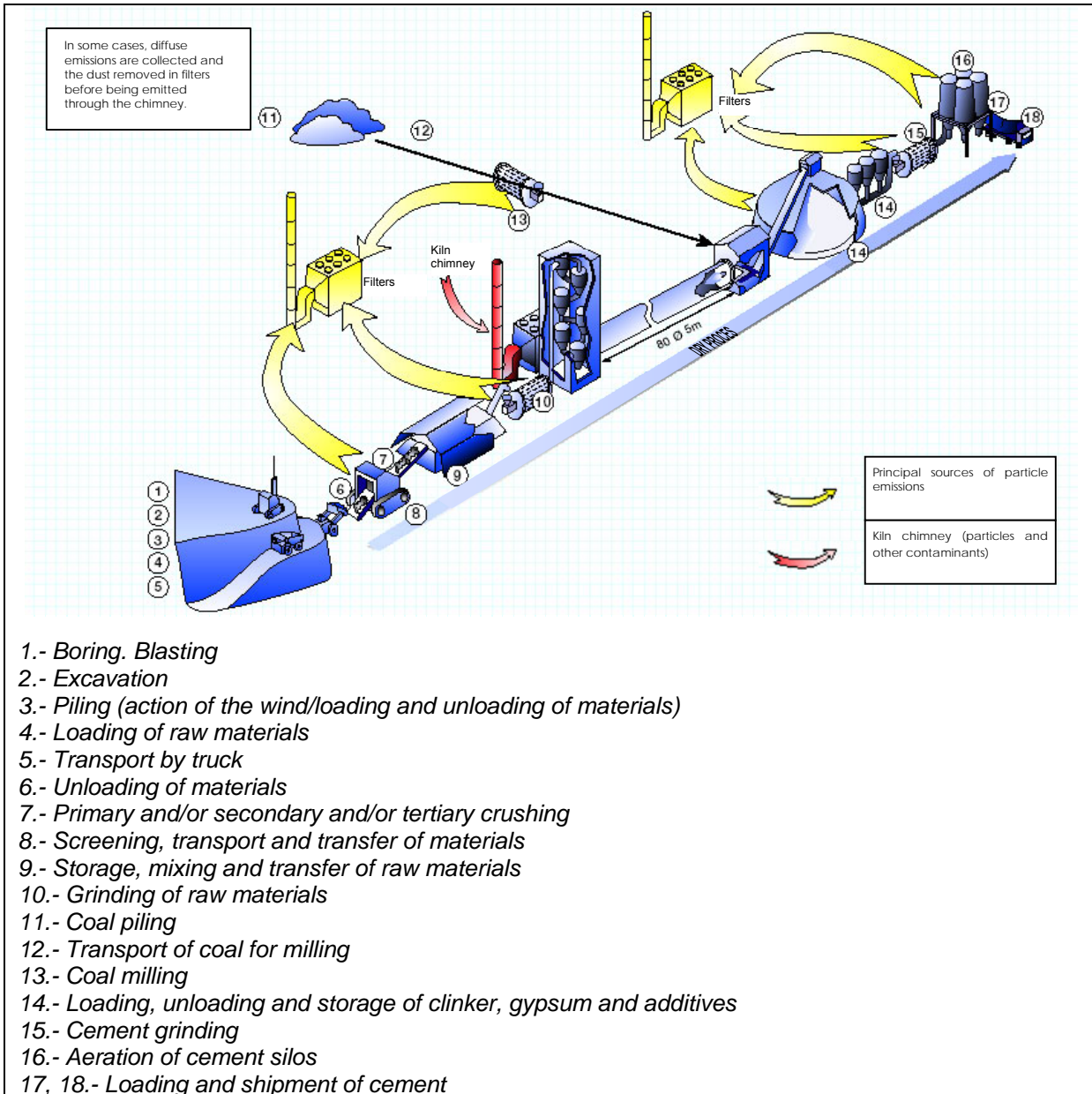


Figure 4.1.1. Atmospheric contaminants linked to the cement industry.

Below is a diagram of the cement manufacturing process, with the principal sources of particle emissions and other contaminants to the atmosphere (Figure 4.1.2.).



Source: Reference documents on the best available techniques applicable to the Cement Industry.

Figure 4.1.2: Diagram of a cement manufacturing process: sources of particle emission and other contaminants to the atmosphere.

This section describes the principal atmospheric emissions on the basis of the different stages of the cement manufacturing process, as well as the most common measuring and control systems for the typical contaminants in the sector.

4.1.1.1. Obtaining raw materials

Due to its very nature, the extraction of raw materials from quarries will clearly have a degree of environmental impact. Nevertheless, it is possible to specify which impacts remain, in the main, localised and do not have large-scale effects, beyond the immediate setting of the quarry workings.

In general the disruption caused by the working of quarries is fairly limited and specific, taking the form of dust emissions, the noise from blasting, the start-up of motors and the traffic of heavy vehicles. Nevertheless, through the application of good practices and modern technology (see *Chapter 5*,

Opportunities for preventing and reducing contamination) it is possible to reduce these impacts considerably, rendering them practically insignificant.

4.1.1.2. Preparation and storage of raw materials

In this phase atmospheric emissions are low in volume and concentration, and include only the emission of particles originating from the grinding of raw materials. In dry countries, particle emissions arising from the storage and handling of raw materials are especially relevant. These include the following:

- Transport to the factory.
- Loading and unloading operations.
- The action of wind on stock piles.
- Transfer points.
- Internal transport.

In certain cases, these emissions may be locally significant, when suitable control systems are not available.

4.1.1.3. Preparation and storage of fuels

As in the case of raw materials, operations of transporting, handling (loading and unloading, packaging) and storage of solid fuels are also a potential source of particle emissions; however, as mentioned above, with the use of suitable environmental technology and practices, the emission of particles in the stage is not a significant problem.

4.1.1.4. Clinker burning

The most important point of atmospheric emissions from chimneys is the clinker kiln. These emissions originate from the physicochemical reactions of the raw materials being processed and the fuel used for burning. The relevant emissions associated to this practice are as follows:

- Nitrogen oxides (NO_x).
- Sulphur dioxide (SO₂).
- Particles (dust).

Environmental legislation and the operation of factories usually focus on these three contaminants, although emissions of carbon dioxide, CO₂, are also considered to be of special relevance in cement production.

The principal constituents of cement kiln exhaust gases are as follows: nitrogen from the combustion of air, CO₂ from the decarbonation of CaCO₃ and the oxidation of the fuel, steam from the combustion process and raw materials, and excess oxygen (see Table 4.1.1.):

Table 4.1.1. Composition of kiln exhaust gases.

Compound	% Volume
Nitrogen (N ₂)	45-75
Carbon dioxide (CO ₂)	11-29
Water (H ₂ O)	10-39
Oxygen (O ₂)	4-12
Others (including contaminants)	< 1

Besides the three aforementioned relevant emissions, others associated with the operation of the kiln include:

- Carbon monoxide (CO).
- Volatile organic compounds (VOC).

The content of these two compounds in the emitted gases is affected, as well as by the combustion conditions, by the organic matter content of the raw materials, which is partially oxidised when coming into contact with the gases in the kiln.

When organic waste is used as an alternative fuel in clinker kilns (tires, solvents, oils, etc.) an exhaustive control of the emissions must be carried out, and should include, as well as the contaminants mentioned in paragraphs above, the following:

- Metals and their compounds.
- HF.
- HCl.
- Dioxins and furans (PCDDs and PCDFs).

The emission of these four contaminants is usually very low (see Table 4.1.2.), but through their control it is possible to guarantee the proper operation of the kiln with regard to waste treatment activities.

In all kilns, the material moves in counterflow to the hot combustion gases; this reduces the emission of contaminants, since it acts as a circulating fluidised bed. In this way, many compounds resulting from the combustion or transformation of raw materials into clinker remain in the gas flow until they are absorbed, condensed or retained by the counterflow of raw materials.

The absorption capacity of the material varies according to its physicochemical state. This, in turn, depends on the area of the kiln in which it is found. For example, material from the calcining (decarbonation) stage of a kiln has a high calcium oxide content, and consequently has a high absorption (neutralisation) capacity for acids, such as HCl, HF and SO₂.

By way of example, Table 4.1.2 gives typical emission data for kilns. The wide range of emissions for kilns can be explained by the following factors:

- The effect of raw materials, of local origin, and, to a lesser degree, of fuels.
- The age and design of the plant, as well as the techniques used.

Table 4.1.2. Range of typical cement kiln emissions.

	mg/Nm ³	Kg/t of clinker	t/year
NO _x (such as NO ₂)	< 200-3.000	< 0,4-6	400 -6.000
SO ₂	< 10-3.500	< 0,02-7	< 20-7.000
Particles (dust)	5-200	0,01-0,4	10 - 400
CO	500-2.000	1-4	1.000-4.000
CO ₂	400-520 g/Nm ³	800-1.040	0,8-1,04 million
COT	5-500	0,01-1	10-1.000
HF	< 0,4-5	< 0,8-10 g/t	< 0,8 -10
HCL	< 1-25	< 2-50 g/t	< 2 -50
PCDD/F	< 0,1 mg/Nm ³	< 200-1.000 g/t	< 0,2-1 g/año
Metals			
(Hg, Cd, Ti)	0,01-0,3 (prin. Hg)	20-600 mg/t	20-600 kg/año
(As, Co, Ni, Se, Te)	0,001-0,1	2-200 mg/t	2-200 kg/año
(Sb, PB, Cr, Cu, Mn, V, Sn, Zn)	0,005-0,3	10-600 mg/t	10-600 kg/año

Source: Cembureau

Normal volumes of gases emitted by grey clinker kilns vary between 1,700 and 2,500 m³ per t of clinker (dry gas, 101.3 kPa, 273 K). Kiln systems with a preheater and precalciner normally have gas volumes of around 2,000 m³/t of clinker (dry gas, 101.3 kPa, 273 K).

Nitrogen oxide emissions

Nitrogen monoxide (NO) and nitrogen dioxide (NO₂) are the principal nitrogen oxides in the gases emitted by cement kilns (NO > 90 % of nitrogen oxides).

Emissions of NO_x depend fundamentally on the type of kiln that is used, and on how raw materials are burned.

The range of nitrogen oxide emissions is approximately between 200 and 3,000 mg NO_x/m³ (such as NO₂, dry gas, 273 k, 101.3 kPa, 10 % O₂).

There are two principal sources for the production of NO_x; these are:

- Thermal NO_x: part of the nitrogen in the combustion air reacts with the oxygen to form nitrogen oxides.
- NO_x from fuel: the nitrogen compounds present in the fuel react with oxygen to form nitrogen oxides.

Thermal NO_x

The formation of thermal NO_x is greatly increased at combustion temperatures over 1,200 °C, when the nitrogen and oxygen molecules react in the combustion air.

Thermal NO_x is principally produced in the clinkering zone of the kiln, where temperatures approach 2,000 °C. The quantity of thermal NO_x generated in the zone is related with both the temperature and oxygen content (excess air factor): the greater the excess of oxygen, the more thermal NO_x will be formed.

When the raw materials are difficult to burn, the temperature in the clinkering zone must be higher, which necessarily implies the generation of more thermal NO_x. The degree of burning for the raw material depends on the crystallography/mineralogy of the compounds that make it up, and on the presence of flux minerals (iron, aluminium). This is the case of the manufacture of white clinker, where the raw materials have low levels of flux materials (so as not to darken the clinker) and require higher sintering temperatures (around 150 °C).

NO_x from fuel

NO_x is generated by the oxidation of the nitrogen (N) present in the fuel, which combines with other nitrogen atoms to form N₂ gas, or reacts with O₂ to form combustible NO_x.

In a precalciner, the temperature is usually within the range of 900 - 1,150 °C, which is low for the formation of thermal NO_x, due to which the majority of NO_x formed in this area of the kiln will be combustible NO_x. The same occurs when part of the fuel is fed into the kiln inlet area, where a zone of secondary combustion is generated at a temperature similar to that corresponding to a precalciner.

In kilns with precalciners, in which 60% of fuel can be burnt in the precalciner, the formation of thermal NO_x is lower than in kilns in which all the fuel is burned in the sintering area.

Besides the temperature and oxygen content (excess air factor), the formation of NO_x may be influenced by the form of the flame and its temperature, the geometry of the combustion chamber, the reactivity and nitrogen content of the fuel, the presence of humidity, the reaction time and the design of the burner.

Sulphur dioxide emissions

Emissions of SO₂ from cement factories are directly related with the content of volatile sulphur compounds in the raw materials. Kilns that use raw materials with low contents of volatile sulphur compounds have much lower SO₂ emissions, in some cases below detection limits.

Sulphur dioxide (SO₂) is the principal sulphur compound emitted (99 %), although small quantities of SO₃ are also emitted and, under reducing conditions, hydrogen sulphide (H₂S) may be generated. The range of emissions for SO₂ is from 10 to 3,500 mg/Nm³.

In the raw material, the sulphur compounds are present principally as sulphates (e.g., calcium sulphate, CaSO₄) or as sulphides (e.g., pyrite, FeS₂).

Sulphates

The sulphates in raw materials are thermally stable above a temperature of 1,200 °C; when they enter the sintering zone of the kiln they break down to form SO₂. Part of this SO₂ combines with alkalis and is thus incorporated into the structure of the clinker; the remainder is carried to cooler areas of the kiln, where it reacts with both calcined calcium oxide and calcium carbonate, and is fed once again into the sintering zone (chemical absorption).

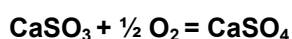
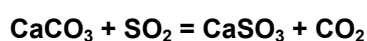
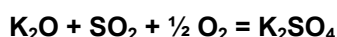
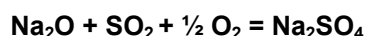


Figure 4.1.3. Chemical reactions with SO₂.

The inorganic or organic sulphur compounds in fuels are subjected to the same cycle, consisting of thermal breakdown, oxidation to SO₂ and reaction with alkalis or calcium oxide. With this closed cycle, all the sulphur introduced by the fuels or by the sulphates in the raw material exits the kiln incorporated into the clinker, without being admitted to the atmosphere in the form of SO₂ emissions, due to which the sulphur present in fuels in kilns with a preheater do not generate significant emissions of SO₂. The excess of oxygen (from 1 to 3 % of O₂ maintained in the kiln to ensure the high quality of a cement) will oxidise the freed sulphurous compounds, transforming them into SO₂.

Sulphides (or organic sulphur compounds)

The sulphides and organic sulphur present in raw materials evaporate when the temperature of the raw meal starts to rise and, unlike sulphates, they break down and oxidise at moderate temperatures between 400 and 600°C, producing SO₂; 30 % or more is emitted from the first stage of the cyclone exchanger. At these temperatures there is not sufficient calcium oxide to react with the SO₂. The gases in this stage are emitted to the atmosphere or piped to the raw meal mill when this is in operation.

In the raw meal mill, between 20 and 70 % of the SO₂ is captured by the finely ground raw materials (physicochemical absorption). Thus it is important that, when there are volatile sulphur compounds in the raw materials, the raw meal mill should be optimised in order to act as an SO₂ collection system.

In a furnace with a grate preheater, the absorption of SO₂ is good; the gas is made to pass through a bed of partially calcined raw material and through mixes of calcium carbonates in the drying chamber.

In long dry or wet kilns, the chemical absorption of SO₂ is generally less efficient, due to the reduced contact between the exhaust gases and the raw material. In these kiln systems, practically all the sulphur fed in contributes to SO₂ emissions, and the levels these emissions are greater than in a dry-process kiln equipped with a preheater.

In the case of manufacturing of special cements, such as white cement, the following determining factors come about:

- Greater difficulty in burning due to the crystallography and mineralogy of the raw meal.
- Absence of fluxes in the raw materials to preserve the colour.
- Absence of alkalis due to the purity of the raw materials.
- Kiln operation conditions (occasionally reducing).

The combination of these conditions may give rise to high SO₂ emissions as a similar percentage of sulphur oxides is not fixed to the same degree as in the manufacture of grey clinker.

Particle (dust) emissions

Historically, the emission of particles (dust), especially by kiln chimneys, has been the principal environmental concern with regard to the manufacture of cement.

The main sources of chimney particles (localised or specific sources) are kilns, crude mills, clinker coolers and cement mills. Enormous volumes of gases circulate in all these processes, flowing through powdery materials, and as result these gases are loaded with particles, owing to which the dust must be removed. The use of secondary materials and fuels does not influence the emission of kiln particles, which only depends on the efficiency of the dust removal.

The design and reliability of modern electrostatic precipitators and baghouses ensures that the particles emitted can be reduced to insignificant levels; in some installations emission levels below 10 mg/m³ have even been obtained. The range of particle emissions is normally between 5 and 200 mg/Nm³.

CO₂ emissions

(See also Greenhouse Gases, Section 4.1.2.)

Traditionally, CO₂ emissions have not been considered contaminants. With the signing and ratification by the majority of countries of the MAP and of the Kyoto Protocol, CO₂ emissions have gone on to be counted in these countries as Greenhouse Gases (GGs), and are thus subject to the national legislations and mechanisms implemented in the Kyoto Protocol (trade of emission rights, joint application projects and cleaner development mechanisms).

On a global level, approximately 5 % of anthropogenic emissions of CO₂ are emitted by the activity of the cement industry. Hence, this industry is subject to the use of GG emission rights in many MAP countries.

The sources of CO₂ emissions include the following:

- The calcining of carbonates and the combustion of organic carbon contained in raw materials.
- Combustion of fossil fuels (inside and outside the kiln).
- Combustion of biomass in the kiln (not counted as GG).

Thus, the total emissions of CO₂ depend on the following parameters:

- Type of process (efficiency of the process and sub-process).
- Fuel used.

Clinker/cement ratio.

The emission of carbon dioxide (CO₂) is 900 to 1,000 kg/t of grey clinker, in relation to specific consumption of approximately 3,500 to 5,000 MJ/t of clinker, depending on the type of fuel used. The ratio is lower with regard to tonnes of cement, since other minerals and gypsum are added in the grinding of cement. In the case of white clinker, the ratio is higher due to its greater energy consumption.

In the manufacturing of grey cement by the dry method, approximately 60 % of the CO₂ generated originates from the dissociation of calcium carbonate from the limestone into calcium oxide and CO₂ (called decarbonation or limestone calcining) and the remaining 40 % is produced with the combustion of the fuel. Emissions resulting from combustion are directly proportional to the specific consumption, and to the ratio between the carbon content (C) and the calorific power of the fuel.

Emissions from biomass are not counted as GG (greenhouse gases).

Emissions of CO₂ from the combustion in the cement industry have been reduced progressively over the past 25 years, by around 30%, principally due to the installation of more efficient kilns.

CO emissions

The emission of CO is related with the organic matter content of the raw materials, and with the conditions of the manufacturing process, but it may also come about due to an incomplete combustion when the control of solid fuel feeding is not optimal. Depending on the characteristics of the quarry, between 1.5 and 6.0 g of organic carbon per kilogram of clinker originating from the raw materials is fed into to the process.

Tests carried out with raw materials from various origins have shown that between 85 and 95 % of the organic compounds present in raw materials oxidise completely to CO₂ in the presence of a 3 % oxygen excess; while between 5 and 15 % oxidise partially to CO. With certain raw materials, the CO concentration may, in certain cases, exceed 2,000 mg/Nm³ (Cembureau Report, 1997).

In order to ensure the uniformity of the solid fuel feed rate, the design of the hoppers, conveyor belts and feeders must be optimal. If it is not the case, this may result in sub-stoichiometric combustion which may result in short periods of over 0.5 % of CO. These CO peaks mean that the electrostatic filters are automatically disconnected to avoid the risk of explosion, resulting in an increase in particle emissions.

Emission of Volatile Organic Compounds

In general, the emission of volatile organic compounds (VOC) and carbon monoxide in the combustion processes is often associated with incomplete combustion. Under normal operating conditions, the emission of these compounds in cement kilns is low, due to the long retention time of the gases in the kiln, the high temperature and the conditions of excess oxygen.

Nevertheless, the basic raw materials (such as limestone, marl, clay or slate) may contain above 0.8 % of organic matter (depending on the geological conditions of their deposits). A large part of this organic matter volatilises in the first stages of the burning process (preheating, precalcining), even at moderate temperatures of between 400 and 600 °C, as the raw meal heats up, giving rise to emissions of VOCs.

It has been demonstrated that, in the presence of an oxygen excess of 3 %, between 85 and 95 % of the organic matter contained in raw material is converted into CO₂ in the kiln exhaust gases, and between 5 and 15 % is oxidised to CO. Only a very small proportion—usually under 1% of Total Organic Carbon (TOC)—is emitted as volatile organic compounds (hydrocarbons).

The content of VOCs in cement kiln gases is normally between 10 and 100 mg/Nm³. In some cases VOC emissions up to 500 mg/Nm³ may be reached, owing to the characteristics of the raw materials [Cembureau Report, 1997].

Concentrations of VOCs may increase during start-up operations or in the case of disturbances to the normal operation of the kiln. The frequency with which situations of irregular kiln operation occur is highly variable, from once or twice a week, up to once every two or three months.

Emissions of polychlorinated dibenzodioxins (PCDDs) and dibenzofurans (PCDFs)

The presence of chlorine and organic compounds in the combustion processes may give rise to the formation of dioxins and furans (PCDDs and PCDFs), if they appear, and in turn, to ideal residence time and temperature conditions.

The formation of dioxins and furans occurs by means of synthesis (known as *de novo* synthesis) between 200 and 450 °C due to the reaction of hydrocarbons (precursors) with the chlorine. Thus, it is important that the gases in the kiln system should be cooled rapidly to below 200 °C. In practice, this is what occurs in systems with a preheater, since the raw materials being fed in are heated with the kiln gases. In any case, the presence of chlorine in the kiln combustion gases is limited by the conditions of the process and the quality of the cement.

Under good operational conditions, cement production is rarely a significant source of dioxin and furan emissions. Nevertheless, there would still seem to be a considerable amount of uncertainty with respect to the emissions of PCDD/F [Landesumweltamt Nordrhein-Westfalen, 1997].

The new ratification of the Stockholm Convention on Persistent Organic Compounds (POCs) is an attempt to prevent and reduce the unintentional emission of polychlorinated dibenzodioxins (PCDD), polychlorinated dibenzofurans (PCDF), polychlorinated biphenyls (PCB) and hexachlorobenzene (HCB). Cement kilns burning hazardous waste are explicitly mentioned in the Stockholm Convention (Annex C, Part II), as industrial sources that “have the potential for comparatively high formation and release of these chemicals to the environment”.

Data obtained from a number of kilns show PCDD/PCDF emissions as high as 1.76 ng EQT/m³ when their environmental contamination control devices operate within the range of 200-230 °C. Other tests carried out indicated greater emissions for some kilns in which hazardous waste was burnt.

In a number of studies, a positive correlation has been found between concentrations of PCDD emissions and the temperature of electrostatic precipitator/chimney. In general, the following correlation was observed: the temperature registered in the electrostatic precipitator varied between 255 °C and 400 °C; PCDD emissions were higher at 400 °C, and were 50 times lower at a temperature of 255 °C. At temperatures lower than 250 °C at the intake of the electrostatic precipitator/chimney, there was no correlation between temperature and PCDD emissions [Karstensen, 2004].

More detailed research suggest that –provided combustion is good– the principal control factor is the temperature in the dust collection device of the gas cleaning system. Plants equipped with low temperature electrostatic precipitators appear to have well controlled emissions whether they use waste as a fuel or not [PNUMA, 2003].

Subsequent to the further research that has been carried out, it can be said that cement kilns can indeed comply with emission levels of 0.1 ng EQT/Nm³, which is the limit value in European Legislation for waste incineration and co-incineration plants (Council Directive 94/67/EC and Directive of the Council and the Parliament 2000/76/EC).

At the current moment in time, the cement industry is carrying out follow-up research into this field.

Emissions of metals and their compounds.

Both flows fed into cement kilns, raw materials and fuels, contain metals at various concentrations, depending on their origin. In particular, the use of waste as fuel can vary the input of metals to the process; consequently, it is useful to know the levels of heavy metals in the raw material and fuel flows.

The principal point of metal emission is the kiln system, including the combustion gases in the air from the clinker coolers. The concentration of metal emissions varies greatly, depending on the raw materials, the fuels and the cycles in the kiln system. Particles emitted in these flows contain small quantities of metallic compounds, such as zinc (Zn), cadmium (Cd), mercury (Hg), lead (Pb), Thallium (Tl) and arsenic (As).

Metallic compounds can be classified into three categories, depending on the volatility of the metals and their salts:

- Metals which are non-volatile, or which have non-volatile compounds: Ba, Be, Cr, As, Ni, V, Al, Ti, Mn, Cu, and Ag.
- Metals which are semi-volatile, or which have semi-volatile compounds: Sb, Cd, Pb, Se, Zn, K and Na.
- Metals which are volatile, or which have volatile compounds: Hg and Tl.

The behaviour of these metals in the kiln system depends on the volatility:

- Non-volatile metal compounds remain in the process and leave the kiln as part of the composition of the clinker.
- Semi-volatile metal compounds are partially vaporised in the sintering zone and they condense over the raw materials in the cooler areas of the kiln system (pre-heater). This leads to a cyclical effect within the kiln system (internal cycles) until a balance is reached between the metals fed into the kiln and those leaving with the cement clinker.
- Volatile metal compounds condense over the raw materials at low temperatures and can form both internal and external cycles. Thallium and mercury, and their compounds, volatilise easily, and to a lesser extent cadmium, lead, selenium and their compounds. Internal cycles of metallic compounds are formed, and these react with the raw meal or condense in the cooler areas of the system (precalciner, preheater or in the grinding of raw meal) and are fed back into the sintering zone in solid form, where they volatilise again. External cycles are formed when dust

along with the condensed metallic compounds are separated in the dust removal equipment, and are fed back into the process with the raw meal.

Research into the balance of cycles shows that metals of low and medium volatility have a high degree of retention in the clinker, while those of high volatility (Hg, Tl) show lower levels of retention.

4.1.1.5. Grinding, packaging and shipment of cement

As in the case of raw materials, the operations of grinding, transport, storage and handling (loading and unloading, packaging) of cement are potential sources of particle emission; nevertheless, with the application of good environmental practices and the use of suitable technology they do not constitute a significant problem.

4.1.2. Greenhouse gases

In recent years, the fight against climate change has become the chief environmental matter. The international scientific community believes that there is a link between the carbon dioxide emissions from energy activities (generation of electricity, transport, heating, thermal processes) and the changes in the climate that have been observed over recent decades.

In 1992 the United Nations (UN) established the United Nations Framework Convention on Climate Change, which was signed by over 140 countries. The convention establishes the basic lines of action on an international level, with special emphasis placed on the study of the consequences of climate change and the means of combating it.

The Kyoto protocol of 1997 was established within the setting of the convention, and has become the foremost tool in the international setting in the fight against climatic change, and in which specific quantitative emission reduction objectives are established.

The Kyoto Protocol establishes emissions trading as one of the tools. The European Union has established a market in the European setting for the trading of carbon dioxide emissions rights, and this has been in operation since 2005. This market only affects energy-intensive industrial activities, among which the manufacture of clinker is included.

The emissions market entails a host of challenges for industrial companies. Some, such as emission monitoring, will be solved by dint of significant efforts. Other matters, such as the impact of the aforementioned market on the competitiveness of companies and its contribution to compliance with the Kyoto protocol have yet to be resolved.

At this moment in time, it is difficult to predict what economic impact the establishment of emission trading will have on the industry. What we can be sure of is that installations affected by this market will immediately incorporate procedures and methodologies allowing them to monitor carbon dioxide emissions in their production installations.

Monitoring methodologies must be adapted, as far as possible, to the equipment already installed in factories, entailing small-scale changes (maintenance, calibration of weighing machines, etc.). In certain cases, requirements of precision may force manufacturers to make modifications to equipment and procedures. In any case, the precise, economical and swift monitoring of CO₂ emissions has become an obligation for those cement factories affected by the Kyoto Protocol.

We now go on to give a brief description of the greenhouse effect and climatic change, the basic aspects of the emissions market, what new demands it places on cement businesses and factories, and how these will monitor their CO₂ emissions.

4.1.2.1. The Greenhouse Effect and Climatic Change

Widely accepted in the scientific community is the theory that the climate change observed on the Earth in recent decades is being brought about by the increase of 'greenhouse gases' in the atmosphere. The most important of these are steam, carbon dioxide and methane.

One of the properties of Greenhouse gases is that of capturing the infrared radiation emitted by the earth's surface, heated by the effect of solar radiation. Thanks to this natural phenomenon the temperature conditions in the troposphere (the lower part of the atmosphere) are suited to the profusion of life on earth, including human beings.

The increase in the concentration of greenhouse gases brought about by human activities (fossil fuels, agriculture, livestock farming) has upset the balance between the solar radiation reaching the Earth and that which the Earth emits back into space. In short, it could be said that the increased concentration of greenhouse gases means that the Earth is emitting less energy to space and, hence, the quantity of energy present in the atmosphere is rising. This is leading to increased temperatures in the atmosphere and the oceans, which in turn is affecting rainfall systems, the development of forests and the environment as a whole.

For all these reasons, through the application of a precautionary principle, the international community decided to take action in the form of research and the fight against climate change.

4.1.2.2. United Nations Framework Convention on Climate Change

The United Nations (UN) promoted negotiations for and the signing of the United Nations Framework Convention on Climate Change in 1992, the result of a number of resolutions made by the United Nations General Assembly, which at the end of the 1980s argued for the need to act jointly in order to study and mitigate climate change and its consequences, through the application of precautionary principles, and taking into account the significant levels of uncertainty summarised in the previous section.

Close to 150 countries from all over the world, and with very different economic and social levels, have ratified the Convention, whose basic objective is the "stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system".

The basic lines of the Convention are the following:

- The study of climate change and its effects on nature. In this sense, great importance is given to the preparation of national emissions inventories, the monitoring and observation of climatological data, and international operation in this matter.
- Developed countries assume their responsibility for historic emissions of greenhouse gases and, thus, the need for them to lead and promote the fight against climatic change.
- The provision of technical, human and financial resources is fundamental. In this sense, poorer countries must obtain resources which will allow them to contribute to the fight against climate change, without renouncing in any way their legitimate aspirations of sustained economic growth and welfare, with explicit mention being made of the "eradication of poverty". The provision of financial resources to international organisations (e.g. World Development Bank) and the transfer of technology to matters which are repeatedly referred to in the Convention.

The fight against climate change must be compatible with economic growth, which must be sustainable in terms of the rational, efficient use of natural and energy resources.

As an instrument for acting in the fight against global warming, the Convention establishes the passing of Protocols to be developed by the Convention.

4.1.2.3. The Kyoto Protocol

The 1997 Kyoto protocol takes its name from the Japanese city in which the conference of the Parties signing the Convention took place that year.

The Kyoto protocol establishes an international distribution of greenhouse gas emission reductions for 38 countries, with the objective of reducing the joint emissions of those countries by at least 5%, with regard to 1990 emissions, during the period of commitment, from 2008 to 2012. It establishes that compliance must be accredited throughout the period 2008- 2012 as an average of the emissions over that five-year period.

Table 4.1.3 shows that the majority of countries in the Mediterranean Action Plan have ratified the Kyoto Protocol:

Table 4.1.3. The Kyoto Protocol in the MAP countries.

Situation of the Protocol in the MAP countries		
	Ratified	Not ratified (as of November 2005)
SOUTH	Algeria	Lebanon
	Egypt	Libya
	Morocco	Syria
	Tunisia	
NORTH	Spain	Monaco
	France	
	Greece	
	Italy	
EAST	Albania	Bosnia and Herzegovina
	Cyprus	Croatia
	Slovenia	Serbia and Montenegro
	Israel	
	Malta	
	Turkey	

A total of six greenhouse gases are contemplated in the Kyoto protocol:

- Carbon dioxide (CO₂).
- Methane (CH₄).
- Nitrous oxide (N₂O).
- Hydrofluorocarbons (HFC).
- Perfluorocarbons (PFC).
- Sulphur hexafluoride (SO₂).

Of these, a predominant role is played by carbon dioxide (CO₂), which is principally generated in combustion processes (power stations, boilers, vehicles, heating, etc.); and methane (CH₄), which originates from the decomposition of organic matter (fermentation in urban waste landfills, livestock farming, etc.).

Gas sinks (for example, reforestation), international emissions trading and flexible mechanisms are options that are expressed in the protocol with which the signatories may comply with their commitments, without having to do so exclusively on the basis of efforts carried out in their own countries. Apart from being necessary, this flexibility is totally coherent with the nature of the environmental problem we are faced with. This is a worldwide matter and, although the effects of climate change vary from one part of the planet to the other, it is not important in which parts of the globe emissions are produced—the atmosphere as a whole is affected.

Among those contemplated in the Protocol, the option which appears to offer the most potential is the Clean Development Mechanism. In short, this consists of one country signatory to the Protocol investing in another developing country, and the reductions in greenhouse gas emissions deriving from this investment are counted as having been made in the investing country. Investments may be made by companies or governmental organisations, and can be carried out directly or through 'carbon funds' established by bodies such as the World Bank. This mechanism acts as a stimulus for investment in developing countries, which is one of the most positive results in terms of international cooperation that may be derived from the Kyoto protocol, and is thus meritorious of promotion by both public administrations and companies.

Worthy of special attention are forestry policies, as besides supplying sinks for discounting emissions, they also allow the recovery of natural spaces and the promotion of rural economies. There are currently problems and limitations for this path, which in the future will need to be overcome in order to make a relevant contribution to the fight against climate change.

The Kyoto Protocol is a firm commitment towards:

- Improving energy efficiency in production processes.
- Energy efficiency in motor transport and heating, which account for the greater part of global emissions.
- The establishment of international cooperation mechanisms for combating climate change whilst supporting the economic and social development of less favoured countries.
- Emissions sinks and deposits (reforestation, agricultural policies, etc.).
- Research and development into ways of generating and transforming energy (the role of renewable energies, expectation of nuclear fusion, natural gas, hydrogen, etc.).

The challenge posed by global warming must be transformed into an opportunity for innovation, investment and ingenuity and, consequently, for the economies.

The Kyoto protocol in the cement industry

The cement industry is one of the sectors most affected, since it is one of the principal sources of CO₂ emissions, which is aggravated by the construction of motorways, roads and other infrastructures. Each tonne of cement consumed leads to the emission of 498 kg of CO₂.

More specifically, the world cement industry generates around 5% of greenhouse gas emissions, which originate, on one hand, from the consumption of fuel (40%) and, on the other, from the cement manufacturing process, due to the decarbonation of raw materials (60%), where the CO₂ originates from the chemical reaction produced within the kiln.

Table 4.1.4 shows both cement production and the tonnes of CO₂ produced by the decarbonation of clinker in the PAM countries for 2002.

Table 4.1.4. Production of cement and tonnes of CO₂ emitted by the decarbonation of raw materials, in 2002.

	Clinker production, kt year 2002	kt CO ₂ by the decarbonation of clinker, year 2002
Albania	190	25
Algeria	8,900	4,488
Bosnia	850	150
Croatia	3,300	1,684
Cyprus	1,790	798
Egypt	28,500	11,469
France	19,437	9,973
Greece	14,680	7,729
Israel	4,582	3,491
Italy	41,400	19,947
Lebanon	3,200	1,422
Libya	3,320	1,496
Malta	0	0
Monaco	0	0
Morocco	8,800	5,086
Serbia and Montenegro	2,485	1,195
Slovenia	1,180	626
Spain	42,420	21,193
Syria	5,010	2,443
Tunisia	5,550	3,003
Turkey	32,758	16,243

Source: CDIAC

In this context, the cement industry is searching for new ways to improve its energy efficiency, carrying out improvements in its installations to optimise energy efficiency and to develop processes and products which require less energy; moreover, it is studying other possible alternatives for reducing CO₂ emissions.

To this end, kilns and cooling systems have been modified, alternative fuels have been searched for, and additional minerals have been used which, ground along with clinker, resulting in cements with similar or enhanced performance, thus reducing the manufacture of clinker. All these improvements reduce the specific emissions of cement manufacture in terms of energy consumed and product.

4.1.3. Noises and vibrations

Under certain circumstances, such as proximity to the plant, or the quarry, to population centres or areas of natural interest, noise may be a significant environmental aspect in this industrial sector.

The noise generated by industrial activities in cement production mainly arise from the operation of machinery, and from blasting in quarries (in the case of integrated factories). Mechanical equipment (mills, chain conveyors, planetary coolers, etc.) generate noise as a consequence of the friction and

collisions between solid materials. Ventilators, compressors and gas ducts generate noise through the friction of gases with the walls of the tubes, with the blades of fans, and through the friction of gases at different speeds (blowers and air exhausters, pneumatic transport, etc.).

Technically, the possible solutions or measures to be taken to reduce the noise emissions of industrial and the efficiency depend basically on the following factors:

- Type of noise emission source.
- Intensity of noise.
- Frequency of sound: low/high pitch.
- Location of equipment and availability of space.

There are three ways of combating noise emissions:

- Actions at the source.
- Actions on the transmitting medium.
- Actions on the receiver.

The measures that are habitually adopted on industrial level include enclosures, acoustic barriers, the covering of conveyor belts, the fitting of soundproofing material and silencers. The most habitual method for combating noise generated by mills and compressors is the installation of enclosures soundproofed with insulating and/or absorbent material, which reduces the transmission to the exterior of high levels of noise intensity produced by these types of installations. The action taken with fans is the installation of silencers.

4.1.4. Odours

The omission of foul odours will depend basically on a high content of sulphur in raw materials and fuels, but is generally not considered to be a significant impact.

4.2. SOURCES OF THE GENERATION OF LIQUID DISCHARGES AND THEIR CONTROL

There are three types of waters deriving from this activity: waste waters, which include sanitary water, water from the cleaning of installations and ordinary services (laboratory); refrigeration water generated when draining the closed-circuit system (which may include regeneration water from the ionic exchange equipment or discharge from reverse osmosis); and rainwater, collected in a network of independent drains.

Any water generated during the cement manufacturing process that is not evaporated in the kiln is recycled back into the process. The filtering water originating from the filter press in the semi-wet process is collected and treated by means of physicochemical methods prior to its discharge to the receiving medium.

In general, discharge waters from this activity do not have a significant effect on the environment, although the specific characteristics of the recipient water medium must always be taken into account.

4.3. SOURCES OF THE GENERATION OF SOLID WASTE AND THEIR CONTROL

The waste generated during the manufacture of clinker consists basically of:

- Materials not conforming with specifications, which are rejected from raw materials during the preparation of the raw meal.
- Articles originating from the bypass or the filter, which cannot be fed back into to the process.

Besides the waste characteristically associated to the clinker and cement manufacturing process, small quantities of waste from the operation and maintenance of mechanical equipment are generated:

- Used oils and lubrication greases.
- Dielectric liquids from electric transformers.
- Other liquids.

4.4. ENERGY CONSUMPTION

The cement industry, along with the paper, steel and petrochemical industries, is characterised as being energy intensive. In the production of Portland cement, energy costs account for between 20 and 30 % of the total cost. A reduction in energy costs has an immediate impact in terms of economic and environmental benefits, due to which the optimisation of energy consumption is a priority objective in the cement industry.

An increase in energy efficiency always entails a reduction of all emissions associated with the combustion process (NO_x, SO₂, CO₂, CO and heavy metals). Nevertheless, the reduction of these emissions should not be considered proportional to the reduction in energy consumption, given that they may also depend on raw materials and associated processes.

With regard to CO₂ emissions, more than half of the emissions associated to cement production are the result of the decarbonation of calcic raw materials, and are thus independent of the combustion process. If zero-emission fuels (such as bio-fuels) are used for the heating process, CO₂ emissions may be reduced by up to 54%.

4.4.1. Principal energy consumers in the cement manufacturing process

4.4.1.1. Extraction of raw materials

The principal raw materials in the cement industry are limestone and clay. The principal raw material (limestone) is generally extracted from a mine working that is either adjacent or very close to the plant.

The material extracted is selected, crushed, milled and mixed to obtain the suitable granulometry and chemical composition for the thermal process in the clinker kiln. This entire process consumes around 8.8 kWh/t of raw material, where 80 % of the energy is consumed in the extraction process, and the remaining 12 % in the crushing process. It should be mentioned that at least 1.5 to 1.75 t of raw material are required for each tonne of cement.

4.4.1.2. Preparation of raw materials

Once the mineral has been mixed, in the correct proportions, with corrective additives and/or some type of industrial waste, it is then ground. This grinding may be wet or dry, depending on the type of kiln in the plant.

The grinding and preparation of raw material consumes between 25 and 35 kWh/t, depending on the type of grinding; electricity consumption is lower for wet grinding with respect to dry grinding. It is not easy to evaluate the efficiency of the grinding processes, as it is extremely difficult to estimate how much work is required to reach a given granulometry. This efficiency is situated between 6 % and 25 %; as this is the consumption of electrical energy, an increase in the efficiency of the process will result in a reduction in the losses associated to transmission lines and the generation of electricity.

One of the aspects to be taken into account with regard to the preparation of raw materials to be fed into the kiln is their humidity content. As has already been mentioned in Section 4, *Description of the processes*, when the raw material contains over 20 % of water, the wet process is preferable. Although

the wet process reduces dust emissions, it requires additional thermal energy to subsequently eliminate the water from the raw material. In general, the slurry fed into a wet-process kiln has a water content of 36%, whilst for the semi-wet process, this content varies between 17 % and 22 %, translating into savings in thermal energy in the production of clinker.

4.4.1.3. Clinker production

Clinker production is the most energy intensive process, accounting for over 90 % of the total consumption of the cement industry. In this stage, heat energy is used for the following:

- Heating of raw materials.
- Evaporation of free humidity.
- Calcining of carbonated components
- The clinkering process.

The consumption of thermal energy is highly dependent on the type of process that is used to manufacture the clinker; more specifically, on the percentage of humidity, and in general terms, we have to distinguish between the dry and wet processes.

Wet process

In a wet rotary kiln, the feed usually contains 36 % of water. These kilns were developed as an alternative to long dry kilns to improve control over the degree of fineness of the raw feed meal. The energy consumption of this type of kiln varies between 5.3 GJ/t of clinker and 7.1 GJ/t of clinker (thermal efficiency of 31 - 25 %). This range is due to the variability in the water content of raw feed meal and the energy required for its evaporation.

Dry process

In a dry kiln the water content of the raw feed meal is 0.5 %, and thus the energy requirements for evaporating the water are reduced along with the length of the rotary kiln. The typical consumption for a kiln with 4/5 preheating cyclone stages varies between 3.2 GJ/t and 3.5 GJ/t clinker (efficiency of 55-50 %), while a kiln with six preheating stages theoretically consumes 2.9-3.0 GJ/t of clinker. The most efficient kilns with precalciner and preheater use 2.9 GJ/t of clinker in the process, reaching a thermal efficiency of 60 %.

4.4.1.4. Cement grinding

Energy consumption depends on the surface area required for the product (fineness) and the additives used. The consumption of electrical energy required in the finish grinding stage is highly dependent on the hardness of the raw material (limestone, clinker, pozzolan, etc.) and the fineness of the final product required, as well as the quantity of the additives used. Blast-furnace ash is a hard material which requires more energy in grinding; between 50 and 70 kWh/t of material for 3,500 Blaine (cm²/g).

Traditionally, of those mills described in point 3.2.5, the ball mill is the most commonly used for this type of milling. Modern ball mills use between 32 and 37 kWh/t to reach a fineness of 3.500 Blaine (cm²/g).

4.4.1.5. Shipment

In this stage, additional energy is used in the conveyor belts and in the packing system. This consumption is usually low and does not exceed 5% of the total energy consumption in cement production.

Estimated energy costs for ordinary systems is estimated at around 10 kWh/t of clinker.

4.4.1.6. Summary table

We now go on to give the characteristics and energy consumption ranges in the cement manufacturing process for the wet, semi-wet, semi-dry, long dry, SP (Suspension Preheater) and NSP (New Suspension Preheater) processes.

A more specific break-down of energy consumption on the basis of the technology used (wet, SP and NSP) is given in the following table:

Table 4.4.1. Characteristics and energy consumption according to type of process.

	Wet	Semi-wet	Semi-dry	Long dry	SP	NSP
Specific heat consumption [GJ/t]	5.0-7.5	3.4-4	3.2-3.9	3.6-4.5	3.1-3.5	3.1-3.2
Specific electrical consumption [MWh/t]	0.025	0.03	0.03	0.025	0.022	0.022
Kiln capacity [t/d]	300-3,600	300-5,000	300-2,000	300-2,800	300-4,000	2000-13,000
Feed meal	Slurry	Filter cake	Pelletised raw material	Dry raw material	Dry raw material	Dry raw material
Percentage of humidity [%]	28-43	16-21	10-12	0.5-1.0	0.5-1.0	0.5-1.0
Type of kiln	Long	Long/Lepol	Long/Lepol	Long	Short	Short
Heat exchange devices	-	Cyclones/Grate preheater	Cyclones/Grate preheater	-	Suspension preheaters	Suspension preheaters

Source: *Ipts, 2003*

Tabla 4.4.2. Summary table of consumption in GJ/t_{cli}.

CONSUMER	TYPE OF PROCESS					
	WET		DRY –(SP)		DRY – (NSP)	
	GJ/t cli	%	GJ/t cli	%	GJ/t cli	%
Theoretical (%=thermal efficiency over kilning)	1.78	30.5	1.83	36.6	1.76	49.9
Loss of exhaust gases	0.75	12.1	1.38	27.7	0.50	14.1
Evaporation of the mix	2.24	35.9	0.30	6.0	0.24	6.7
Dust in exhaust gases	0.01	0.2	0.01	0.3	0.00	0.0
Discharge of clinker	0.06	0.9	0.06	1.2	0.07	1.9
Exhaust gases, clinker cooling	0.19	3.0	0.59	11.8	0.61	17.4
Losses to kiln wall	0.68	10.9	0.61	12.2	0.18	5.0
Various consumptions	0.09	1.4	0.19	3.8	0.17	4.9
TOTAL CONSUMPTION OF KILN	5.84	93.7	4.99	92.7	3.53	90.0
Extraction of raw materials	0.03	0.5	0.03	0.6	0.03	0.8
Preparation/grinding of raw materials	0.11	1.7	0.11	2.0	0.11	2.8
Cement grinding	0.22	3.5	0.22	4.0	0.22	5.5
Shipment	0.04	0.6	0.04	0.7	0.04	0.9
TOTAL CONSUMPTION OF PLANT	6.23	100.0%	5.38	100.0%	3.92	100.0%

Source: The Rotary Cement Kiln, Chemical Publishing Co., Inc.; CEMBUREAU et al.

(SF: Suspension Furnace / PC: Precliner)

4.5. WATER CONSUMPTION

Depending on the production process, the cement industry can be characterised as being a large consumer of water—this is true of the wet or semi-wet processes. Nevertheless, the characteristics of these processes implies practically no generation of liquid discharge.

In cement factories 0.6 m³ of water are required per tonne of cement for the cooling of the machinery. The majority of this water is usually in circulation, due to which it is only necessary to replace any losses.

Apart from the use of water for cooling machines, in wet or semi-wet processes there is a high consumption of water in the raw material grinding stage, as water is added to form a slurry to be fed into the kiln. The addition of water is normally between 400 and 600 L of water per tonne of dry material, in the case of grinding in ball mills, and between 500 and 800 L per tonne of dry material for the grinding of raw materials in wash mills.

Given that the higher the concentration of water in the slurry, the more energy is required in the kiln, this consumption must be reduced, so that it should be the minimum possible to obtain the flow needed and the characteristics required of the slurry for pumping.

As can be seen in Table 4.5.1., the semi-wet process offers a reduction of 60 % in water consumption as opposed to the wet process; nevertheless, it requires an average supply of 0.26 m³ of water per tonne of clinker.

Table 4.5.1. Water consumption depending on type of kiln.

TYPE OF KILN	WATER CONSUMPTION (m ³ /t of clinker)	REMARKS
Long wet process	0.65 – 0.85	To increase the fluidity of the slurry
Semi-wet and semi-dry process	0.17 – 0.35	
Dry process	None	

Source: Cembureau

4.6. USE OF INDUSTRIAL WASTE AS RAW MATERIAL OR FUEL

Since the mid-1980s alternative raw materials and fuels derived from industrial processes have been used in the cement industry.

The efficient use of alternative raw materials and fuels, as well as the mineral additives in cement plants, can result in a good number of environmental and social economic advantages (see 4.6.1. *Environmental advantages* and 4.6.2. *Socio-economic benefits*); hence, cement kilns play an important role, both economically and ecologically, in recycling and recovery programmes.

4.6.1. Environmental benefits

Conservation of the natural setting

Cement kilns make use of both the calorific and mineral contents of alternative materials. Fossil fuels, such as coal or crude oil, are replaced by other materials, which if not used in the cement production process, would be sent to landfill or incinerated.

The mineral part of alternative fuels (ashes) as well as non-combustible industrial waste, or by-products, may partly substitute natural raw material (limestone, clay, etc.). Practically all the components of these materials are fed into the product and, with few exceptions, generate no waste.

The use of mineral additives originating from other industrial processes as substitutes for clinker reduces both consumption of natural resources of raw materials, as well as energy resources, given that the intense consumption of energy required for the production of clinker is reduced.

Protection of the atmosphere

Considering the special characteristics of the burning process, emissions from the cement kiln do not depend on the characteristics of fuels. The use of industrial waste as fuels in cement plants eliminates the corresponding emissions from the incinerator plants and landfills, and makes it possible to avoid generating new emissions.

Protection of surface waters and subsoil

Due to the use of industrial waste as fuels in the cement process, this residue is not taken to landfills; hence, the generation of liquid effluents and contaminating gases in landfills is avoided, thus reducing the risk of contamination.

Reduction of greenhouse gases

By substituting fossil fuels with alternative (renewable) fuels, there is a decrease in the total emissions of CO₂ of a thermal origin (CO₂ neutrality). In a cement plant with an annual production of one million tonnes of clinker, a thermal substitution ratio of 40% reduces the net generation of CO₂ by some 100,000 tonnes.

Even more important is the substitution of clinker by mineral additives; this reduces both the formation of CO₂ from the combustion of fossil fuels, and the CO₂ generated from the decarbonation of raw material.

Moreover, the use of alternative raw materials and fuels, as well as mineral additives, contributes significantly to the world programme for the reduction of greenhouse gases.

Generation of electricity

Through the suitable use of waste, cement kilns contribute to the supply of electrical or heat energy, reducing the consumption of natural resources and reducing the total emissions of CO₂.

4.6.2. Social economic benefits

Reduction of controlled waste deposit taxes

Cement plants benefit economically from the use of industrial waste, given that not only do they save on the cost of the substituted raw material, but they also receive payment for its management, offering a competitive price at a lower cost than that required for its dumping in landfills, or for its treatment in specialised incinerators. Moreover, the public investment required for the installation of incinerator plants is reduced.

Reduction of land requirements

Through the integration of cement kilns into national waste management programs, the need for additional land for landfills is reduced.

Investment in Cleaner Technologies

The replacement materials originating from waste flows generally reduce the cost of cement production, strengthening the position of the industry, particularly in relation to imports from countries with less restrictive environmental legislations. This also facilitates the development in the industry of cleaner technologies for atmospheric emissions.

5. OPPORTUNITIES FOR PREVENTING AND REDUCING CONTAMINATION

The aim of this chapter is to provide technicians and managers in the industries in the cement sector with an opportunity to reflect on their own processes and alternative technologies which are more respectful of the environment, as well as to supply a guide to the competent authorities for establishing specific policies for promoting environmental improvements.

With this in mind, this chapter covers the information available on the alternative technologies for the at-source prevention and reduction of contamination in the cement industry for the countries of the Mediterranean Action Plan. The scheme we have followed to do so has been to carry out an analysis of the different techniques which may have a bearing on the reduction of emissions and energy consumption during the manufacture of cement, and more specifically, on the levels of reduction that can be expected with the application of the technique, the applicability thereof, and the investment and operating costs, as well as any negative aspect found during their operation on an industrial scale.

The technological alternatives proposed range from the modification of traditional production systems—by proposing in some cases alternative systems to determined production processes or individual operations—to alternatives for controlling the final emissions of these installations. Similarly, the technological alternatives proposed herein are supplemented with other measures of a general nature based on good practices and the motivation of staff, which, in conjunction, may help in the optimisation of each industrial installation.

The alternatives have been classified in the following manner:

- Technological alternatives of a general nature.
- Technological alternatives for the correct management of energy.
- Technological alternatives for the control of NO_x emissions.
- Technological alternatives for the control of SO₂ emissions.
- Technological alternatives for the control of particle emissions.
- Technological alternatives for the control of VOCs.
- Technological alternatives for the control of PCDD/F.
- Technological alternatives for the control of metal emissions.
- Technological alternatives for the control of CO₂ emissions.
- Technological alternatives for the control of odours.
- Technological alternatives for the control of noise.
- Technological alternatives for the control of vibrations.
- Technological alternatives for the control of waste.
- Emerging techniques.

All these alternatives are defined, and some of them are presented in the form of Files (due to them being important alternatives worthy of mention, see 5.1.1. *Theoretical Specifications*), giving, as far as possible, both a detailed description thereof, and the environmental and economic benefits of its

implementation, as well as its investment cost in new and existing plants. The alternatives presented herein are not exclusive, nor are they the only ones possible; rather factories generally adopt various measures simultaneously, as is described in the practical cases.

The economic data presented herein have been taken from the BREF (Reference Document on Best Available Techniques in the Lime and Cement Manufacturing Industries, 2000), from the BAT document (Best Available Techniques, Cembureau 1997) and “The Impact of Best Available techniques (BAT) on the Competitiveness of the European Cement Industry”, 2001. These data are merely indicative, and are presented by way of reference to the order of magnitude of the different alternatives, being expressed normally in millions of euros (€ M.). Investment costs do not include any additional costs for equipment or any civil construction required to implement the measure.

It should be borne in mind that the application of these measures in a new plant presents totally different aspects to their application in existing plants. Moreover, the application of these techniques is highly conditioned by local aspects that are characteristic of each individual factory, due to which the information supplied in this chapter should not be considered applicable to each and every manufacturing installation, neither with regard to the practical possibility of applying the techniques, nor to the emission levels associated.

Also considered as new plants are those which undertake improvements at high cost, such as, for example, considerable increases in capacity and/or making changes to the processes. On the contrary, those plants carrying out limited investment, such as the modernisation of areas or limited equipment, are considered as refurbishments, in the same category as existing plants.

THEORETICAL SPECIFICATIONS	
Action	Action: Prevention at source (substitution of raw materials, technological changes, Good Environmental Practices) or end-of-pipe treatment.
Stage of the process	Stage or operation in which the Alternative is applied. The following stages can be differentiated in the cement manufacturing process: obtaining raw materials, preparation and storage of raw materials, burning of clinker, grinding and storage of cement, shipment.
Environmental problems	The important drawbacks regarding the environment which are carried out with the original production process, these are minimised or reduced with the application of the Alternative.
Environmental benefits of the Alternative	Principal advantages that are obtained with the application of the Alternative.
Description	Scientific and technological bases upon which the alternative is based, and a description of its operation.
Procedure	Description of the most frequent applications used for the integration of the Alternative into the production process.
Comments	Additional information to complement the above sections.
Economic Aspects	Wherever possible, economic guidance is given regarding the costs of implementation and operation of the Alternatives. The data presented herein have been taken from the reference document: BREF, Reference Document on Best Available Techniques in Cement Industry (2001).

5.1. TECHNOLOGICAL ALTERNATIVES OF A GENERAL NATURE

As well as the proximity of the production plant, as far as possible, to the extraction plant to avoid any environmental impacts associated with the transport of raw materials (energy consumption, vehicle emissions, various particle emissions to the atmosphere and noise), there are a number of other technological alternatives available for the manufacture of cement which include a series of general primary measures:

- **Optimisation of process control.** Through the use of automatic control systems, expert systems, etc., a stable, uniform process is obtained, with operation close to the optimal levels for the process parameters, which is beneficial for all the emissions from the kiln as well as for energy consumption.
- **Control of the substances fed into the process** and which, depending on where they enter and how they are processed, may have a direct or indirect effect on the emissions of the kiln (sulphur and volatile organic compounds in raw material, heavy metals, chlorine compounds).
- **Reduction in the consumption of resources.** Maximum exploitation of the materials that are used in cement manufacturing reduces the total consumption of raw materials. For example, the dust collected in the clinker kiln filter may be fed back into the process. The use of waste suitable for substituting raw materials reduces the consumption of natural materials, but it should always be carried out with the proper control of substances introduced in the kiln.
- **Reduction of the clinker/cement ratio.** One technique for reducing energy consumption and emissions in the cement industry, expressed on the basis of the unit of cement produced, is the reduction of clinker content. Everything which involves reducing the proportion of clinker—for the manufacture of which materials must be sintered in a rotary kiln at temperatures around 1,450°C—constitutes a reduction in the total emissions per unit of cement manufactured.

Alternative	5.1.1. OPTIMISATION OF PROCESS CONTROL
Action	Action: Prevention of contamination at source. Good Environmental Practices.
Stage of the process	Cement production process.
Environmental problems	Generation of atmospheric emissions and energy consumption.
Environmental benefits of the Alternative	<p>The principal benefits of the application of this alternative are:</p> <ul style="list-style-type: none"> • Reduction in fuel consumption. • Reduction in energy consumption. • Reduction of atmospheric emissions (particles, NO_x, SO₂, CO, etc.).
Description	<p>The optimisation of the cement production process implies controlling the flow of materials to the production system. The results supplied by the laboratory, from periodical analyses at various points of production process, supply the information necessary for the adjustment of the key points in the plant and control systems.</p> <p>The degree of automation varies between total automation option (in the treatment of the sample, to its analysis, including the adjustment of the production process parameters) and partial automation in the laboratory setting.</p> <p>The need for analytical reproducibility and precision, along with the increasing efficiency of laboratories, has led to an investment into automated laboratories supplying data with high-quality information on raw materials, fuel, the process and final product.</p>

	<p>The optimisation of the clinkering process is normally carried out with the aim of reducing the specific consumption of fuel, and of increasing the quality of the clinker and prolonging the service life of equipment (e.g. the refractory coating).</p> <p>The reduction of emissions, such as particles of NO_x and SO₂, is a by-product of this optimisation. The smooth, stable operation of the kiln, with the process parameters close to its design values, is beneficial during the operation of the kiln, and generates fewer emissions.</p> <p>Optimisation includes measures such as:</p> <ul style="list-style-type: none"> • The homogenisation of raw materials. • Safety with the uniform metering of fuel. • The optimisation of the cooler operation. <p>Similarly, in order to ensure that the solid fuel feed rate is uniform, with minimal peaks, optimal designs for hoppers, conveyor belts and feeders, as well as a modern solid-fuel gravity-feed system, are essential.</p>
<p>Procedure</p>	<p>The reduction of the flame temperature, the reduction in the use of fuel and the formation of reducing atmosphere zones in the kiln all lead to lower emissions of NO_x. The control of the oxygen content is critical for limiting the levels of NO_x. Generally, the lower the oxygen content at the outlet end of a kiln, the less NO_x is produced. Nevertheless, a balance must be sought between the generation of NO_x and the generation of CO and SO₂, given that the lower the percentage of oxygen, the more CO and SO₂ is produced.</p> <p>By applying process control optimisation techniques, reductions in NO_x of up to 30 % have been recorded. Nevertheless, the experience of applying process optimisation systems indicates that the reduction in NO_x emissions is much more modest, and not quantifiable <i>a priori</i>, as it depends on initial emissions along with many other factors.</p> <p>The reduction of SO₂ emission is brought about by the decrease in its volatility at lower flame and combustion temperatures, and by the oxidising atmosphere in the kiln, along with its stable operation. The positive effect of process control on SO₂ emissions is marginal for kilns with preheaters, although it is substantial for long (dry and wet) kilns, where reductions in SO₂ emissions of up to 50 % have been recorded [Cembureau, 1997].</p> <p>In kilns with electrostatic precipitators, particle emissions are reduced and, in this way, the emissions of any substance absorbed by these particles, such as metals, will also be reduced.</p>
<p>Comments</p>	<p>The optimisation of the kiln operation can be applied to all types of kilns, and includes a great many factors, from the training of kiln operators to the installation of new equipment, such as metering systems, homogenisation silos, pre-mixing beds or modifications to the clinker cooler.</p>
<p>Economic Aspects</p>	<p>The cost of these measures is, thus, highly variable, ranging from € 0 to € 5 million [Cembureau, 1997]. The effectiveness of these measures is also highly variable, depending on each installation, on the initial level of emissions, and on numerous other factors.</p> <p>Various suppliers of equipment for the cement industry have developed expert control systems based generally on combustion control, taking NO_x levels as a reference. The investment required for a high-level computerised control system is in the region of € 300,000; additional investment may be necessary to install the metering and measuring systems required in the plant [Cembureau, 1997].</p>

Alternative	5.1.2. ADAPTATION AND CONTROL OF THE SUBSTANCES FED INTO THE PROCESS
Action	Action: prevention of contamination at source. Good Environmental Practices and/or substitution of raw materials.
Stage of the process	Cement production process.
Environmental problems	Generation of atmospheric emissions.
Environmental benefits of the Alternative	Reduction in the generation of atmospheric emissions.
Description	Selection and control of the substances fed into the process as raw materials and fuel.
Procedure	Certain fuels and raw material may have high levels of nitrogen, sulphur, heavy metals or organic compounds which affect the emission of NO _x , SO ₂ , heavy metals or VOCs, respectively. Through the application of this technique, the generation of these emissions can be avoided by selecting suitable raw materials and fuels.
Comments	The physical state of fuels also affects the generation of NO _x . Thus, for example, liquid fuels can be controlled more easily, and tend to generate lower emissions of NO _x than solid fuels, owing to the reduction in hot-zone formation. In the case of solid fuels, the evolution of thermal NO _x would seem to be related to the granulometry, so that the lower the granulometry is, the lower NO _x emissions will be; once again, this is probably related with the formation of hot zones. Hence, it is important to control the granulometry of the fuel.
Economic Aspects	No estimate can be made of the economic cost, as it depends to a great extent on the raw materials and fuel markets.

Alternative	5.1.3. REDUCTION IN THE CONSUMPTION OF NATURAL RESOURCES (RAW MATERIALS)
Action	Action: prevention of contamination at source. Good Environmental Practices, substitution of raw materials.
Stage of the process	Cement production process.
Environmental problems	Consumption of natural resources, environmental impact due to the depositing of industrial waste in landfill.
Environmental benefits of the Alternative	Reduction of natural resource consumption. Eliminates the visual impact generated by dumping waste in landfills.
Description	Maximum exploitation of the materials used in the manufacture of cement, as well as the use of waste from other industrial processes as substitutes, reduces the total consumption of raw materials.

<p>Procedure</p>	<p>The cement industry uses certain types of waste and mineral by-products with similar compositions to its raw materials, which may even improve the performance of cements. Given the enormous quantities of raw materials processed by the sector, this recycling results in enormous savings in natural resources, and avoids the discharge of large amounts of reusable materials.</p> <p>The use of waste and mineral by-products as material in the cement production process supplies the following benefits for the environment:</p> <ul style="list-style-type: none"> • It reduces quarry workings, replacing natural resources with waste. • It avoids the use of landfills and their associated impact. <p>Another example of taking advantage of by-products is the use of dust collected in the clinker kiln filter, by re-feeding it into the raw meal grinding process.</p>
<p>Comments</p>	<p>Those materials that are suitable for use as raw materials may be by-products of other industrial processes, such as:</p> <ul style="list-style-type: none"> • Pyrite cinders, due to their high iron content. • Blast-furnace slag • Paper mill sludge, due to due to its high calcium carbonate content. • Foundry sand, due to due to its high silicon oxide content. • Demolition waste, of a calcic or siliceous nature. <p>The use of waste fit for substituting raw materials reduces the consumption of natural materials, but it should always be with the proper control of all substances fed into the kiln.</p>
<p>Economic Aspects</p>	<p>Cement plants charge for waste management. By saving on the cost the raw materials substituted, they can offer competitive prices with regard to dumping in landfill or treatment and specialised incinerators. Nevertheless, lower landfill prices have been detected within the Mediterranean Arc, which means that no waste management technology can compete with landfills, and thus the waste management hierarchy is not complied with.</p>

<p>Alternative</p>	<p>5.1.4. REDUCTION OF THE CLINKER/CEMENT RATIO.</p>
<p>Action</p>	<p>Action: Prevention of contamination at source. Good Environmental Practices.</p>
<p>Stage of the process</p>	<p>Cement grinding.</p>
<p>Environmental problems</p>	<p>Generation of atmospheric emissions and energy consumption.</p>
<p>Environmental benefits of the Alternative</p>	<p>Reduction in energy consumption and the generation of atmospheric emissions. Eliminates the visual impact generated by dumping waste in landfills.</p>
<p>Description</p>	<p>This technique makes it possible to reduce energy consumption and emissions in the cement industry, expressed in terms of unit of cement produced, through the reduction of clinker content per tonne of cement.</p>

Procedure	<p>Certain materials are suitable for use as components in cement grinding (as additives to the clinker) since they improve its properties, such as workability, water retention, durability, mechanical resistance, sulphate resistance, cold resistance, etc.</p> <p>Thus, the addition of minerals in cement grinding cuts back on the production of clinker, which results in a reduction of the total emissions per unit of cement produced.</p> <p>The use of waste and mineral by-products as additives to the clinker in the cement production process supplies the following benefits:</p> <ul style="list-style-type: none"> • It reduces energy consumption by manufacturing less clinker, thanks to the use of additives. • It reduces atmospheric emissions, thanks to lower fuel consumption.
Comments	<p>Those materials that are suitable for use as clinker substitutes may be natural or may originate from by-products of other industrial processes, such as:</p> <ul style="list-style-type: none"> • Natural or industrial pozzolans • Power station fly ash • Blast-furnace slag • Silica fume from the ferro-alloy industry • Calcined shales
Economic Aspects	<p>Through the use of natural additives or industrial waste as substitutes for clinker, an economic benefit is obtained thanks to savings in energy costs due to the substituted clinker.</p> <p>Cement plants charge for waste management. By making savings on the cost of the raw materials substituted, they can offer competitive prices with regard to dumping in landfill or treatment and specialised incinerators. Nevertheless, lower landfill prices have been detected within the Mediterranean Arc, which means that no waste management technology can compete with landfills, and thus the waste management hierarchy is not complied with.</p>

5.2. TECHNOLOGICAL ALTERNATIVES FOR THE CORRECT MANAGEMENT OF ENERGY.

The greatest opportunities for increasing energy efficiency in the cement manufacturing process are to be found in the clinker burning stage, and include the following:

- Integral measures for optimising energy in the process.
- Improvements to the dry process.
- Suspended preheaters.
- Modern reciprocating grate cooler.

Opportunities for optimising energy consumption in the crushing and grinding processes can also be considered.

- Grinding technologies for the preparation of raw materials.
- Roller grinding for the preparation of fuel.
- Integral energy optimisation measures for the finish grinding of the cement.

There is also the possibility of reformulating the product with the aim of improving energy efficiency (see Section 5.1. *Technological alternatives of a general nature*).

- Alkali content of the cement
- Reduction of the clinker/cement ratio.

The following table gives a summary of possible transformations for improving energy efficiency that can be carried out in the kiln of an existing plant.

Table 5.2.1. Transformation possibilities of the different types of kiln.

FROM / TO	Wet	Semi-wet	Semi-dry	Long dry	Dry with preheater	Dry with precalciner	Vertical
Wet		√	√		√	√	
Semi-wet					√	√	
Semi-dry					√	√	
Long dry					√	√	
Dry with preheater						√	
Dry with precalciner							
Vertical							√

Source: IPTS, 2003

Alternative	5.2.1. INTEGRAL MEASURES FOR OPTIMISING ENERGY IN THE PROCESS
Action	Action: Prevention of contamination at source. Good environmental practices and/or technological changes.
Stage of the process	Clinker burning
Environmental problems	Energy consumption.
Environmental benefits of the Alternative	<p>Increased energy efficiency in the burning stage always implies a reduction of all emissions directly associated with the combustion process (NO_x, SO₂, CO₂), as well as a reduction in the use of natural resources, in the case of these being used as fuel.</p> <p>Similarly, the savings in electrical consumption and its associated losses (transport and generation) indirectly affect the contamination produced in the electrical generation process.</p>
Description	By energy optimisation measures for the burning process, we refer to those measures for improving energy efficiency which can be identified in the process. These measures are obtained from carrying out an energy audit on the entire installation and identifying any possible opportunities associated with the energy consumption shown in Table 5.4.1.
Procedure	<p>Reduction in the losses associated with kiln exhaust gases</p> <ul style="list-style-type: none"> • Installation of devices to increase the transfer of heat from gases to materials. • Operation with optimal levels of oxygen. • Optimisation of the geometry of the burner flame and its temperature. • Improve or add capacity to the preheating stage. <p>Reduction of the energy absorbing capabilities of raw materials and fuel (e.g. reduction of the water content).</p> <p>Reduction of the dust content of exhaust gases by reducing gas turbulence.</p> <p>Reduction of the clinker discharge temperature.</p> <p>Reduction of the kiln's radiation losses, using suitable mixes and more efficient refractory materials.</p> <p>Reduction in the output temperature of gases from the cooler</p> <ul style="list-style-type: none"> • Improve the efficiency of the cooler (e.g. reduction of excess air, control of the thickness of the clinker bed or the introduction of new grates). • Recirculation of excess air from cooling. • Use of the exhaust air for drying raw materials, or for pre-heating fuel and air. <p>Reduction of air leaks</p> <ul style="list-style-type: none"> • Elimination of unnecessary openings. • Provision of energetically more efficient sealings.

	<ul style="list-style-type: none"> • Operation with the maximum possible primary air temperature. <p>General measures</p> <ul style="list-style-type: none"> • Existence of energy management programmes. • The existence of maintenance programmes (installation, compressed air systems, etc.). • High efficiency motors. • High efficiency fans with variable speed motors. • Optimisation of compressed air systems.
Comments	<p>Not all measures can be applied to all plants Applicability depends on the current and future state of the plant.</p> <p>In spite of reduced energy consumption due to technological changes, altering the habits and attitudes of staff employed in the plants may have an even greater impact on energy efficiency.</p>
Economic Aspects	<p>Investment costs may vary, depending on the state of the plant and the measures adopted.</p> <p>The economic impact due to the energy saving may be twofold:</p> <ul style="list-style-type: none"> • Reduction of fuel or kWh of electricity consumed per tonne of clinker. • Reduction of environmental costs (such as the purchase of CO₂ emission rights in certain countries or the reduction of end-of-pipe contamination treatment costs).

Alternative	5.2.2. IMPROVEMENTS TO THE DRY PROCESS.																
Action	Action: prevention of contamination at source. Technological changes.																
Stage of the process	Clinker burning																
Environmental problems	Generation of atmospheric emissions and energy consumption.																
Environmental benefits of the Alternative	Reduction in the generation of atmospheric emissions and energy recovery.																
Description	<p>This file deals with the possible improvements in the reduction of thermal energy in a previously installed dry process kiln through the addition of a preheater and a precalciner in the external part of the kiln:</p> <ul style="list-style-type: none"> • Conversion of a long dry kiln to a kiln with preheater. • Conversion of a kiln with a preheater to one with preheater and precalciner. • Conversion of a long kiln to one with preheater and precalciner. 																
Procedure	<p>Long kilns for dry processes are practically no longer in use.</p> <p>As was mentioned in the previous alternative, kilns can be made shorter through the use of external preheaters, thus reducing heat loss and increasing the energy efficiency of the whole installation. This is the case of cyclone exchangers before a dry kiln. There may be a number of cyclone stages, preheating in 2 stages, 4 stages, and 6 stages for the most modern ones.</p> <p>Moreover, by employing a precalciner after the cyclones it is possible to remove the rotary kiln decarbonation process, thus improving specific consumption thanks to the effect of reducing the size of the kiln and improving heat exchange quality.</p> <p>The following table shows the energy consumption involved for each type of kiln. It can be seen that consumption falls as the number of cyclone stages increases, a precalciner is added and a high efficiency cooler is installed.</p> <p>Table 5.2.2. Specific consumption by type of kiln</p> <table border="1"> <thead> <tr> <th>Type of kiln</th> <th>Consumption (MJ/tonne of clinker)</th> </tr> </thead> <tbody> <tr> <td>Dry process</td> <td>4,500</td> </tr> <tr> <td>Preheater with 1 cyclone stage</td> <td>4,200</td> </tr> <tr> <td>Preheater with 2 cyclone stages</td> <td>3,700</td> </tr> <tr> <td>Preheater with 4 cyclone stages</td> <td>3,350</td> </tr> <tr> <td>Preheater with 4 cyclone stages and precalciner</td> <td>3,200</td> </tr> <tr> <td>Preheater with 5 stages, precalciner and high-efficiency cooler</td> <td>3,000</td> </tr> <tr> <td>Preheater with 6 stages, precalciner and high-efficiency cooler</td> <td>2,900</td> </tr> </tbody> </table> <p>Source: Cembureau, 1997 and Cement Industry Federation</p>	Type of kiln	Consumption (MJ/tonne of clinker)	Dry process	4,500	Preheater with 1 cyclone stage	4,200	Preheater with 2 cyclone stages	3,700	Preheater with 4 cyclone stages	3,350	Preheater with 4 cyclone stages and precalciner	3,200	Preheater with 5 stages, precalciner and high-efficiency cooler	3,000	Preheater with 6 stages, precalciner and high-efficiency cooler	2,900
Type of kiln	Consumption (MJ/tonne of clinker)																
Dry process	4,500																
Preheater with 1 cyclone stage	4,200																
Preheater with 2 cyclone stages	3,700																
Preheater with 4 cyclone stages	3,350																
Preheater with 4 cyclone stages and precalciner	3,200																
Preheater with 5 stages, precalciner and high-efficiency cooler	3,000																
Preheater with 6 stages, precalciner and high-efficiency cooler	2,900																

<p>Comments</p>	<ul style="list-style-type: none"> • <u>Conversion of a long dry process kiln to one with a Multi-stage preheater</u> The installation of suspended preheaters of various stages reduces heat loss in a long kiln fitted with chains, and this increases the energy efficiency of the system. The productivity of the kiln increases with the new preheaters, owing to 40 % of the calcining having been carried out prior to the material being fed into the kiln. Moreover, the kiln is shortened by 20-30 %, thus reducing radiation loss. Since the capacity of the plant is increased, the clinker cooler will have to be adapted to deal with the new volume of production. The energy saving depends on the energy consumption of the dry kiln and the number of preheaters installed (see Table 5.2.2. Specific consumption by type of kiln). • <u>Conversion of a kiln with a preheater to one with preheater and precalciner of various stages</u> The installation of a precalciner generally results in an increase in the capacity of the plant, while the specific fuel consumption and thermal NO_x emissions are reduced (owing to the low combustion temperature in the precalciner). In general, when carrying out this conversion, the kiln, the foundations and the towers are kept, while the cooler and the precalciner are replaced by others which are adapted to the plant's new capacity. The energy saving is highly dependant on the efficiency of the existing kiln and on the new process parameters (e.g. degree of precalcining, cooling efficiency). The conversion of a rotary kiln in a plant in Italy resulted in an increase in capacity of 80-100 % (from 1,100 t/d to 2,000-2,200 t/d), while the specific fuel consumption was reduced from 3.06 to 2.63-2.74 GJ/t of clinker, which is a saving of 11-14 % [Sauri, 1993]. • <u>Conversion of a long kiln to one with preheater and precalciner:</u> This option includes the two aforementioned improvements, implementing them in one single step. If this conversion is economically viable, savings of 1.2 GJ/t of clinker are estimated, with respect to the long dry process kiln.
<p>Economic Aspects</p>	<ul style="list-style-type: none"> • <u>Conversion of a long dry kiln to one with a multi-stage preheater</u> The conversion of a long kiln may be attractive when it needs to be replaced and the installation of a new kiln is very expensive. <i>Vleuven</i> (1994) gives estimated costs of \$ 25 per tonne/year for the installation of suspension preheaters. • <u>Conversion of a kiln with a preheater to one with preheater and precalciner of various stages</u> For the installation of a preheater and a precalciner for a kiln with a preheater, the estimated investment cost is \$ 15 per tonne/year.[<i>LBNL, 2004</i>]. With the increase in production capacity it is possible to achieve saving of \$ 1/tonne in operating costs [<i>Jaccard and Willis, 1996</i>]. • <u>Conversion of a long kiln to one with preheater and precalciner.</u> A cost of \$ 25 per tonne of clinker/year is assumed [<i>LBNL, 2004</i>].

Alternative	5.2.3. SUSPENDED PREHEATERS.
Action	Action: Prevention of contamination at source. Technological changes.
Stage of the process	Clinker burning
Environmental problems	Energy consumption.
Environmental benefits of the Alternative	Improved energy exploitation.
Description	The installation of suspended preheaters reduces the energy consumption of the kiln exhaust gas ventilator.
Procedure	Depending on the efficiency of the ventilator, savings of between 0.6-0.7 kWh/tonne of clinker are possible for each 50 mm of the load water column that are reduced. For many older kilns, the energy saving can be between 0.6-1 kWh/tonne of clinker if this type of system is installed [Birch, 1990].
Comments	One possible drawback of this system is the increase in the load of particles in exhaust gases, and thus an increase in particles dragged from the preheater tower. Nevertheless, if the raw material grinding unit is placed after them, the problem of dragging particles is reduced.
Economic Aspects	The installation of the system may be expensive; nevertheless, it often involves the reconstruction or modification of the preheater towers, due to which the costs may fluctuate greatly depending on the specific condition of each plant. A cost of € 2.8 per tonne of clinker/year is estimated [LBNL , 2004].

Alternative	5.2.4. MODERN RECIPROCATING GRATE COOLER.
Action	Action: Prevention of contamination at source. Technological changes.
Stage of the process	Clinker burning
Environmental problems	Energy consumption.
Environmental benefits of the Alternative	Improved energy exploitation.
Description	The reciprocating grate cooler is the modern variant of cooler; they are installed in almost all plants with modern kilns with a capacity exceeding 10,000 t/day. They recover more heat than other types of coolers.
Procedure	<p>The advantages of grate coolers lie in their high capacity (permitting large kiln capacities) and efficient heat recovery (the temperature of the clinker discharged from the cooler may be as low as 83 °C, as opposed to the 120-200 °C in the case of planetary coolers [Vleuten, 1994].</p> <p>Modern reciprocating coolers increase heat recovery efficiency by 65 % or more, while reducing the fluctuations therein.</p>
Comments	The conversion to or installation of this technology is economically attractive when a precalciner is to be installed, or when planned capacity has been increased, since the recovery of the tertiary air needed for the precalciner is incompatible with planetary coolers [Cembureau, 1997], thus limiting heat recovery efficiency.
Economic Aspects	<p>This is the favoured option for high-capacity plants. For plants producing less than 500 tonnes/day, this system may be very expensive.</p> <p>The conversion cost is estimated to be between \$ 0.4 and \$ 5 per tonne/year, depending on the degree of reconstruction required. Annual operating costs are increased by \$ 0.1 /t of clinker [Jaccard and Willis, 1996].</p>

Alternative	5.2.5. MILLING TECHNOLOGIES FOR THE PREPARATION OF RAW MATERIALS.								
Action	Action: Prevention of contamination at source. Technological changes.								
Stage of the process	Preparation of raw materials.								
Environmental problems	Energy consumption.								
Environmental benefits of the Alternative	Reduction in the generation of atmospheric emissions and energy recovery								
Description	<p>The traditional ball mill, which is used for grinding raw materials, can be replaced by high energy efficiency roller mills, by ball mills in combination with high-pressure roller presses, or by horizontal roller mills. These technologies save energy without affecting the quality of the product.</p> <p>The choice of milling system may vary in different installations, depending on a number of factors. While the energy consumption for ball mills is higher, they have lower operation and maintenance costs than other mills. In general, it is difficult to compare investment costs, since the specific limitations of the location play an important role. Other non-economic factors affecting the choice include the humidity content of raw materials (vertical mills can dry and grind, while roller presses and horizontal mills require a separate dryer) and the desired fineness of the product. A number of options involve the use of two types of mills consecutively, in order to make use of the advantages of both.</p> <p>The installation of high-efficiency classifiers and separators in mills is also an energy improvement.</p>								
Procedure	<p><u>Roller mills</u> require less energy and have a higher drying capacity than ball mills; nevertheless, they are not suitable for highly abrasive materials.</p> <p>Roller mills are built with processing capacities of up to 400 t/h, and have lower specific energy requirements than ball mills, around 10-14 kWh/t, since they work at higher pressures and require feeding with a relatively low water content.</p> <p>Energy savings of 6-7 kWh/t of raw material are estimated with the installation of a vertical or horizontal roller mill [LBNL, 2004]. A saving of up to 20 % can be obtained if a horizontal mill is used instead of a vertical roller mill [wbcasd, 2002].</p> <p>The following table shows the percentage of energy consumption for each milling system with respect to the ball mill.</p> <p>Table 5.2.3. Percentage of energy consumption with respect to ball mills.</p> <table border="1"> <thead> <tr> <th>Type of Mill</th> <th>%</th> </tr> </thead> <tbody> <tr> <td>Vertical roller mill.</td> <td>70-75</td> </tr> <tr> <td>Horizontal roller mill.</td> <td>65-70</td> </tr> <tr> <td>Roller (or high-pressure roller mill) press</td> <td>50-65</td> </tr> </tbody> </table> <p>Source: LBNL, 2000</p>	Type of Mill	%	Vertical roller mill.	70-75	Horizontal roller mill.	65-70	Roller (or high-pressure roller mill) press	50-65
Type of Mill	%								
Vertical roller mill.	70-75								
Horizontal roller mill.	65-70								
Roller (or high-pressure roller mill) press	50-65								

	<p><u>High efficiency Classifiers/Separators:</u></p> <p>These classifiers separate fine particles from coarse ones more efficiently and selectively, which avoids over-grinding. They can be used to grind raw materials as well as for the finish grinding.</p> <p>Electrical savings of 8% of the specific consumption are estimated. [LBNL, 2004]</p>
Comments	<p>One additional advantage of the in-line installation of a vertical roller mill is that it can combine the drying of raw materials with the grinding process by using the residual heat from the kiln or from the clinker cooler.</p> <p>With regard to the installation of high-efficiency classifiers or separators, replacing a conventional classifier with a high-efficiency one can give rise to a 15 % increase in grinding capacity, and improve the quality of the product, owing to greater uniformity in the size of particles. The improvement in the size of raw materials results in savings in fuel consumption for the kiln and improved clinker quality.</p>
Economic Aspects	<p>A number of different roller mill designs are available on the market.</p> <p>The installation of a roller mill entails investment costs estimated at \$ 5 per tonne of raw material [Holderbank, 1993].</p> <p>The installation of classifiers or separators involves a cost of \$2 per tonne of raw material/year [Holderbank, 1993].</p>

Alternative	5.2.6. INSTALLATION OF ROLLER MILL FOR THE PREPARATION OF FUEL
Action	Action: Prevention of contamination at source. Technological changes.
Stage of the process	Preparation of fuel.
Environmental problems	Reduction in the generation of atmospheric emissions and energy recovery
Environmental benefits of the Alternative	Reduction in the generation of atmospheric emissions and energy recovery
Description	<p>Fuel preparation is carried out <i>in situ</i>. This may include the crushing, grinding and drying of coal (which is transported while damp to avoid the formation of dust in transit; if the coal should require drying, the residual heat from the kiln, e.g. from the clinker cooler, can be used).</p> <p>For crushing and grinding fuel, the roller mill is energetically more efficient than ball or impact mills (see Table 5.2.3. <i>Comparison of energy consumption for the different types of mills</i>)[Cembureau, 1997].</p>



Figure 5.2.3. Vertical roller mill.

<p>Procedure</p>	<p>Roller mills have a number of advantages: fuel can be fed in without having to be crushed beforehand (large coal sizes), they can take coal with a high humidity content, and they can handle significant variations in performance. Nevertheless, for abrasive coals, the use of ball mills is preferable.</p> <p>Roller mills for coal are available for outputs of between 5 and 200 t/h.</p> <p>The following table shows consumption values for the different types of fuel grinding. It can be seen how the energy consumption of roller mills is considerably lower than that of ball and impact mills.</p> <p>Table 5.2.1. Comparison of energy consumption for the different types of mills.</p> <table border="1"> <thead> <tr> <th>Type of mill</th> <th>Consumption (kWh/ ton of fuel)</th> </tr> </thead> <tbody> <tr> <td>Ball Mill</td> <td>45-60</td> </tr> <tr> <td>Impact mill</td> <td>25-26</td> </tr> <tr> <td>Roller mill.</td> <td>16-18</td> </tr> </tbody> </table> <p>Source: Cembureau, 1997</p>	Type of mill	Consumption (kWh/ ton of fuel)	Ball Mill	45-60	Impact mill	25-26	Roller mill.	16-18
Type of mill	Consumption (kWh/ ton of fuel)								
Ball Mill	45-60								
Impact mill	25-26								
Roller mill.	16-18								
<p>Comments</p>	<p>In the same manner as for the grinding of raw material and the finish grinding, there is a roller press system that is generally more efficient than conventional grinding with mills. The roller press can be used to grind raw materials and coal, although the grinding equipment must be fitted with special protection against explosions.</p>								
<p>Economic Aspects</p>	<p>Investment costs for roller mills are generally higher than for ball or impact mills, the operating costs are lower - approximately 20 % lower than for ball mills, and 50 % lower than for impact mills [Cembureau, 1997]. A saving of between 7-10 kWh/t of coal is estimated.</p>								

<p>Alternative</p>	<p>5.2.7. INTEGRAL ENERGY OPTIMISATION MEASURES FOR THE FINISH GRINDING OF CEMENT.</p>
<p>Action</p>	<p>Action: Prevention of contamination at source. Good Environmental Practices and technological changes.</p>

Stage of the process	Cement grinding.
Environmental problems	Energy consumption.
Environmental benefits of the Alternative	Reduction in the generation of atmospheric emissions and energy recovery
Description	Energy optimisation measures for the finish grinding stages refers to those measures that improve the energy efficiency of both the control and the type of mill or classifiers.
Procedure	<p>Control of process and management. Grinding.</p> <p>The control systems for grinding operations have been developed using the same philosophy as for the process control systems (see File 5.2.1).</p> <p>The system controls the input flow to the mill and the classifiers, obtaining a high-quality stable product.</p> <p>Advanced grinding concepts</p> <p>The energy efficiency of ball mills for finish grinding is relatively low, consuming between 30 and 42 kWh/t of clinker, depending on the fineness of the cement [Cembureau, 1997]. New milling concepts—including the installation of roller presses, roller mills and roller presses for pre-grinding in combination with ball mills—can reduce this consumption to 20-30 kWh/t of clinker.</p> <p>Vertical mills with air sweepers and classifiers are normally used for finish grinding. A technology consisting of pre-grinding with vertical roller mills, without air sweepers, in combination with a ball mill is now starting to be used. The inclusion of a pre-grinding system prior to the ball mill results in an energy saving of between 6 and 22 kWh/t of cement. One variation in roller mill technology is the roller mill with an air-sweeper ring, which has a consumption of 23 kWh/t of cement for cement with a granulometry of 3,000 cm²/g.</p> <p>Another new concept in roller mills is the <i>Horomill</i>, which is a horizontal mill with compact rollers that is capable of obtaining the final product in one stage. The pressure generated by the rollers is in the region of 700-1,000 bar [Marchal, 1997]. For the grinding of Portland cement with a granulometry of 3,200 cm²/g, this type of mill consumes approximately 21 kWh/t; and for the grinding of pozzolanic cement with a granulometry of 4,000 cm²/g less than 25 kWh/t.</p> <p>Those companies which have installed a horizontal roller mill show energy savings in excess of 20% in the grinding of raw materials (compared with vertical roller mills) and 40% for the grinding of cement.</p> <p>Nowadays, high-pressure roller presses are frequently used if an increase in the capacity of mills is desired. This type of press comprises two rollers which exert a pressure of up to 3,500 bar on the material, dramatically increasing grinding efficiency.</p> <p>High efficiency classifiers</p> <p>These classifiers separate fine particles from coarse ones more efficiently and selectively, which avoids over milling, and thus results in energy savings.</p>

	<p>Improvements in grinding materials.</p> <p>With special reference to ball mills, it is possible to make improvements to the grinding materials to improve their durability. An increase in the distribution load of the balls, in the surface hardness of the grinding media and in the wear-resistant cladding for the mill, results in savings in the wear and tear of materials as well as in energy consumption.</p>								
<p>Comments</p>	<p>Advanced milling concepts</p> <p>The table below gives a summary of the consumptions commented on in the paragraph above.</p> <p>Table 5.2.1. Comparison of energy consumption of mills for finish grinding</p> <table border="1"> <thead> <tr> <th>Type of mill</th> <th>Consumption (kWh/t of fuel)</th> </tr> </thead> <tbody> <tr> <td>Ball Mill</td> <td>>30-42</td> </tr> <tr> <td>Vertical roller mill with ball mill.</td> <td>23</td> </tr> <tr> <td>Horizontal roller mill.</td> <td>21-25(*)</td> </tr> </tbody> </table> <p>Source: [LBNL , 2004]</p> <p>(*)Depending on the type of cement and its granulometry..</p> <p>If a ball mill is replaced by a finish grinding mill with the new technology incorporated (roller mill), the energy savings are estimated to be 20 kWh/t of cement [LBNL, 2004].</p>	Type of mill	Consumption (kWh/t of fuel)	Ball Mill	>30-42	Vertical roller mill with ball mill.	23	Horizontal roller mill.	21-25(*)
Type of mill	Consumption (kWh/t of fuel)								
Ball Mill	>30-42								
Vertical roller mill with ball mill.	23								
Horizontal roller mill.	21-25(*)								
<p>Economic Aspects</p>	<p>Advanced grinding concepts</p> <p>As the horizontal roller mill is a system that is capable of obtaining a final product in one single stage, it will have low investment costs.</p> <p>The estimated costs for the installation of a roller press are approximately \$ 4 per tonne of cement/year.</p> <p>The investment costs of roller presses are lower than, or at least comparable to, those of other systems.</p> <p>These new grinding concepts allow reductions in operating costs of between 30-40 %.</p> <p>High efficiency classifiers</p> <p>In a study carried out in Great Britain, a reduction in the use of electricity of 6 kWh/t of cement was obtained after the installation of these classifiers in the finish grinding, and an increase in production of 25 % [Parkes, 1990].</p> <p>Holderbank estimated a reduction of 8 % in energy consumption (5 kWh/t), while other studies estimated 1.7-2.3 kWh/t of cement [LBNL, 2004, LBNL, 2000].</p> <p>Current savings vary on the basis of the plant and type of cement and fineness required. For example, electrical savings for the installation of high efficiency classifiers in a cement plant in France (Origny-Rochefort) varied between 0 and 5 kWh/t, involving an investment cost of \$2/t of final product per year. [LBNL, 2004]</p>								

Alternative	5.2.8. REDUCTION OF THE ALKALI BY-PASS FLOW
Action	Action: Prevention of contamination at source. Technological changes.
Stage of the process	Clinker burning
Environmental problems	Reduction in the consumption of resources.
Environmental benefits of the Alternative	Reduction in the generation of atmospheric emissions and energy recovery
Description	<p>Many clients request low-alkali cement, as it allows a greater choice of aggregates for forming concrete. Nowadays, these requirements have changed, and a product with a higher alkali content can be sold.</p> <p>However, in some countries raw materials have a high alkali content (e.g. Egypt), due to which both the preheater and the precalciner must be equipped with a by-pass system to reduce this content. Reduction by means of a by-pass will depend to a great degree on the type of cement that is required.</p>
Procedure	<p>In order to obtain the reduction in alkali content a by-pass system for the hot gases and the alkaline metal-laden particles from the plant is used. The by-pass prevents the blockage of the preheater, since it does not receive the entire flow kiln exhaust gases, and thus, fewer particles reach it.</p> <p>Nevertheless, the production of low-alkali cement also entails higher energy consumption, since it removes hot gas from the burning process that could be used in the preheater, and it reduces the quantity of particles which could form part of the clinker.</p> <p>Savings of 2-5 Kcal/kg are estimated on the percentage of gas that is not passed through the by-pass, where the lower value is attributed to kilns with precalciner, and the higher one to kilns with preheater.</p> <p>The by-pass normally involves between 10-70 % of kiln exhaust gases. By way of example, if we assume a reduction of 20 % in the quantity of gases sent to the by-pass, savings of between 0.16-0.4 GJ/t of clinker would be made [LBNL, 2004].</p> <p>The use of fly ash and blast-furnace slag as aggregates can reduce the need to produce low alkali cement.</p>

	<p style="text-align: center;">Figure 5.2.4. Production process with alkali by-pass.</p>
<p>Comments</p>	<p>Apart from resulting in energy savings through reductions made using the alkali by-pass, the change in the cement composition also involves maximising the use of new NO_x control technologies, reducing emissions of NO_x and particles, since a greater flow of gas would pass through these technologies which otherwise (removed with the by-pass) would be emitted directly to the atmosphere.</p> <p>Another benefit is the reduction of particle emissions and the possibility of re-circulating the particles generated by the by-pass gas to the kiln, since as the quantity is lower, it would not block the system.</p>
<p>Economic Aspects</p>	<p>This alternative has no associated costs, since it is merely a change of process; nevertheless, it may entail additional costs for consumers, as it requires the aggregates used to be substituted by another type in order to generate concrete with the same characteristics.</p>
<p>This technique is a specific case of File 5.1.4 “REDUCTION OF THE CLINKER/CEMENT” due to which, it can be removed.</p>	

5.3. TECHNOLOGICAL ALTERNATIVES FOR THE CONTROL OF NO_x EMISSIONS

The technological alternatives of a general nature described in Point 5.1—for example, optimising process control (controlling the oxygen content), the choice of raw materials and fuels with lower nitrogen contents, the installation of a precalciner/preheater, among others—improve NO_x emissions, thanks to the reduction in the energy consumption required and maintaining the work level within the design parameters, placing special emphasis on those that are decisive for the formation of NO_x.

The technical improvements available for reducing NO_x emissions are the combination of the general primary measures explained above, and the following techniques, which are described individually in file form below.

- Low NO_x burner.
- Flame cooling.
- Multi-stage combustion.
- Selective non-catalytic reduction (SNCR).

The combined use of multi-stage combustion and selective non-catalytic reduction is currently at the developmental stage (see *Section 5.14. Emerging techniques*).

Some modern dry kilns with cyclone exchanger and precalciner have reached emission levels below 500 mg/Nm³ (expressed as NO₂); in some cases using only primary measures, in other cases, also using multi-stage combustion. The characteristics of the raw material (difficult to burn) and the design of the kiln may make it unfeasible to reach these values.

For the majority of kilns that use SNCR, emissions are between 500 and 800 mg/Nm³. Some installations have obtained emission values below 200 mg/Nm³, although the experience accumulated in these cases is still insufficient. More specifically, data are only available on two factories, with relatively short periods of industrial use. One of the strongest concerns regarding the application of SNCR relates to possible ammonia leaks, in both transport/storage operations and in the form of emissions during its use as a reducer.

In order to apply the SNCR technique in a clinker kiln, there must be access to a temperature window in the region of 900 °C. This is relatively simple in dry ovens with four or more exchanger stages, while it is impossible in semi-wet or wet kilns.

The application of the multi-stage combustion technique means that the kiln must have a precalciner with a design that permits long retention times.

With regard to low-NO_x burners, the results are usually satisfactory, although in some cases it has been observed that there is no reduction in NO_x emissions.

In relation to the levels associated with the aforementioned techniques, the following points can be made:

With regard to the levels associated with the aforementioned techniques, the following points can be made:

- Newly constructed dry kilns with a precalciner and a multi-stage combustion system may obtain NO_x emission values below 500 mg/Nm³.
- Dry kilns with a precalciner which do not have a multi-stage combustion system are normally within the range of 500-800 mg/Nm³.
- Dry kilns with no precalciner which apply the aforementioned primary measures should normally obtain emission values below 1,200 mg/Nm³. With the aim of reducing emissions of NO_x in dry kilns with a 4-stage interchanger, the injection of ammonia has been applied in 20 European kilns; in this way values below 800 mg/Nm³ were obtained, but these must be offset with the transport and handling of ammoniac compounds, as well as the atmospheric emission of the part of the ammonia not reacting with the NO_x.
- For dry kilns with less than four stages, semi-wet and wet kilns there are no secondary measures that have been proven to be effective; the values attainable with these kilns are those resulting from the combination of the primary techniques.

As has already been mentioned repeatedly above, the ranges described are of a general nature, and there will be cases in which an installation's emissions may even be lower than the values that could be expected for its technology, and others in which the characteristics of the raw materials or of the process will give rise to emission values higher than the ranges given. In this sense, it should be pointed out that the normal emission ranges in new grey clinker installations (between 500 and 800 mg/Nm³) are generally lower than those for existing installations (between 800 and 1,200 mg/Nm³).

The table below shows the application characteristics of the different NO_x reduction techniques:

Table 5.3.1. Overview of techniques for the control of NO_x emissions.

Technique	Applicability	Reduction Efficiency (%)	Emissions ⁽²⁾		Costs ⁽³⁾	
			mg/m ³ (1)	kg/t (2)	Investment	Operation
Low NO_x burner	All kilns	0-30	400	0.8	0.15 – 0.8	0
Flame cooler	All kilns	0- 50	400	0.8	0 – 0.2	0 – 0.5
Multi-stage combustion	Precalciner	10-50	<500-1,000	<0.1-2.0	0.1 -2	0
	Preheating				1 - 4	0
SNCR	Preheating and precalcining	10-85	200-800	0.4 – 1.6	0.5 - 1.5	0.3 – 0.5

(1)Referring normally to daily averages, dry gas, 273 K, 101.3 kPa and 10 % O₂.

(2)kg/t clinker: Based on 2,000 m³t of clinker.

(3)Investment cost is expressed in € M. and the operational cost in € / t of clinker, referring normally to a kiln capacity of 3,000 t of clinker/day and initial emission levels in excess of 2000 mg NO_x/Nm³.

Source: Cembureau

Alternative	5.3.1. LOW NO _x BURNER.
Action	Action: Reduction at source. Technological changes.
Stage of the process	Clinker burning
Environmental problems	Generation of atmospheric emissions of NO _x .
Environmental benefits of the Alternative	<p>Although its installation is not always linked to a reduction in NO_x emissions, reductions of up to 30 % in these emissions have been obtained [Int. Cem. Rev., Octobre 1997] in kilns in which this type of burner has been most successful, while reductions in excess of 10 % are not uncommon.</p> <p>These low NO_x burners can be applied to all rotary kilns, with emission levels of 600 - 1.000 mg/Nm³ having been obtained. [Dutch Report, 1997].</p>
Description	The principle of this technique is based on the reduction of localised hot zones through the use of vortex-induced gas and low levels of primary air.
Procedure	<p>Except for a small proportion, the formation of nitrogen oxides takes place in fuels containing organic nitrogen, through a chemical combination between nitrogen and the oxygen in the air. The conditions that must be avoided to minimise the formation of NO_x are high combustion temperatures and an oxidising atmosphere.</p> <p>In low-emission NO_x burners, the central combustion area has an air defect, so that the temperature in this zone is affected by the lack of air, and there is a reducing atmosphere; the combustion is completed by feeding secondary air to the zone outside the flame.</p> <p>Low-NO_x burners vary in detail, but essentially the fuel and the air are injected into the kiln through concentric tubes. The proportion of primary air is reduced to 6- 10 % of that required for stoichiometric combustion, normally around 13 % in indirect combustion burners [World Cement, April 1990] or 20-25 % in traditional direct combustion ones. The axial air is injected at a high velocity into the outer channel.</p> <p>The fuel can be feed in through the central tube of the mid channel. A third channel is used for the vortex-induced air, which is injected by vanes at the nozzle outlet.</p> <p>The net effect of the burner design is to produce very rapid ignition, especially of the volatile compounds in the fuel, in an oxygen-deficient atmosphere, which will tend to reduce the formation of NO_x.</p>
Comments	Low-NO _x burners can be applied in both new and existing installations.
Economic Aspects	The investment cost for a low-NO _x burner is approximately € 150,000 to € 350,000 for a kiln capacity of 3,000 t of clinker/day [Cembureau, 1997] [Dutch, 1997]. If the existing combustion systems are direct, they must be replaced by an indirect combustion system to allow combustion with low primary air flows; this will involve investment costs in the region of € 600,000 to € 800,000 for a kiln capacity of 3,000 t of clinker/day [Cembureau, 1997]. In Spain, all existing kilns use indirect fuel feeding systems.

Alternative	5.3.2. FLAME COOLING.
Action	Action: Reduction at source. Technological changes.
Stage of the process	Clinker burning
Environmental problems	Generation of atmospheric emissions of NO _x
Environmental benefits of the Alternative	Emissions of NO _x may be reduced by up to 50 %. This reduction can be reached under optimal conditions, the maximum reduction being based on initial emissions of 2,000 mg/Nm ³ .
Description	Cooling of the flame temperature through the addition of water.
Procedure	The addition of water to the fuel, or directly to the flame, reduces the temperature and increases the concentration of hydroxyl radicals. This may have a positive effect on the reduction of NO _x in the combustion zone. The results are optimal if they are reached using alternative fuels with a certain water content.
Comments	<p>A water consumption of between 3 and 20 kg/t of clinker must be considered, taking into account that this added water may cause problems in the operation of the kiln.</p> <p>An additional energy consumption of between 10 and 65 MJ/t_{cl} must be considered, owing to the additional heat required for the evaporation of the added water.</p> <p>Thus, in this NO_x-reduction system, an additional small CO₂ emission of 0.1-1.5 % associated with the increase in energy use must be counted. The additional CO₂ may be minimised if wastewaters are used.</p> <p>The system of NO_x injection, or the addition of water to fuel, can be applied in both existing and new installations.</p>
Economic Aspects	<p>The investment cost for flame-cooling system via the addition of water is approximately from € 0 to € 200,000.</p> <p>It has a service life in excess of 5 years, and operating costs of € 0.03 to € 0.52/t of clinker must be taken into consideration, as well as a potential penalisation -which is difficult to estimate- due to a possible reduction in clinker production capacity (owing to limitations on volumetric consumption, which has increased with the injection of water) [BREF, 2001].</p>

Alternative	5.3.3. MULTI-STAGE COMBUSTION.
Action	Action: Reduction at source. Technological changes.
Stage of the process	Clinker burning: Kilns with preheating and/or precalcining
Environmental problems	Generation of atmospheric emissions of NO _x
Environmental benefits of the Alternative	Some well optimised modern plants attain emission levels below 500 mg NO _x /Nm ³ with multi-stage combustion.

Description	<p>This technique basically consists of breaking the combustion down into various phases, by introducing fuel at various points, doing so in specially designed precalciner.</p> <p>The first combustion stage takes place in the kiln's main burner. The second combustion stage consists of a burner at the intake of the kiln, which produces a reducing atmosphere that breaks down part of nitrogen oxides generated in the sintering zone.</p>
Procedure	<p>The high temperature in this zone is particularly favourable for the reaction that converts NO_x back into elemental nitrogen. In the third stage, fuel is fed into the calciner with a quantity of tertiary air, also producing a reducing atmosphere at that point. This system reduces the generation of NO_x from the fuel, and thus reduces the NO_x discharged from the kiln.</p> <p>In the fourth and final combustion stage, the residue tertiary air is fed into the system as "finish air" to complete the combustion. [Dutch, 1997].</p> <p>The principle of this technique, described above, is the same as for NO_x observed in kilns into which non-ground fuels, such as cut up tyres, are fed.</p> <p>The basic difference among the calciners currently in use are the location of the fuel intake, the manner in which the fuel, feed, and tertiary air are distributed, as well as their geometric geometry. [Dutch, 1997].</p>
Comments	<p>Multi-stage combustion technology can only be used in kilns fitted with a precalciner. Substantial modifications are required in plants with cyclonic preheaters and no precalciner.</p> <p>If the combustion process is not completed in the precalciner, CO and SO₂ emissions may increase [Cembureau Report, 1997] with problems having been detected with CO and blockages when high efficiencies are aimed for [Cembureau, 1997]. In spite of reductions in NO_x emissions of up to 50 % being guaranteed, reaching these levels and maintaining levels of CO emissions is very difficult.</p> <p>In wet or long kilns, alternative fuels may be fed into a specially adapted part in the kiln, creating a reducing zone (patented 'Mid Kiln' system). The opening made in the rotary kiln and the system of hatches means that fuel can be fed in with each rotation of the kiln.</p>
Economic Aspects	<p>The investment cost of installing a multi-stage combustion system in a kiln with a precalciner is € 0.1-2 million, depending on the design of the existing calciner [Cembureau, 1997].</p> <p>In a kiln with a capacity of 3,000 t/day, equipped with preheater and precalciner, the investment cost for the installation of the precalciner and the tertiary air duct is in the region of € 1 to € 4 million. [Cembureau, 1997].</p> <p>The investment cost for transforming a kiln with a capacity of 3,000 t/day equipped with preheater and planetary cooler into a kiln with a precalciner and a grate cooler is around € 15-20 million.</p>

Alternative	5.3.4. SELECTIVE NON-CATALYTIC REDUCTION (SNCR).
Action	Action: End-of-pipe treatment.
Stage of the process	Clinker burning: Kilns with preheating and/or precalcining

Environmental problems	Generation of atmospheric emissions of NO _x
Environmental benefits of the Alternative	<p>With this process reductions of over 50 % are possible.</p> <p>There are a number of SNCR installations on a real scale with NO_x reduction values of 10-50 % (with molar NH₃/NO₂ ratios of 0.5-0.9) and emission levels of 500-800 mg NO_x/Nm³.</p>
Description.	SNCR consists of the injection of NH ₂ -X compounds (commonly ammonia solution with 25 % NH ₃ , also gaseous ammonia, urea solutions, nitrolime, cyanamides, bio-solids, or other similar substances) into the exhaust gas to reduce NO _x to N ₂ .
Procedure	<p>The reaction (reduction of NO_x to N₂) has an optimum point within a range of temperatures between 800 and 1,000 °C, and sufficient retention time must be allowed for the injected agents to react with the NO_x.</p> <p>It is important to maintain the range of temperatures mentioned above; if the temperature falls below this level, unreacted ammonia is emitted, and at significantly higher temperatures the ammonia oxidises to NO_x, resulting in the emissions of gases it is aimed to eliminate being increased instead of reduced.</p> <p>The efficiency of the NO_x reduction increases with the molar ratio NH₃/NO₂, the value of a reduction in NO_x cannot simply be increased at will, given that at high doses there is a greater probability of causing NH₃ leakage. These emissions of unreacted NH₃ have taken place in other industrial sectors, in the form of chloride aerosols and ammonium sulphate, which are not captured in filters, and which may be visible as a white plume rising over the chimney.</p> <p>In short, the efficiency of the reduction depends on the temperature and residence time, as well as the ammonia and NO_x concentration in the gases.</p>
Comments	<p>Access to the correct temperature window is easy to achieve in kilns with preheater and kilns with a precalciner. Nevertheless, the same is not true of Lepol kilns, and there are in fact no installations of SNCR on an industrial scale in this type of kiln. In long, dry and wet kilns, the correct temperature cannot be attained with the necessary retention times, hence this technique cannot be applied to them.</p> <p>It should be pointed out that the aim of this technique is to limit emissions of certain contaminants (NO_x) by using a reducing agent (ammonia) which is significantly more dangerous in the case of atmospheric emissions than the contaminants it aims to eliminate.</p> <p>Unreacted ammonia may oxidise and be transformed into NO_x in the atmosphere. Leakage of NH₃ may enrich the dust that is subsequently collected in the electro-filter with ammonia, rendering it unsuitable for recirculation to the cement mill, and generating a waste that requires specific treatment [Cembureau, 1997]. Additional heat is required to evaporate the water from the ammonia solution, which results in a slight increase in carbon dioxide emissions.</p> <p>Other potential dangers for the environment included the transport, storage and handling of ammonia, due to which additional safety measures are required.</p>

	Table 5.3.2. Different environmental aspects related with the compound used in SNCR			
		Ammonium solution	Bio-solids	Urea
	Water consumption	1.5 kg/t _{cli}	140 kg/t _{cli}	1.5 kg/t _{cli}
	Energy consumption	5 kJ/kg _{cli}	500 J/kg _{cli}	0
	Emission of gases	NH ₃ , N ₂ O, CO ₂ , aerosols, dust	NH ₃ , N ₂ O, CO ₂ , aerosols, dust	NH ₃ , N ₂ O, CO ₂ , aerosols, dust
Economic Aspects	The following table gives a summary of the economic parameters depending on the compound used in SNCR.			
	Table 5.3.3. Summary of economic aspects.			
		Ammonium solution	Bio-solids	Urea
	Service life	> 5 years	S.D.	S.D.
	Investment	0.5-1.5 M€	0.4-0.6 M€	0.5-1 M€
	Operating costs	0.3-0.5 €/t _{cli}	1.9-5.5 €/t _{cli}	1-1.5 €/t _{cli}
	<p>For a kiln with a preheater producing 3,000 t/day with initial NO_x emissions of up to 2,000 mg/Nm³ and with reduction of NO_x up to 65 % (i.e. 700 mg NO_x/Nm³), the investment cost for SNCR using ammonium solution as a reducing agent is € 0.5-€ 1.5 million.</p> <p>The cost is greatly affected by the safely regulations on the storage of ammonium solution.</p> <p>The operating cost for the kiln itself is € 0.3- € 0.5/t clinker, being principally determined by the cost of the injected ammonia [Cembureau, 1997].</p>			

5.4. TECHNOLOGICAL ALTERNATIVES FOR THE CONTROL OF SO₂ EMISSIONS

The best available techniques for the reduction of SO₂ emissions are the combination of the general primary measures described above, and the addition of an absorbent in dry kilns (for initial emissions no higher than 1,200 mg/m³) or a dry/wet gas scrubber (for initial emissions higher than 1,200 mg/m³).

The following table shows the comparison of the alternative technologies in terms of applicability, reduction efficiency, emissions and costs.

Table 5.4.1. General view of techniques for the control of NO_x emissions.

Technique	Kilns applicable	Reduction efficiency	Emissions		Costs ⁽³⁾	
			(mg/m ³) ⁽¹⁾	Kg/t cli ⁽²⁾	Investment	Operation
Addition of absorbent	All	60 - 80 %	400	0.8	0.2 - 0.3	0.1 - 0.4
Dry scrubber	Dry	> 90 %	<400	<0.8	11	1.4 - 1.6
Wet scrubber	All	> 90 %	<200	<0.4	6-10	0.5 - 1
Active carbon	Dry	> 95 %	<50	<0.1	15 ⁽⁴⁾	N.D.

1) Referring to normal conditions

2) Kg/t clinker: calculated for 2,000 m³/t cli

3) Research costs are expressed in € 10⁶ and operating costs in €/t cli

4) These costs include the SNCR process referred to for a kiln capacity of 2,000 t clinker/ day and initial emissions of 50-600 mg SO₂/m³.

Alternative	5.4.1. REDUCTION OF SULPHUR CONTENT IN RAW MATERIALS AND FUEL
Action	Action: Prevention of contamination at source. Substitution of raw materials.
Stage of the process	Preparation of raw materials and fuel. Clinker burning: kilns with preheating and/or precalcining and others.
Environmental problems	Generation of SO ₂ emissions.
Environmental benefits of the Alternative	Reduction of SO ₂ emissions.
Description	Sulphur can be found in the fuel and/or in volatile or non-volatile form in raw materials. Its oxidation in the clinker burning process gives rise to the formation of SO ₂ .
Procedure	Substitution of raw materials or fuels with high sulphur content by other, more environmentally friendly ones.
Comments	The behaviour of sulphur in kilns with preheating and long dry/wet kilns is significantly different. In preheating and precalcining kilns, the sulphur content of the fuel generates practically no emissions, owing to the efficient counter-current scrubbing of kiln exhaust gases with the raw mill in the preheating and/or precalcining stage. In kilns with preheating, all the sulphur from the fuel is transformed into well defined compounds, such as as K ₂ SO ₄ and Ca ₂ k ₂ (SO ₄) ₃ , or into a solid solution in the clinker minerals, such as, for example, in the form of Belite. Thus the sulphur content in the fuel does not contribute significantly to increasing SO ₂ emissions in kilns with preheating and/or precalcining.

Nevertheless, if other kilns are used, the sulphur content in the fuel may give rise to a significant impact with regard to SO₂ emissions. Since, in this case, contact between the raw mix and the exhaust gases is less intense (reduction in the scrubbing effect). In this type of kiln, on average, 10 - 50 % of the sulphur content in fuel is emitted in the form of SO₂.

The sulphur contained in the raw materials in the form of sulphides (pirite) or organic sulphur may increase SO₂ emissions in preheating or precalcining kilns. On average, between 30-50 % of the sulphides present in the raw materials are emitted in the form of SO₂.

The sulphur content of raw materials in the form of sulphides does not contribute to increasing SO₂ emissions in this type of kiln, but it does leave it in the same state as the sulphur present in the fuel, i.e., integrated into the clinker.

If other kilns are used, generally dry kilns, the sulphur content in the raw materials contributes to increasing SO₂ emissions in a similar way to the sulphur content in the fuels. The sulphurs oxidise to SO₂ and the sulphides disassociate. Around 10 - 50 % of the sulphur content in raw materials is emitted from the kiln in the form of SO₂.

Thus, a reduction in the sulphur content of the raw material may reduce SO₂ emissions in kilns with preheating and/or a precalciner. Nevertheless, the reduction of the sulphur and sulphides in the fuel does not influence the SO₂ that may be generated in these types of kilns.

In other types of kiln, without preheater, all the sulphur contributes to the emissions of SO₂.

Table 5.4.2. Emissions of SO₂ in cement kilns.

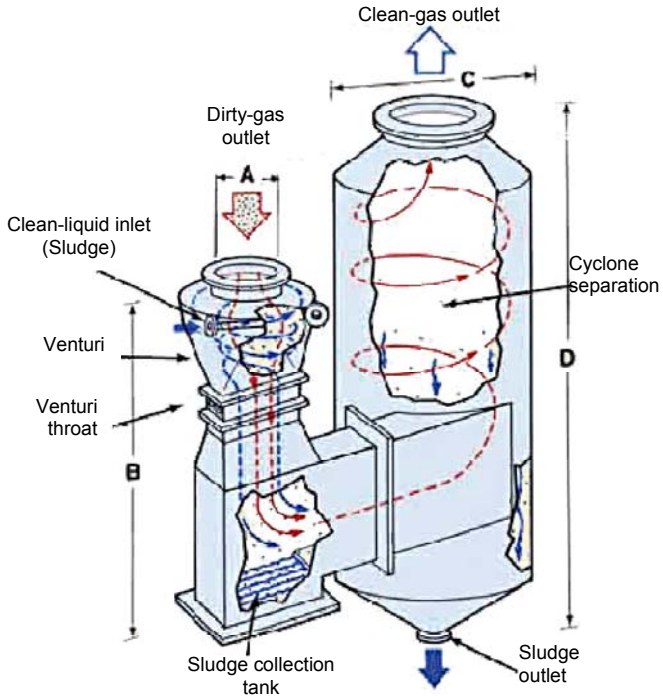
	Lepol, preheating/precalcining kilns	Other kilns
Sulphur in fuel	No emissions generated	Emissions generated
Volatile sulphur in raw materials	Emissions generated	Emissions generated
Non-volatile sulphur in raw materials	No emissions generated	Emissions generated

Economic Aspects The economic aspects relative to this measure are those associated with the cost of substituting the raw material or fuel containing sulphur with others with lower contents [BREF, 2001].

Alternative	5.4.2. ADDITION OF ABSORBENT
Action	Action: End-of-pipe treatment.
Stage of the process	Clinker burning: Rotary kiln
Environmental problems	Generation of atmospheric emissions of SO ₂ .
Environmental benefits of the Alternative	Reductions of sulphur dioxide of 60 to 80 % can be achieved through the injection of absorbents into kilns with suspended preheaters. This technique can be applied to both existing and new installations.
Description	This consists of the addition of absorbents, such as dead lime (Ca(OH) ₂), quick lime (CaO) or fly ashes activated with a high content of CaO, to kiln exhaust gases to absorb part of the SO ₂ . The SO ₂ will react with the lime to give CaSO ₃ and CaSO ₄ , which are fed into the kiln along with the raw materials, and are incorporated into the clinker.
Procedure	This technique is capable of cleaning gas currents with moderate sulphur dioxide concentrations, and can be applied at temperatures over 400 °C. The highest reduction values are obtained at temperatures exceeding 600 °C. The use of a dead lime-based absorbent with a high specific surface and porosity is recommended. Dead lime does not have high reactivity; consequently, high molar ratios Ca(OH) ₂ /SO ₂ , of between 3 and 6, must be applied. Gas currents with high concentrations of sulphur dioxide require 6 to 7 times the stoichiometric quantities of absorbent, resulting in high operating costs.
Comments	In those cases in which the primary measures described in Section 5.1. <i>Technological alternatives of a general nature</i> , are not sufficient, additional measures may be taken at the end of the process if the special situation of the factory's setting justifies the substantial investments required for the installation and maintenance of these devices. In principle, the addition of absorbents is applicable to all kilns, although it is more commonly used in dry kilns with suspension preheaters. For kilns with a preheater, the direct injection of dead lime to the exhaust gases has been found to be less efficient than the addition of dead lime to the raw meal fed into the preheater. In grey clinker kilns, initial levels do not usually exceed 1,200 mg/m ³ . For these, the addition of absorbents would reduce emissions to levels of around 400 mg/m ³ . If, on the contrary, initial levels are higher than 1200 mg/m ³ , the addition to the kiln of absorbents, such as dead lime, would not be economically viable. The addition of lime when feeding the kiln reduces the quality of the granules/nodules and gives rise to flow problems in Lepol kilns. The addition of absorbents is used in certain plants to ensure that normal limits are not exceeded in extreme situations. Thus, in general, it is not in continual use—only when required by specific circumstances.
Economic Aspects	With an initial concentration of sulphur dioxide up to 3,000 mg/Nm ³ , a reduction of up to 65 % and a cost of dead lime of € 85/t, the investment cost for a kilns with a preheater producing 3,000 t clinker/day is in the region of € 0.2 - € 0.3 million, and the operating costs around € 0.1 - € 0.4 /t of clinker. The average service life of equipment is in excess of 5 years [BREF, 2001].

Alternative	5.4.3. DRY GAS SCRUBBERS
Action	Action: End-of-pipe treatment.
Stage of the process	Clinker burning: Rotary kiln
Environmental problems	Generation of atmospheric emissions of SO ₂ .
Environmental benefits of the Alternative	<p>Reductions in sulphur dioxide emissions of over 90 % can be achieved with the use of dry gas scrubbers.</p> <p>This technique can be applied in both new and existing plants, provided the concentration of SO₂ is high.</p> <p>Not only does it reduce SO₂, but also other components that are present in the exhaust gases.</p>
Description	<p>Dry gas scrubbers are also called circulating fluidised bed absorbers (CFBA). This is a Venturi-type column reactor in which a fluidised bed is generated; this is formed by a mixture of dead lime, quick lime (the absorbents) and the raw meal.</p> <p>The scrubber is located at the kiln gas outlet, prior to emission to the atmosphere.</p>
Procedure	<p>The intensive contact between gas and absorbent, the long retention time and low operating temperature (close to the condensation point) allow for high efficiency in the absorption of SO₂.</p> <p>Gas discharged from the Venturi is loaded with absorbent, which is recovered in the electrostatic precipitator.</p> <p>Part of the recovered absorbent is re-circulated to the CFBA, and the other part is fed into the kiln intake, where it is converted into clinker.</p>
Comments	Maximum reduction efficiency is reached when the SO ₂ concentrations in the exhaust gases are close to 3,000 mg/Nm ³ .
Economic Aspects	<p>The investment cost of technique is €11 M/t of clinker.</p> <p>The service life is in excess of 9 years, and operating costs in the region of € 1.6/t of clinker must be considered.</p> <p>If we include the contribution in the form of the reduction of gypsum required for the grinding of cement due to the greater quantity of sulphur in the clinker, operating costs will be reduced to € 1.4/t of clinker. This contribution may vary greatly, depending on the type of cement produced. [BREF, 2001].</p>

Alternative	5.4.4. WET GAS SCRUBBERS
Action	Action: End-of-pipe treatment.
Stage/Operation	Clinker burning: Rotary kiln
Environmental problems	Generation of atmospheric emissions of SO ₂ .

<p>Environmental benefits of the Alternative</p>	<p>Reductions of sulphur dioxide of between 75 and 90 % can be achieved with the installation of a wet gas scrubber at the kiln gas outlet. And the reduction of other contaminants, such as HCl, waste particles, metals, and emissions such as NH₃. This technique can be applied in both new and existing plants, provided the concentration of SO₂ is high.</p> <p>Gypsum is generated, and this can be used for the production of cement.</p>
<p>Description</p>	<p>This is an alternative system to the CFBA one described above.</p>
<p>Procedure</p>	<p>The exhaust gases from the kiln pass through a gas/water heat exchanger before entering the scrubber at a temperature of 115 °C.</p> <p>In the scrubber, the SO₂ is absorbed by a sludge with a solid load of 6-10 % comprising 98 % dehydrated gypsum (CaSO₄*2H₂O) and 2 % limestone (CaCO₃). The sludge is pulverised counter current to the exhaust gases, and is collected in a recirculation tank, located in the lower section of the scrubber, where is oxidises with the air.</p> $\text{CaSO}_3 + 0.5 \text{O}_2 \longrightarrow \text{CaSO}_4$ <p>One part of the sludge is pumped to a centrifuge, where the gypsum is separated from the water. The rest is re-fed into the scrubber via a tube. The limestone sludge at 30 % humidity is injected via a tube prior to the aerosol injectors, in order to replace the used absorbent.</p> $\text{CaSO}_3 + \text{SO}_2 \longrightarrow \text{CaSO}_3 + \text{CO}_2$ <p>The exhaust gases leave the scrubber at a temperature of 70 °C.</p>  <p>Figure 5.4.1. Venturi wet gas scrubber.</p>
<p>Comments</p>	<p>Maximum reduction efficiency is reached when the SO₂ concentrations in the exhaust gases are in the region of 3,000 mg/Nm³.</p>
<p>Economic Aspects</p>	<p>The service life of a wet gas scrubber is 6 years and the investment cost is between €10- €14 million /t clinker.</p>

	The operating costs for the implementation of this technique in a given plant (including the material required, the power consumed and the maintenance costs) are € 2.7 /t cli. These costs can be reduced to €0.3- €0.8/t cli if the benefits the technique can supply are made use of; i.e, for the heat generated in the heat exchanger and its possible sale, € 3.5 €/t cli, and for the heat generated in the process and which can be used in cement grinding, € 0.18 /t clinker [BREF, 2001].
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Alternative	5.4.5. ADSORPTION WITH ACTIVE CARBON
Action	Action: End-of-pipe treatment.
Stage of the process	Clinker burning: Exhaust gases.
Environmental problems	Generation of atmospheric emissions of SO ₂ .
Environmental benefits of the Alternative	Reduction in the emissions of VOCs, SO ₂ , NH ₃ and heavy metals (HM). Specific deduction of over 95 % of SO ₂ .
Description	The POLVITEC system consists of an active carbon bed.
Procedure	<p>The kiln exhaust gases, from which dust has been removed, are passed through a bed of active carbon, where compounds such as VOCs, SO₂ and NH₃ are adsorbed. Clean gases are subsequently emitted to the atmosphere.</p> <p>The spent active carbon is periodically extracted to a silo, separated and replaced with new absorbent. The carbon from the silo is fed into the kiln along with other fuels. The adsorbed SO₂ is then integrated into the clinker.</p> <p>Due to the characteristics of the activated carbon, only organic compounds of more than five carbons can be adsorbed with a high degree of efficiency.</p>
Comments	This is a highly expensive technique, which means it must be financed by public bodies.
Economic Aspects	This measure involves fairly high investment and operating costs [BREF, 2001].

5.5. TECHNOLOGICAL ALTERNATIVES FOR THE CONTROL OF PARTICLES EMISSIONS

The best available techniques for the reduction of particle emissions are the combination of the general primary measure described above, along with the following:

- Reduction of the different emissions through the application of the techniques describe below in Section 5.5.1. *Control of emissions from diverse sources*.
- Reduction of particle emissions from chimneys through the installation of (see Section 5.5.1. *Control of emissions from diverse sources*):
 - Electrostatic filters, with CO-measuring systems which minimise the number of triggerings.
 - Multi-chamber baghouses and systems for detecting tears in bags.

5.5.1. Control of emissions from diverse sources

The principal sources of diverse emissions are generated in the storage and handling of raw materials, fuels and clinker, and vehicular traffic through the factory.

Possible sources of emissions can be minimised with a simple linear layout for the factory; proper comprehensive maintenance of the installation always has the indirect result of reducing diverse emissions due to the reduction of air escapes and spillage points. The use of automatic control devices and systems also help to reduce diverse emissions.

Techniques for reducing diverse emissions include the following:

- **Wind protection for stockpiles open to the elements.** In the case of storing materials in the open air, diverse emissions can be reduced by using specially designed wind barriers.
- **Water spray and chemical dust suppressors.** When the point of origin of dust is well located, a water spray injection system can be installed. The humidification of dust particles helps in their agglomeration and induces their settlement. A wide range of chemical agents are also used to ensure the total effectiveness of the water spray.
- **Paving, cleaning and sprinkling of roads.** Areas used by lorries must be paved and kept as clean as possible. Road sprinkling reduces dust emissions, especially during dry periods. The adoption of good organisation and cleaning practices also reduces dust emissions.
- **Fixed and mobile suction.** There may be spillage of materials during maintenance operations, or in the case of problems with transport systems. Suction systems can be employed to prevent the formation of dust emissions during cleaning operations. New buildings can easily be fitted with fixed suction-cleaning systems, while existing buildings can be better equipped with mobile cleaning systems fitted with flexible connections.
- **Ventilation and collection in baghouses.** Whenever possible, materials that need to be handled must be transported by means of sealed transport systems kept under depression. The suction air from the system must be subsequently purified in baghouses before emission to the atmosphere.
- **Sealed storage with automatic handling systems.** Clinker silos and sealed stockpiles with automatic handling devices are considered to be the most effective solution for the problem of emissions of dust generated by high volume stockyards. These stockpiles are fitted with baghouses to prevent the formation of dust during loading and unloading operations.

5.5.2. Control of emissions from specific sources:

There are three main specific sources of dust emissions in cement plants: kilns, clinker coolers and cement mills. In each of these sub-processes, the kiln exhaust gas, or air, is made to pass through the dusty materials, so that there is no possibility of a primary reduction.

Nowadays, emissions from these three types of sources are combated with installation of electrostatic precipitators (EPs), baghouses or hybrid filters.

Table 5.5.1. shows a general overview of the data available. This table is a summary, and should be read along with the corresponding points that appear below.

Table 5.4.1. General view of techniques for dust control.

Technique	Applicability	Emission's	Cost ⁽²⁾		Additional effects
		mg/Nm ³ ⁽¹⁾	Investment	Operation	
Electrostatic precipitator	All kilns	<50	2.1-4.6	0.1-0.2	Reduction of metals
	Clinker coolers	<50	0.8-1.2	0.09-0.18	
	Cement mills	<50	0.8-1.2	0.09-0.18	
Baghouses	All kilns	<50	2.1-4.3	0.15-0.35	Reduction of metals
	Clinker coolers	<50	1.0-1.4	0.1-0.15	
	Cement mills	<50	0.3-0.5	0.03-0.04	

(1) For kilns referred to with daily averages, dry gas, 273 K, 101,3 kPa and 10 % oxygen.

(2) Investment cost is expressed in M€/t clinker and the operating cost in €/t of clinker in order to reduce emissions to <50 mg/Nm³, referring normally to a kiln capacity of 3,000 t of clinker/day and initial emission levels of up to 500 g dust/Nm³.

(3) Additional effects on other emissions

Source: Guide to Best Available Techniques in Spain for the Manufacture of Cement (2003)

Both EPs and baghouses have their advantages and disadvantages. Both types are extremely efficient in removing dust during the normal operation of the installation. Some of these new filters, correctly sized and maintained under optimal operation conditions, have made it possible to reach emission values of between 5 and 20 mg/Nm³.

Nevertheless, under special conditions (such as, high concentrations of CO, kiln firing, the start-up or shut-down of the raw mix mill) the effectiveness of EPs may be severely reduced while the effectiveness of baghouses remains unaltered. Consequently, baghouses have a greater total effectiveness if they are well maintained and the filter bags are substituted periodically.

Due to the maximum operating temperatures in the case of baghouses, and due to the electrical resistivity of the dust entering EPs, kiln exhaust gases must be treated by the injection of water in the conditioning tower, or gas outlet duct, or they may be cooled by means of air in a heat exchanger, or through dilution in air.

One disadvantage of baghouses is that used filter bags constitute waste and must be adapted to the corresponding national regulations.

In recent years, the so-called hybrid filters have been developed, consisting of a combination of both systems, so that the gases pass first through an electrostatic chamber, where the dust is partially removed, to then pass through the bag chamber. The aim is to combine the advantages from both systems, and compensate for the disadvantages.

Alternative	5.5.3. ELECTROSTATIC PRECIPITATOR
Action	Action: End-of-pipe treatment.
Stage of the process	Clinker burning: Kiln, clinker cooler, cement mill.
Environmental problems	Generation of atmospheric particles.

<p>Environmental benefits of the Alternative</p>	<p>Reduction of particle emissions with performance of up to 99.99%, and the possibility of recovering reagents.</p> <p>The energy consumption by the electrostatic precipitation is lower than that of other particle purification systems of similar effectiveness.</p> <p>Table 5.5.2. Reduction in the generation of articles with an EP depending on the process.</p> <table border="1"> <thead> <tr> <th>Environmental benefits</th> <th>Electrostatic precipitators for kiln exhaust gases</th> <th>Electrostatic precipitators for clinker output gases</th> <th>Electrostatic precipitator for cement mill output gases</th> </tr> </thead> <tbody> <tr> <td>Reduction in particle generation</td> <td>Up to 99.99 %</td> <td>Up to 99.99 %</td> <td>Up to 99.99 %</td> </tr> </tbody> </table> <p>Maximum efficiency is not guaranteed for applications in any type of kiln. The highest effectiveness is only guaranteed under normal operation conditions. During start-up and shutdown effectiveness is lower.</p>	Environmental benefits	Electrostatic precipitators for kiln exhaust gases	Electrostatic precipitators for clinker output gases	Electrostatic precipitator for cement mill output gases	Reduction in particle generation	Up to 99.99 %	Up to 99.99 %	Up to 99.99 %
Environmental benefits	Electrostatic precipitators for kiln exhaust gases	Electrostatic precipitators for clinker output gases	Electrostatic precipitator for cement mill output gases						
Reduction in particle generation	Up to 99.99 %	Up to 99.99 %	Up to 99.99 %						
<p>Description</p>	<p>Electrostatic precipitators generate an electrostatic field along the path of the particles in the air current. The particles are negatively charged and migrate towards the positively charged collecting plate. The collecting plates are periodically tapped or vibrated for cleaning, discharging the material which falls into hoppers situated below.</p> <p>It is important that the EP cleaning cycles be optimised to minimise the re-entry of macro-particles, thus limiting as far as possible the visibility of the plume that is emitted. EPs are characterised by their ability to work under conditions of high temperatures (up to approximately 400 °C) and high humidity.</p> <p>Among the advantages of electrostatic precipitators is also their capacity to treat large flows of gas (in the order of 0.25 to 1.25 mbar) with small losses of load.</p> <div> </div> <p>Figure 5.5.1. Electrostatic precipitator.</p>								
<p>Procedure</p>	<p>The factors affecting the efficiency of this type of precipitator are the velocity of the gases, the intensity of the electric field, the load rate of the micro-particles, the sulphur dioxide concentration, the humidity content and the shape and area of the electrodes.</p>								

	<p>Operation can be adversely affected by the accumulation of material which may form an insulating layer over the collecting plates, thus reducing the intensity of the electric field. This may come about if there are high inputs of chlorides and sulphur to the kiln, forming chlorides and alkaline metallic sulphates. The alkaline metallic chlorides form a very fine powder (0.1-1 µm) and have a high specific resistivity (between 10^{12} -10^{13} Ωcm) forming insulating layers over the electrodes and hindering the elimination of dust.</p> <p>In existing plants where the electrostatic precipitators installed do not meet with operating standards, the following improvement techniques can be applied:</p> <ul style="list-style-type: none"> • The introduction of vanes into the exhaust gas flow. • Improvement of electric system. • Considering the use of conditioning towers upstream from the EP, introducing steam into the gas flow and thus improving the performance of the precipitator. • Considering the use of pulverised conditioning water in the duct itself, to control the temperature. • Installation of a cyclonic separator prior to the EP, if so required by the conditions of the output gases, thus increasing the efficiency of the EP. • Substitution of the EP by baghouses when substantial improvements are required.
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Comments	Table 5.5.3. Comments on EPs according to process.			
	Comments	Electrostatic precipitators for kiln exhaust gases	Electrostatic precipitators for clinker output gases	Electrostatic precipitator for cement mill output gases
	Water consumption (kg/t clinker)	25-75 (1)	---	---
	Electrical energy consumption (kWh/t clinker)	1.5-2.0 (2)	1.0-1.6	1.0-1.6
	Waste generation (g/t clinker)	5-20	5-20	5-20
	Service life	> 30	> 10	> 10
<p>(1) Water consumption depends on the temperature at the outlet of the preheater, the relative duration of the direct operation with the crude mix mill shut down, and the humidity of the raw material.</p> <p>(2) There is electrical consumption in the powering up of the EP and the operation of the filter ventilator and conditioning tower.</p> <p>The maintenance of the electrostatic precipitators cannot be carried out online, but does not involve any complication whatsoever.</p> <p>One disadvantage of electrostatic precipitators is the risk of explosion arising from incomplete combustions in the kiln. This risk is minimised by the automation of the EP when the carbon monoxide content in the gases entering the EP reaches a high level (below the limit for explosions). For the effective operation of electrostatic precipitators it is important to avoid peaks of CO.</p>				

Economic Aspects

Table 5.5.4. Economic aspects of EPs according to process .

Comments	Electrostatic precipitators for kiln exhaust gases	Electrostatic precipitators for clinker output gases	Electrostatic precipitator for cement mill output gases
Investment Cost (Million of Euros)	1.5-3.8 (0.6-0.8)	0.8-1.2	0.8-1.2
Operating cost (Euro / t cli)	0.1-0.2	0.09-0.18	0.09-0.18

The investment cost for a new EP for a kiln with a capacity of 3,000 t clinker/day, with an initial particle load of up to 500 g/m³ and a dust content in clean gases of <50 mg/Nm³ is in the region of € 1.5- € 3.8 million, and an extra € 0.6- € 0.8 million for the conditioning tower and the filter ventilator, if required. The associated operating cost is around € 0.1- € 0.2/t clinker.

For a clinker cooler for a kiln with a capacity of 3,000 t clinker/day, an initial particle load of up to 20 g/m³ and a dust content in clean gases of <50 mg/Nm³ and a ball mill for cement with a capacity of 160 t cement/hour, with an initial level of two 300 g/m³ and dust content in clean gases of <50 mg/Nm³, the investment cost is in the region of € 0.8- € 1.2 million and the operating cost in the region of € 0.09- € 0.18 /t clinker [Cembureau, 1997].

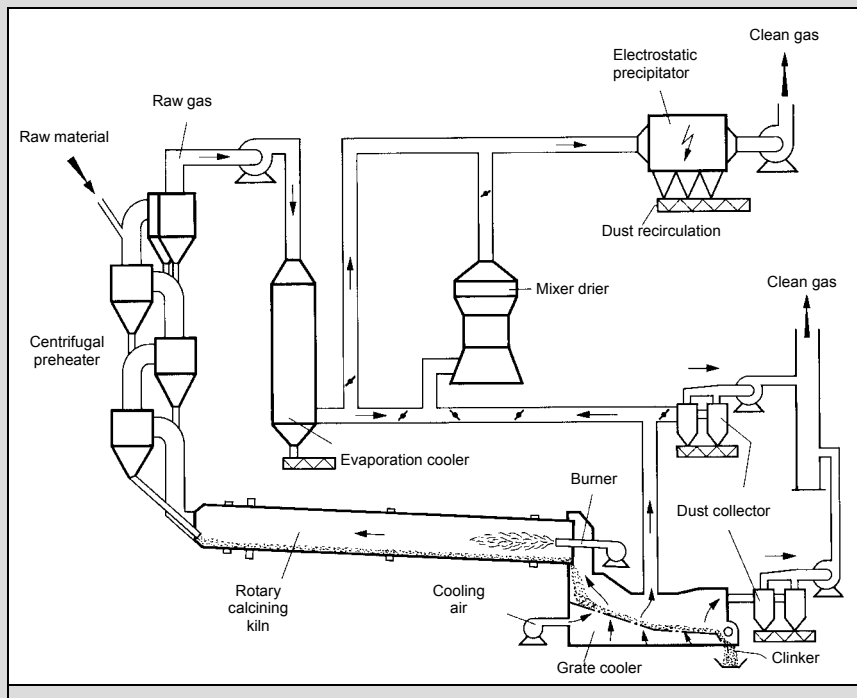


Figure 5.5.2. Cement manufacturing process with a rotary kiln, centrifugal preheater and electrostatic precipitator and dust collector

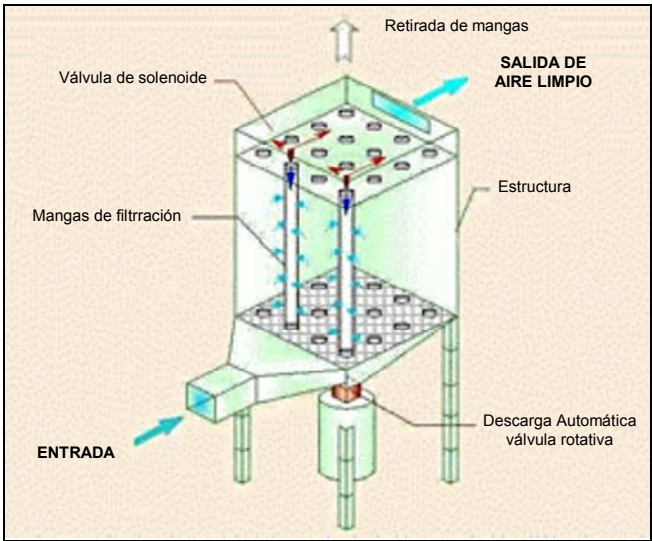
Alternative	5.5.4. BAGHOUSES
Action	Action: End-of-pipe treatment.
Stage of the process	Clinker burning: Kiln, clinker cooler, cement mill.
Environmental problems	Generation of atmospheric particles.
Environmental benefits of the Alternative	A reduction in the omission of articles to the atmosphere of up to 99.99 % is obtained.
Description	The basic principle of baghouses is the use of a cloth membrane which is permeable to gas, but which retains dust.
Procedure	<p>The current designs for fabric filters depend on the cleaning method used. The most common cleaning methods include reverse gas flow, mechanical shaking, vibration and impulsion with compressed air.</p> <p>In the most primitive form of baghouses, the filter is cleaned with a vibrator. The lower open end of the bags are attached, at the openings, to the plate of tubes which separate the lower dirty gas input chamber from the upper clean gas chamber. The brackets from which the bags are suspended are connected to a vibrating mechanism. The dirty gas flows upwards and towards the interior of the filter bags, and the dust builds up on the internal surfaces thereof.</p> <p>As the dust cake builds up in thickness, the resistance to the flow of gas increases; consequently, periodic cleaning of the filtering medium is required to control the drop in gas pressure throughout the filter.</p> <p>The baghouse may have a number of compartments which are individually isolated in case one of the bags rips (Figure 5.5.3.). This increases the cost and size of the filter, but means that online maintenance can be carried out. The filter must be sufficiently large to allow its correct operation in the case of one of the compartments being out of service. The installation of "torn-bag detectors" in each compartment makes it possible to be aware of maintenance needs at all times.</p>  <p>The diagram illustrates the internal structure of a baghouse. It shows a cylindrical chamber divided into two main sections. At the bottom, there is an 'ENTRADA' (entrance) where air enters. The air flows upwards through a grid of 'Mangueras de filtración' (filtering hoses) which support several vertical 'Mangas de filtración' (filter bags). A 'Válvula de solenoide' (solenoid valve) is located at the top of the filter bags. Above the filter bags, the air is cleaned and exits through a 'SALIDA DE AIRE LIMPIO' (clean air outlet). At the bottom of the chamber, there is a 'Descarga Automática válvula rotativa' (automatic discharge rotating valve). The entire structure is supported by an 'Estructura' (structure). A 'Retirada de mangas' (bag removal) mechanism is shown at the top, indicating the process of cleaning the filter bags.</p>

Figure 5.5.3. Diagram of the operation of a baghouse.

	<p>Depending on the cleaning method used (continuous or batch), two different types and filters can be distinguished: reverse-air and mechanical-shaker baghouses.</p> <p>The shaking method is employed when there is the possibility of taking the filter out of service for a short period of time. Thus it requires discontinuous operation, with a filtering cycle and a cleaning cycle. The simplest and most inexpensive type consists of a certain number of bags housed inside a casing. It functions at a velocity of approximately 0.01 m/s through the filter bag. For small units, cleaning can be carried out manually. There is also a more complicated and robust version which includes an automatic shaking mechanism for cleaning the cloth, and this may function by mechanical, vibratory or pulsatory methods. The bags are fastened to a mechanical support connected to a system which is shaken or vibrated by an electric motor. As the fabric is thicker, higher frontal velocities can be used (up to 0.02 m/s) and it can operate under more demanding circumstances than the aforementioned ones.</p> <p>With respect to reverse air, there are many different types of devices, but the normal cleaning mechanism consists of the introduction of a jet of high pressure air (counter-current and for short bursts) by means of a nozzle connected to a compressed air circuit. The frontal velocity is in the region of 0.05 m per second, and high concentrations of dust can be treated with high levels of efficiency. Mixes that are difficult to separate can be treated with this filter in a compact economical unit. This cleaning mechanism is also called "jet pulse", and is more efficient than the one above.</p> <p>A method which combines the two aforementioned techniques (shaking and reverse air) is used to obtain continuous operation, and to this end the filtering elements must be laid out in two or more independent chambers, each one of which has its own shaking system and clean air inlet. The air enters the bags in the opposite direction by means of a ventilator which forces the flow, from outside in, thus favouring the separation of the cake.</p>
<p>Comments</p>	<p>The use of baghouses with gases at high temperatures requires the fitting of more resistant fabrics than those usually supplied, and thus higher costs.</p> <p>The principal advantage of baghouses is that their effectiveness is always high, even if the parameters of the process are altered (e.g., during the start-up or shutdown of the Kiln, clinker cooler or cement mill, etc.).</p> <p>One of the main drawbacks of baghouses is the high loss of pressure (8 - 20 mbar) which occurs within the filter, giving rise to greater energy consumption for the fan.</p> <p>Nevertheless, owing to their simplicity, reliability, greater elimination ratios than EPs and economic competitiveness, baghouses are the most suitable for installation in the cement industry. Moreover, these filters can eliminate certain contaminants that may be emitted by adsorption into the cakes in the dust collector, on the surface of the bag.</p>

Economic Aspects	Table 5.5.5. Economic aspects of EPs depending on the process.			
	Comments	Baghouses for kiln exhaust gases	Baghouses for output gases from the clinker cooler, with jet pulse cleaning system	Baghouses for output gases from the cement mill, with jet pulse cleaning system
	Investment Cost (Million of Euros)	0.15-0.35 (0.6-0.8)	1.0-1.4	0.3-0.5
	Operational cost (Euro/t cli)	0.5-0.9	0.10-0.15	0.03-0.04
<p>The investment cost of installing a new baghouse for a kiln with a capacity of 3,000 t clinker/day, with initial emissions of up to 500 g/m³ and a dust content in clean gases of <50 mg/Nm³ is in the region of € 1.5- € 3.5 million, and an extra € 0.6- € 0.8 million for the conditioning tower and the filter ventilator. Conditioning towers are required only for applications at low temperatures with filter bags, for example, polyacrylonitrile. The operating cost for the kiln baghouse itself is in the region of € 0.5- € 0.9/t of clinker.</p> <p>The investment required for the installation of a baghouse with a jet pulse cleaning system in a clinker grate cooler for a capacity of 3,000 t clinker/day, with initial emissions of up to 20 g/m³ and a dust content in clean gases of <50 mg/Nm³ is in the region of € 1.0- € 1.4 million (including the air heat exchanger and the filter ventilator) and the operating cost is approximately € .10 - € 0.15 €/t clinker.</p> <p>For a ball cement mill with a capacity of 160 tonnes of cement/hour, with initial emission levels of 300 g/m³ and a dust content in clean gases of <50 mg/Nm³, the investment costs for a baghouse with an air pulse cleaning system is in the region of € 0.3- € 0.5 million, including the filter ventilator, and the operating cost is in the region of € 0.03- € 0.04 /t clinker [BREF, 2001].</p>				

Alternative	5.5.5. HYBRID FILTERS
Action	Action: End-of-pipe treatment.
Stage of the process	Clinker burning
Environmental problems	Generation of atmospheric particles.
Environmental benefits of the Alternative	Reduction of particle emissions by 99.99 %.
Description	<p>Advanced Hybrid Filters form a contamination control system which eliminates microscopic particles from the output gases of coal plants, incinerators and cement plants, comprising an electrostatic precipitator and baghouse.</p> <p>This technology is currently in use in a number of cement plants. In Spain, the first hybrid filter was installed in the Gádor factory (Almería) in 2004.</p>

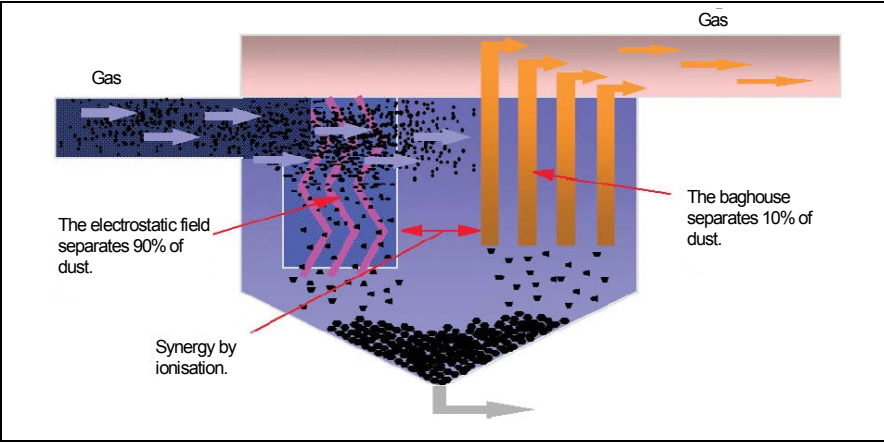
<p>Procedure</p>	<p>These devices make use of the advantages of the two traditional particle purification methods employed in cement factories: firstly, they conserve an electrostatic field due to the fact that their theoretical collection efficiency is around 90 % (collection due to electrostatic precipitation and by sedimentation), then they have bank of bag filters which purifies a gas flow that is cleaner than that dealt with by conventional baghouses.</p>  <p>Source: <i>Cemento y Hormigón</i>, May 2005</p> <p>Figure 5.5.4. Diagram of the operation of a bag filter.</p> <p>Faced with situations in which a classic electro-filter is disconnected (due to the presence of CO, or when its behaviour is diminished, such as in the case of the transitory periods that occur during changes of cycle) the hybrid filter continues to purify the gases efficiently, thanks to the role played by the filter bags.</p> <p>These are subjected to much lower mechanical requirements than in conventional baghouses, since they deal with a much lower dust load and thus require much less cleaning. Consequently, the service life of bag filters is extended and the consumption of cleaning air and the loss of load by the filter are reduced, making it possible to save energy.</p>
<p>Comments</p>	<p>According to research, there is an important additional advantage; the finest dust particles, which during normal operation escape the electrostatic part and reach the baghouse, are ionised by the effect of the electric field and have a certain tendency to repel each other. This effect facilitates the elimination of dust from the surface of the baghouse, which may be carried out with low flows of low pressure air, thus helping to reduce the mechanical forces to which the filter and medium is subjected, and extending its service life. According to the same information, the residual electrostatic effect is very short lived and would be lost if, for example, a set of conventional baghouses were set in series after an existing electrostatic filter.</p> <p>Table 5.5.6, below, shows the advantages of implementing this technology as opposed to other types of substitution alternatives in a plant wishing to change the existing electrostatic precipitator.</p>

Table 5.5.6. Evaluation of the different substitution alternatives.				
	Hybrid filter	Transformation of the EP into a baghouse	Optimisation of the EP	New Baghouse
Emissions	√√	√	X	√
Length of stop	14 days	19 days	3 days	5 days
Available space	√	√	√	X
Energy consumption	√	X	√√	X
Economic Aspects	The investment cost of installing a hybrid filter in a plant that currently has an electrostatic precipitator is lower than converting it into a baghouse or replacing it by a new baghouse, and approximately the same as the cost involved in the optimisation of the EP [Cemento y Hormigón, 2005].			

5.6. TECHNOLOGICAL ALTERNATIVES FOR THE CONTROL OF VOCs AND PCDD/PCDFs

The principal source of emissions of VOCs (Volatile Organic Compounds) originating from cement kilns is the organic matter present in raw materials. A portion of this organic matter is extracted when exposed to high temperatures in the kiln system. Under these conditions, some organic compounds oxidise (burn), but the others leave the kiln in the form of emissions. The lower the quantity of organic matter in the raw material, and the higher the temperature is in the kiln, the lower the emissions of VOCs will be.

The performance of the extraction of organic matter present in the raw materials depends, and other things, on the type of kiln. Thus for example, the oxygen concentration in the exhaust gases of kilns with preheating has only a slight effect on the emission of VOCs, while the concentration of oxygen in long wet and dry kilns is potentially important for the reduction of VOCs.

With an increase in oxygen concentration, emissions of VOCs in wet kilns are lower, for the same raw material, in comparison to kilns with preheating. This is due to the high differences in temperature between the raw meal and the exhaust gases from long wet and dry kilns in comparison with kilns with preheaters.

The combustion in the burning zone produces flame temperatures in excess of 2,000 °C. Thus, all the organic compounds that are fed into the principal burner are completely oxidised (burnt) and do not contribute to the emission of VOCs. In both the secondary burning stage and the precalciner, temperatures in the region of 900 -1,000 °C are produced, due to which special care must be paid to the choice, preparation and injection of fuels.

The emission of VOCs in cement kilns is normally between 10 and 100 mg/Nm³; nevertheless, depending on the characteristics of the raw materials, up to 500 mg/Nm³ may be generated.

One aspect to be borne in mind is the emission of CO, which is normally high when the content of organic matter present in the raw materials is elevated. The VOCs extracted from raw materials are usually oxidised to CO₂ or CO. Especially in zones where there is a low O₂ content, or whether temperatures are not high, there are incomplete oxidations of VOCs, which give rise to CO.

In order to reduce emissions of VOCs in pyroprocesses to a given controlled level, there are three basic measures:

- Maintaining the existing process and reducing the quantity of organic matter in the system.
- Modifying the existing process (at-source prevention measures or reduction measures).
- Maintaining the existing process and adding a gas cleaning unit for the exhaust gases (secondary reduction measure, end-of-pipe treatment).

Another aspect to be taken into account is the formation in the combustion process of persistent organic compounds, dioxins and furans (PCDDs and PCDFs). Along with the careful selection and control of the raw materials fed into the kiln, the rapid cooling of the kiln exhaust gases to a temperature below 200°C is considered to be the best measure for avoiding the formation of these molecules.

Under normal operating conditions, the primary measure is assumed to be sufficient in order to comply with the emission levels of 0.1 ng EQT/Nm³.

We now go on to describe a number of measures for reducing emissions of VOCs with efficiencies of between 0 and 95 %. These measures require certain conditions prior to their application. In certain cases it is possible to adapt the existing kiln system to permit the application of reduction measures. Nevertheless, this causes additional problems with regard to investment costs.

The application of these measures is limited to certain highly specific cases, and normally involves high investment and operating costs. There is no possibility of applying at-source prevention measures for emissions of VOCs without these high investment and operational costs.

The only secondary reduction technique (end-of-pipe treatment) possible is the adsorption of active carbon (see File 5.6.4.) which makes it possible to reduce emissions of the organic compounds of more than six carbons C₆. Compounds smaller than or equal to C₅ cannot be eliminated efficiently. Nevertheless, it should be mentioned that more than 80 % of VOC emissions in cement kilns consist of compounds equal to or smaller than C₅.

Alternative	5.6.1. SELECTION OF RAW MATERIALS AND FUEL.
Action	Action: Prevention of contamination at source. Substitution of raw materials.
Stage of the process	Preparation of raw materials and fuel.
Environmental problems	Generation of emissions of Volatile Organic Compounds (VOCs).
Environmental benefits of the Alternative	Reduction of VOC emissions.
Description	Depending on the geological history of the rock used as raw material, it will have a content of organic matter or not. A portion of this organic matter is extracted after being fed into the kiln. Some of these organic compounds oxidise, others leave the kiln as emissions. Thus, the lower the content of organic matter present in the raw material and the higher the temperature of the elimination of organic compounds, the lower the generation of organic emissions from the kiln will be.
Procedure	Substitution of raw materials or fuels with high organic matter content for other, more environmentally friendly ones.

Comments	It is not possible to reduce the organic matter content of natural raw materials.
Economic Aspects	The economic aspects relative to this measure are those associated to the cost of substituting the raw material or fuel with a high content of organic matter.

Alternative	5.6.2. ADDITION OF RAW MATERIAL IN THE HOT ZONE OF THE KILN
Action	Action: Prevention of contamination at source. Modification of processes.
Stage of the process	Clinker burning: Kiln
Environmental problems	Generation of emissions of Volatile Organic Compounds (VOCs).
Environmental benefits of the Alternative	Reduction of VOC emissions by up to 95 %.
Description	Addition of raw material with organic matter content in the hot zone of the kiln.
Procedure	If any component of the raw material causes high emissions of VOCs, this is added directly to the hot zone of the kiln, in order for the organic compounds to be burnt before they reach the atmosphere.
Comments	<p>If part of the raw material is responsible for the emission of VOCs, it is possible to feed all the material into a flash calciner, where the temperature destroys practically all organic matter. Installing this calciner with all the additional equipment required involves a substantial investment. Moreover, the energy consumption of the kiln with a flash calciner is significantly higher than that of a kiln with a preheater.</p> <p>The disadvantages of this addition are as follows: the high energy consumption of the kiln, the possible need for additional work at the injection point, and less homogenous feeding into the kiln, which may adversely affect the quality of the clinker.</p> <p>The consumption of thermal energy due to the application of this measure ranges from 0-3,300 KJ/ t clinker, it being practically null if small portions of raw material are fed directly into the hot zone of the kiln.</p> <p>This measure is only applicable for components that represent a very small percentage of the raw material.</p>
Economic Aspects	The investment costs for this technique exceed € 25 million, taking into account that if only a small portion of the raw material is fed into the hot zone, the cost is greatly reduced, and if all the raw material needs to be passed through a flash calciner, the cost is much greater. Operational costs are an excess of € 8.9 / t clinker [BREF, 2001].

Alternative	5.6.3. ADSORPTION WITH ACTIVE CARBON
Action	Action: End-of-pipe treatment. Secondary solution only if exceeding 0.1 ng/m ³ after primary techniques.
Stage of the process	Clinker burning Kiln exhaust gases.
Environmental problems	Generation of emissions of Volatile Organic Compounds (VOCs) and PCDD/PCDFs.
Environmental benefits of the Alternative	Reduction in the emissions of VOCs, SO ₂ , NH ₃ and heavy metals (HM) and PCDD/PCDF
Descripción	The POLVITEC system consists of an active carbon bed.
Procedure	<p>The kiln exhaust gases, from which dust has been removed, are passed through a bed of active carbon, where compounds such as VOCs, SO₂ and NH₃ are adsorbed. Clean gases are subsequently emitted to the atmosphere.</p> <p>The spent active carbon is periodically extracted to a silo, separated and replaced with new absorbent. From the carbon silo, it is fed into the kiln along with other fuels, where the adsorbed VOCs are burned. Owing to the characteristics of activated carbon, only organic compounds with more than five carbons can be absorbed with a high degree of efficiency.</p>
Comments	This is a highly expensive technique, which must be financed by public bodies.
Economic Aspects	This measure involves fairly high investment and operating costs [BREF, 2001].

5.7. TECHNOLOGICAL ALTERNATIVES FOR THE CONTROL HEAVY METAL EMISSIONS

Metals heavy than titanium (4.51 g/cm³) are considered to be heavy metals (HM). Not all heavy metals are toxic, and not all toxicities of metals are of the same level. Nevertheless, in some countries heavy metals are differentiated according to their toxicity:

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

Class I HMs are more toxic, and Class III metals are less toxic.

The principal sources of heavy metal emissions from cement kiln chimneys are the contents of heavy metals in raw materials and in fuels. Depending on their behaviour in the Kiln system, three different types of metals can be distinguished:

- Non-volatile heavy metals, or those with low volatility (As, Be, Co, Cr, Cu, Mn, Sb, Se, Te, V, Zn): up to 100% of these are incorporated into the clinker, and there are practically no emissions.
- Semi-volatile heavy metals (such as Ti, Pb and Cd): these are not completely incorporated into the clinker. The remaining part, which is not incorporated into the clinker, is almost completely adsorbed into the surface of dust particles in the kiln exhaust gas system. Filters such as electrostatic precipitators and baghouses can efficiently eliminate semi-volatile heavy metals. The dust collected in filters is normally re-fed into the kiln, which gives rise to an accumulation

of heavy metals therein. To prevent this, a portion of the dust collected in the filters is fed into the cement mill.

- Volatile heavy metals: these cannot be effectively controlled by removing the dust from kiln exhaust gases, as a proportion of the volatile metals always remain volatile (they are not adsorbed onto the surface of the dust particles). The most characteristic example in the cement industry is mercury, Hg, which is emitted to a great degree in vapour form; thus, the lower the temperature of the exhaust gas in the filter, the greater the proportion of mercury adsorbed in the dust particles that can be eliminated by the exhaust gases will be.

There are basically three ways of reducing heavy metal emissions in pyroprocesses:

- Maintaining the existing processes and reducing the amount of heavy metals fed into the system.
- Modifying the existing process (at-source primary prevention measures or reduction measures).
- Maintaining the existing processes and adding a gas cleaning unit for the output gases (secondary reduction measures, end-of-pipe treatment).

Each measure requires its own preliminary conditions. The most common measures for reducing heavy metal emissions are to reduce the input of HMs and efficient dust removal. To avoid the accumulation of HM in the kiln system, a portion of the dust in filters must be continuously or periodically extracted from the process. There are also a number of secondary measures, such as adsorption with active carbon, which are only required if the volatile HM content is very high.

Alternative	5.7.1. SELECTION OF RAW MATERIALS AND FUEL
Action	Action: Prevention of contamination at source. Substitution of raw materials.
Stage/Operation	Preparation of raw materials and fuel.
Environmental problems	Generation of emissions of heavy metals (HM).
Environmental benefits of the Alternative	Reduction in emissions of heavy metals (HM).
Description	Heavy metals are found naturally in certain raw materials used in the manufacture of cement. Non-volatile heavy metals reach the dust removal unit incorporated in dust particles. Semi-volatile and volatile metals may reach the dust removal unit either as described above, incorporated in dust particles (e.g. Ti), or in vapour form (e.g. Hg). The higher the content of volatile HMs in raw materials or fuel, the higher the emissions normally are, but generally at a low level.
Procedure	Substitution of raw materials or fuels with high heavy metal content with other, more environmentally friendly ones.
Comments	The reduction of semi-volatile and volatile HMs in natural raw materials or fuels is practically impossible. The use of waste containing excessive quantities of HMs as alternative raw materials or fuels must be avoided.
Economic Aspects	The economic aspects relative to this measure are those associated to the cost of substituting the raw material or fuel with a high content of HMs.

Alternative	5.7.2. ADSORPTION IN ACTIVE CARBON
Action	Action: End-of-pipe treatment. Secondary solution only if exceeding 0.1 ng/m ³ after primary techniques.
Stage of the process	Clinker burning. Kiln exhaust gases.
Environmental problems	Generation of emissions of heavy metals (HM).
Environmental benefits of the Alternative	Reduction in the emissions of heavy metals (HM), VOCs, SO ₂ and NH ₃ .
Description	The POLVITEC system consists of an active carbon bed.
Procedure	<p>The kiln exhaust gases, from which dust has been removed, are passed through a bed of active carbon, where compounds such as HMs, VOCs, SO₂ and NH₃ are adsorbed. Clean gases are subsequently emitted to the atmosphere.</p> <p>The spent active carbon is periodically extracted to a silo, separated and replaced with new absorbent. From the carbon silo, it is fed into the kiln along with other fuels, where the adsorbed HMs are integrated into the clinker, or otherwise, emitted by the kiln system. If there is a build-up of HM, then these must be eliminated from the system by means of a small dust extraction collected in the kiln filter, and then fed into the cement mills.</p>
Comments	The adsorption of active carbon is a highly expensive measure; its application is only viable through the financing of public bodies.
Economic Aspects	This technique involves fairly high investment and operating costs [BREF, 2001].

5.8. TECHNOLOGICAL ALTERNATIVES FOR THE REDUCTION OF CO₂

As has already been mentioned, in Section 5.1.1.4 *Clinker burning*, emissions of CO₂ depend on the energy efficiency of the process, the fuel used and the clinker/cement ratio, except in the case of carrying out end-of-pipe CO₂ capture treatment, which is currently in the developmental phase.

Thus, the following alternatives are available for the prevention of CO₂ emissions at source:

- Improvement in the energy efficiency of the process. See Section 5.1 *Technological alternatives for the correct management of energy*.
- Replacing one technology with another of greater energy efficiency (e.g. from a wet process to a dry one). See Section 5.1 *Technological alternatives for the correct management of energy*.
- Replacing fuel with waste.
- Reduction of the clinker/cement ratio. See Section 5.1.4. *Reduction of the clinker/cement ratio and 5.2.11*.

Alternative	5.8.1. Substitution of fuel with waste
Action	Action: Prevention of contamination at source. Substitution of fuel.
Stage/Operation	Preparation of fuel.
Environmental problems	Generation of CO ₂ emissions.
Environmental benefits of the Alternative	Reduction of CO ₂ emissions.
Description	<p>The emission of CO₂ originating the combustion per kilogram of clinker is directly proportional to the carbon content per unit of energy of the fuel. Thus, the substitution of one fuel by another with lower carbon content per unit of energy entails a reduction in CO₂ emissions.</p> <p>Similarly, the use of certain types of hazardous and innocuous industrial wastes (distillation waste, non-halogenated solvents, certain oils) leads to reduction in CO₂ emissions, as they have lower GG emission factors than if they were incinerated or sent to landfill. In the case of biomass, the emission coefficient is zero.</p>
Procedure	Substitution of fuels for waste with low CO ₂ emission coefficients.
Comments	<p>The CO₂ originating from combustion accounts for only part of CO₂ emissions.</p> <p>Substitution by biomass results in a decrease in GG emissions, since the emission coefficient is zero and the substitution by non-biomass waste does not reduce the emissions of the cement sector, but does reduce the country's emissions by avoiding waste treatment in landfill or incinerators.</p>
Economic Aspects	The economic aspects relative to this measure are those associated to the cost of substituting the fuel, which are as variable as local fuel prices.

5.9. TECHNOLOGICAL ALTERNATIVES FOR THE REDUCTION OF ODOURS

The chemical elements that may be given off by a chimney in a cement plant are due principally to SO₂, and to a lesser extent, NH₃ and organic compounds; all of these have a detection threshold of 50-100 %, ranging from 100 ppt to 10 ppm.

With respect to diffuse odours, these are principally due to the unloading of fuel and storage sites, due to which suitable handling is required in unloading and storage operations.

With regard to odours, the term 'control' is used to refer to processes which render the specific smell more acceptable to people. This is normally obtained reducing the intensity of the odour.

Relating to the operation of the cement plant, the reduction in the intensity of an odour is accompanied by the elimination of odorants in the gas and steam, and even via the reduction of particles.

The identification of the odour of an odorant is determined by two parameters:

- Detection of the odour threshold, which is defined as the concentration of odorant at which it is detected.
- Odour index: this also takes into account evaporation as a ratio between the steam pressure and 100 % of the threshold for detection as an odorant.

In general, both gases and vapours are odorous. The practically inodorous gases are: O₂, N₂, H₂, H₂O, CO, CO₂, CH₄, NO, as well as noble gases.

Odours may also be associated with airborne particles, as certain particles can stimulate the sense of smell, either because they themselves are volatile or because they give off a volatile odorant.

5.10. TECHNOLOGICAL ALTERNATIVES FOR THE CONTROL OF NOISE EMISSIONS

Noise reduction is becoming an ever more important aspect to be taken into account in cement plants. This aspect has a certain degree of controversy associated to it, perhaps not so much due to the requirements of high-technology for the reduction of noise in existing plants, as to the high investment costs and problems in carrying out the necessary modifications.

Unlike the emission of particles to the air, the assessment of noise in the environment depends greatly on the plant's surrounding area. Thus, for example, the impact the noise has on the residential areas surrounding the location of the plant must be taken into account for the application of reduction measures.

In practice, and in the majority of cases, the best noise reduction techniques can be implemented in new plants. This underlines the importance of good acoustic designs, from a preliminary study of the layout of the plant to the suitable selection of machinery: the most effective noise reduction is carried out on surfaces.

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

The principal sources of surface noise emissions are airflow, machinery and noise from the buildings.

5.10.1. Noise generated by airflow

In general, air flowing through a duct, tube or chimney generates a noise whose sound level depends on the cross-section, flow and velocity.

Flow speeds in excess of 15-20 m/s generate a noise which must be reduced. The installation of silencers is one of the only techniques available for reducing noise generated by airflows.

The silencers must be installed as close as possible to the surface generating the noise, and as far away as possible from its output, taking into consideration the maintenance of airspeed after the reduction device.

Silencers may be of three types:

- The simple cladding of ducts with sound proofing materials such as rock wool or glass wool.
- Parallel reflecting silencers
- Plenum silencers.

The silencers used for the inlet and outlet of compressors are normally designed by the suppliers of the machinery.

Simple cladding with soundproofing materials serves for many purposes, and gives rise to very low drops in pressure, but for a reduction efficiency of -2 dB/m, it must be installed over substantial lengths.

Parallel reflecting silencers are used in ducts with variations in flow of up to 250,000 m³/h, and have a reduction efficiency of 10-15 dB/m; nevertheless, for higher flow variations they may give rise to substantial falls in pressure (40-60 mmWG).

Plenum silencers (a series of aligned expansion chambers with acoustic insulators) are preferred for higher flow variations due to their reduction efficiency and the low drop in pressure (max. 20 mmWG); nevertheless, they involve higher investment costs.

The primary measures for controlling surface noise, such as the proper calibration of the inputs and output of ducts in order to reduce velocity, or the modification of existing machinery (e.g. low-speed fans fitted with aerodynamic blades), may be only moderately effective.

5.10.2. Noise generated by machinery

By machinery we refer to any equipment in the process capable of generating noise, including crushers, mills, etc., as well as fans, motors and compressors.

In some cases, noise can be primarily reduced through the choice of less noisy machinery. Compressors are usually connected to a soundproofing box, designed specifically by the suppliers.

In other cases, noise can be reduced through the insulation of the machinery with suitable materials, or by setting the machinery inside a soundproof box. In any case, a safe cooling device must be provided, and this in turn must be soundproofed, with the aim of dissipating heat.

The insulating materials used are various layers of rock wall (up to 120 kg/m³), glass wool (up to 80 kg/m³) or wooden cladding (up to 120 mm).

5.10.3. Noise from buildings

When the aforementioned incubation measures are not possible, due to lack of space or the layout of the plant, or do not work sufficiently well, the only solution is to enclose the machinery in a building or to build curtain walls to reduce the propagation of sound. In these cases it may also be necessary to install cooling devices, which must in turn be soundproofed, with the aim of dissipating heat.

Many types of materials can be used to build curtain walls, avoiding at all times the transmission of vibrations from the ground or from the structure toward the building. If this occurs, the façade may act as a loudspeaker, generating levels of low-frequency noise, but with high power, taking into account the total vibrating surface.

The efficiency of the curtain wall depends proportionally on its specific mass (kg/m³) and sound frequency. This efficiency seems to be greater for higher frequencies.

Materials that can be used in the construction of curtain walls include, among others:

- Concrete blocks or hollow bricks: owing to their rigidity, they offer greater noise reduction with a thickness of over 200 mm (150 kg/m²).

Prefabricated concrete: for the same reason, the thickness must be over 80 mm (175 g/m²).

5.11. TECHNOLOGICAL ALTERNATIVES FOR THE CONTROL OF VIBRATIONS

In recent years, a number of problems have arisen regarding vibrations associated with structures that are increasingly more intricate and complicated, and machinery that is ever more rapid and complex. These problems go hand-in-hand with the demand for lower costs and increased efficiency.

The intensity of vibrations is measured in speed (m/s) or acceleration (m/s²).

Nowadays only a small number of countries place limits with regard to the vibration of structures, or maximum vibrations which are unpleasant for humans. Moreover, the transmission of vibrations towards the ground or structures of industrial buildings is also a strong potential source of noise generation.

Some examples of equipment in cement plants which cause vibrations are roller mills and the clinker silo.

5.11.1. Vibration in roller mills

Any machine characterised by high rotation velocities and stress is a potential source for the generation of vibrations. In order to avoid these vibrations, good environmental practices must be carried out, such as the installation of these machines on anti-vibration mountings and concrete foundations. If these measures do not function properly, greater investment will have to be made to insulate the foundations of the machinery and thus avoid transmitting vibrations to the rest of the structure.

5.11.2. Vibration in clinker silos

Vibrations in clinker silos are fairly infrequent, and can be avoided or reduced by means of the correct evaluation of the structure, quality control of the clinker and temperature, as well as through the proper distribution and number of extraction hoppers.

5.12. TECHNOLOGICAL ALTERNATIVES FOR THE CONTROL OF WASTE

Hazardous waste (HW) must be properly collected, stored, labelled and handed over to so-called authorised hazardous waste managers.

The basic steps for the proper management of waste generated in cement factories should include the following practices:

- Characterisation of waste to determine its hazardousness.
- Study of the sources of waste and the possibilities of avoiding all reducing its generation.
- At-source selection and segregation of waste
- The promotion of recycling and reuse of non-hazardous waste within the factory itself or its deliver to waste managers for them to implement these practices.

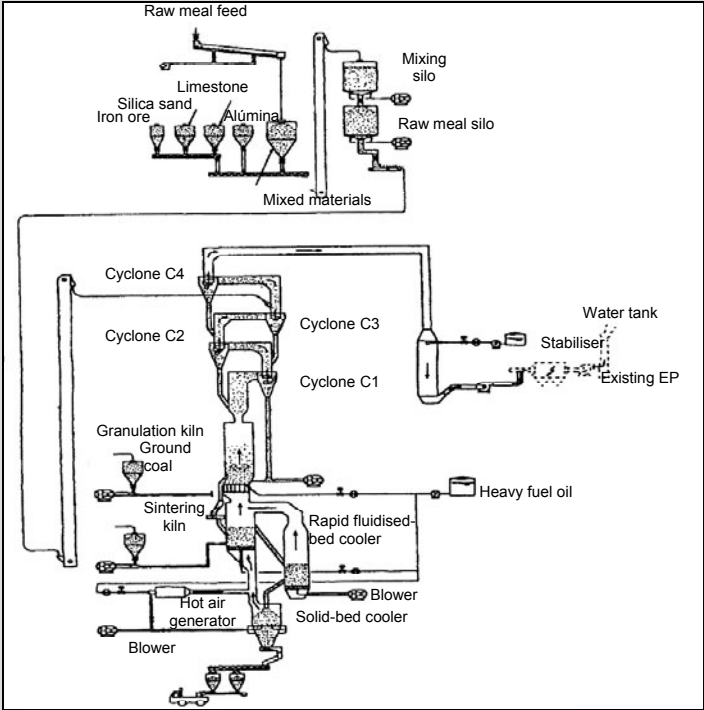
Protecting storage and handling systems for hazardous waste, in order to minimise the risk of the accidental contamination of soils and water.

5.13. EMERGING TECHNIQUES

Emerging techniques are considered to be those that have yet to be fully assimilated by the market, and which may even be in the research or testing phases, due to which the development is not definitive and certain economic and technical parameters remain unknown.

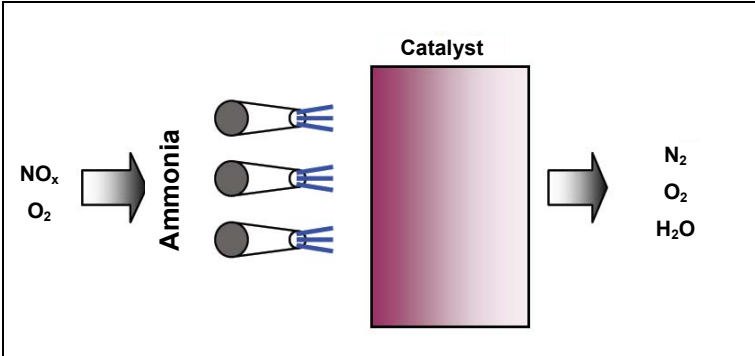
The following are some of these emerging techniques, which are described below in the form of files:

- **At-source prevention technologies:** Those which consist of technological changes, and which are preventative measures.
- **Technology of fluidised bed clinker manufacture**
- **Multi-stage combustion in combination with selective non-catalytic reduction (SNCR).**
- **End-of-pipe technologies:** Those which act once the damage has been produced (contamination); these are corrective measures.
 - Selective catalytic reduction (SCR).

Alternative	5.13.1. TECHNOLOGY OF FLUIDISED BED CLINKER MANUFACTURE
Action	Action: Treatment at source. Modification of processes.
Stage of the process	Clinker burning
Environmental problems	Generation of SO ₂ , NO _x . High energy consumption
Environmental benefits of the Alternative	With the technology of manufacturing clinker in fluidised beds, SO ₂ emissions can be reduced by 10-12 %, thanks to the combustion of SO ₂ emissions from the rotary kiln. It is estimated that the emission levels for NO _x will be 380 mg/m ³ or lower.
Description	<p>The technology of burning in a fluidised bed kiln is a project that has been subsidised by the Japanese Ministry of International Commerce and Industry since 1986.</p> <p>Between 1989 and 1995 it was operational in a pilot plant with a capacity of 20 t clinker/day, in the Toshigi plant of the Sumitomo Osaka Cement Co. Ltd. At the end of 1995 another pilot plant was constructed with a capacity of 200 t clinker/day.</p> <p>The following diagram shows the layout of the fluidised-bed kiln system for the pilot plant with a capacity of 20 t clinker/day. The system comprises a suspended preheater, a fluidised-bed granulation kiln, a fluidised bed rapid cooler, and a solid bed cooler.</p>  <p style="text-align: center;"><i>Source: Japanese Cement Association, 1996.</i></p> <p style="text-align: center;">Figure 5.13.1. Fluidised bed kiln.</p>

Procedure	The suspended preheater is a conventional preheater with four cyclone stages for preheating the raw meal. The granulation kiln granulates the raw meal into granules with a diameter of 1.5 - 2.5 mm at a temperature of 1,300 °C. The clinkering of the granules is completed in the sintering kiln at a temperature of 1,400°C. The fluidised-bed rapid cooler rapidly cools the cement clinker from 1,400° C to 1,000°C. And finally, the cement clinker is cooled to approximately 100° in the solid bed cooler.
Comments	The clinker cement produced in the fluidised bed kiln is of a similar quality to that produced in a rotary kiln. The emission of NO _x is 115-190 mg/Nm ³ when heavy fuel oil is used, and 440-515 mg/Nm ³ when pulverised carbon is used as a fuel (emissions referred to at 10% O ₂). The viability studies for a plant producing 3,000 t clinker/day consider that the energy consumption could be 10-12 % less than that corresponding to a rotary kiln with a cyclonic preheater and grate cooler, thus the emissions of SO ₂ from combustion could be reduced by 10-12 % [Cembureau, 1997].
Economic Aspects	In summary, the advantages arising from the development of a fluidised bed system for cement kilns, in economic terms, would be as follows: <ul style="list-style-type: none"> • Reduction energy consumption of 10-12 %. • 30 % reduction in operating costs • 30 % reduction in the area of the installation.

Alternative	5.13.2. MULTI-STAGE COMBUSTION IN COMBINATION WITH SELECTIVE NON-CATALYTIC REDUCTION (SNCR).
Action	Action: Treatment at source. Modification of processes.
Stage of the process	Clinker burning
Environmental problems	Generation of atmospheric emissions of NO _x .
Environmental benefits of the Alternative	The effectiveness of NO _x reduction may reach values of between 30 and 80 %, being greater when the molar ratio NH ₃ /NO ₂ is higher. It has also been observed that with molar ratios higher than 1, there is a significant increase in emissions of ammonia to the atmosphere.
Description	This technique consists of a combination in series of precalcining, multi-stage combustion and the addition of ammoniacal compounds to reduce nitrogen oxides.
Procedure	Tests carried out in recent years seem to indicate that the injection of ammonia must be carried out relatively far away from the combustion chamber in order for the efficiency of the reduction not to be adversely affected by the competition established between reactions of combustion and the reduction of NO _x .
Comments	Other effects observed include an increase in emissions of CO, an increase in energy consumption and a loss in production capacity due to the incorporation of volumes of gas which have to circulate through the cyclone tower.
Economic Aspects	The total cost will be approximately that resulting from the sum of the costs of each one of the combined processes [Cembureau, 1997].

Alternative	5.13.3. SELECTIVE CATALYTIC REDUCTION (SCR).
Action	Action: End-of-pipe treatment.
Stage of the process	Clinker burning
Environmental problems	Generation of atmospheric emissions of NO _x .
Environmental benefits of the Alternative	<p>With this process reduction efficiencies of up to 85-95 % are possible.</p> <p>Selective catalytic reduction (SCR) with ammonia appears to be the best technology currently available for reducing NO_x levels in gaseous waste from fixed sources.</p> <p>This technique has high reduction potential, not only for NO_x but also for VOCs, CO and dioxins.</p>
Description	<p>SCR has been applied satisfactorily in other industries. In the cement industry, there is still not one single SCR installation on an industrial scale. The characteristics of the cement kiln exhaust gases mean that the existing SCR for other industries will have to be adapted specifically for the cement industry.</p> <p>Studies and pilot tests consider two options:</p> <ul style="list-style-type: none"> • Treatment of gases prior to the removal of dust (high particle load). • Treatment after the removal of dust (lower particle load). <p>The latter requires reheating the gases after the dust filter, which implies an additional energy cost.</p> <p>Experiments have been carried out in pilot plants in Austria, Germany, Italy and Sweden for the treatment of relatively small fractions of gas (3 %). The emission levels for NO_x were within the range 100-200 mg/Nm³. [MTD Report Spain]</p>
Procedure	<p>In this process, the ammonia, which is normally diluted with air or steam, is injected downstream of the combustion unit by means of a grille system in the flow of hot gases. The mixture of the gases and the reagent passes through the catalyser bed, where the reactions of the catalytic reduction of the NO_x take place in the presence of oxygen.</p> <p>The principal reactions are as follows:</p> $4\text{NH}_3 + 4\text{NO} + \text{O}_2 \longrightarrow 4\text{N}_2 + 6\text{H}_2\text{O}$ $4\text{NH}_3 + 2\text{NO}_2 + \text{O}_2 \longrightarrow 3\text{N}_2 + 6\text{H}_2\text{O}$ <div style="text-align: center;">  <p>The diagram illustrates the SCR process. On the left, an arrow labeled 'NO_x' and 'O₂' points into a chamber. Inside the chamber, three nozzles labeled 'Ammonia' are shown injecting the reagent into the gas flow. The chamber contains a vertical rectangular 'Catalyst' bed. An arrow on the right points out of the chamber, labeled with 'N₂', 'O₂', and 'H₂O', representing the treated exhaust gases.</p> </div> <p>Source: M.J. Bradley & Associates</p> <p>Figure 5.13.2. Diagram of the SCR process.</p>

	<p>The optimum temperature range for these catalytic reactions is usually between 300-400 °C. [NO_x. EPA]</p> <p>The temperature, the quantity of the reducing agent, the design of the grille for injecting the ammonia and the activity of the catalyser are the principal factors determining the effectiveness of the real removal.</p> <p>Leakage of NH₃ in SCR is less than may occur in SCNR for high reduction efficiency. If the quantity of ammonia emitted by the raw materials is significant, the SCR uses these emissions to reduce the NO_x in the catalytic reaction, and thus reduce the quantity of ammonia emitted.</p> <p>If there is any leakage of ammonia, this may react with the SO₂ and other components in the kiln exhaust gas, giving rise to the formation of aerosols [Cembureau, 1997].</p>
<p>Comments</p>	<p>One of the critical questions to be resolved in order to guarantee the technical and economic feasibility of a system is abrasion in the catalyser, which in some other tests carried out was severe.</p> <p>Other matters which lend a degree of uncertainty to the practical application of SCR included the elimination of dust from the catalyser, the service life of the catalysers and the total investment costs. [Report MTD Spain].</p> <p>The use of the catalyser gives rise to two principal advantages of the SCR process over the SNCR one: greater efficiency in the control of NO_x and reactions within a wider, lower range. These benefits are accompanied by a significant increase in investment and operating costs.</p>
<p>Economic Aspects</p>	<p>Of the two possible SCR systems, only that of treating gases prior to the removal of dust has been taken into account (high particle load), as the investment/operating costs and heat consumption are much lower than for treatment after dust removal (low particle load) [Cembureau, 1997].</p> <p>The total costs of this emerging technique have been evaluated between € 2 and € 4 /t clinker, with an investment cost of between € 5 and € 10 million. [Report MTD Spain]. These costs include the selective catalytic reduction unit, the ammonia storage tank, the ammonia injection system and the preheater required to maintain gases within the optimum temperature range for carrying out the reduction.</p>

6. PRACTICAL CASES

In this chapter we supply examples of both the prevention of contamination at source and end-of-pipe treatment. Each one of the examples is shown in the form of file which summarises the alternative carried out by a certain company on the basis of its objectives (both environmental and economic), the results obtained after the application of the measure are described, and economic data on the said application are provided.

The information given in the files has been obtained principally from publications in the literature. It should be mentioned that the information given in the economic evaluation, results and savings sections are merely for guidance.

The implementation of the prevention-at-source and end-of-pipe treatment alternatives have enabled companies to obtain both environmental and productive improvements. It is considered that the putting into practice of the alternatives described in Chapter 6 of this manual represents, in the majority of cases, success on both contamination and economic levels, as well as improvements in the quality of the product.

Practical Case 1	6.1.1. INSTALLATION OF A HORIZONTAL ROLLER MILL
Country	ITALY
Type of Plant	Clinker grinding plant
Environmental problems	Low exploitation of energy. CO ₂ emissions.
Objective	Reduction at source. Reduction in the generation of atmospheric emissions and energy recovery
Background	Up until September 1993, the plant had an open-circuit ball mill and a closed-circuit ball mill. The entire grinding stage had an approximate capacity of 480 kt/year.
Measure applied	<p>In 1993, a 400 kW horizontal roller mill was installed. This was a new technology which was to be tested on an industrial scale.</p> <p>The new horizontal roller mill (Horomill 2200) has a cement grinding capacity of 220 kt/year. This type of grinding provides energy savings of 40% in comparison to the consumption of a conventional ball mill. Ventilation can be carried out in the open air, or with hot air for drying raw materials.</p> <p>The improvement consisted of the installation, in a new closed-circuit, of a horizontal roller mill operating with multiple compressions. This system uses less pressure than that employed in a roller mill, and is fitted with internal devices that ensure the infeed and crushing of the material, guaranteeing its reduction to the desired granulometry.</p> <p>The principal characteristics of the roller mill are as follows:</p> <ul style="list-style-type: none"> • Lower energy consumption, similar to that of roller presses. • A grinding procedure similar to that of a ball mill, making it possible to obtain the same final product. • Reliability and service life similar to those of a ball mill.

<p>Results obtained</p>	<p>Problems related with the resistance of the roller coatings were detected, but these were solved.</p> <p>The mill operates very stably, and has low levels of vibration. It is also fitted with a built-in automatic control system, and given that it has a rapid response to input changes, it shows good quality performance during normal operation. This also implies short conditioning times, resulting in energy savings, as the unproductive periods of the machine are reduced.</p> <p>With regard to noise, a number of problems were observed due to the reduction gears. It has been decided that for future mills helical gears should be used at a maximum of 1,000 rpm, in order to thus reach noise levels of 80 dB, significantly lower than noise levels reached by ball mills.</p> <p>The expected energy savings of between 35 to 41% for the cement mill were easily obtained, while the raw material mill only supplied an energy saving of 35 % as opposed to the expected 50 %. This is due to the oversizing of certain components of the plant, and generally not having designed the mill specifically for the grinding of raw material.</p> <p>Summary of results:</p> <table border="1"> <thead> <tr> <th></th> <th>Energy saving (%) (*)</th> </tr> </thead> <tbody> <tr> <td>Cement grinding</td> <td>35-41</td> </tr> <tr> <td>Grinding of raw materials</td> <td>35</td> </tr> </tbody> </table> <p>(*) with respect to the consumption of a ball mill.</p> <p>The quality of product obtained was the same or even higher than that obtained with a ball mill. The cement produced with the new horizontal roller mill for the same fineness had greater levels of resistance than that generated with the ball mill.</p>		Energy saving (%) (*)	Cement grinding	35-41	Grinding of raw materials	35
	Energy saving (%) (*)						
Cement grinding	35-41						
Grinding of raw materials	35						
<p>Economic Aspects</p>	<p>An investment of \$ 3.5 million was required for the installation of the small Horomill on an industrial level. (*)</p> <p>(*) In 2002, this plant installed a new horizontal roller mill unit (3800 Model) with a capacity of 600,000 t/year, and with which it is hoped to obtain a reduction in energy costs of 10 kWh/t of cement along with a reduction in maintenance tasks.</p>						

Source: wbcasd, 2002 and European Commission's "Energy".

<p>Practical Case 2</p>	<p>6.1.2. CLOSED-CIRCUIT WATER COOLING</p>
<p>Country</p>	<p>FRANCE</p>
<p>Type of Plant</p>	<p>Integrated</p>
<p>Environmental problems</p>	<p>High cooling water consumption. Risk of contamination due to discharges to the river.</p>
<p>Objective</p>	<p>Prevention at source. Reducing the water consumption and thus discharges to the river.</p>

Background	<p>The plant in question is located in eastern central France, between the Burgundy Canal and the River Armançon.</p> <p>The water consumption in the plant was due basically to use for the cooling of installations.</p> <p>The plant was originally designed with an open-circuit cooling system, which meant that the water was used to cool equipment, treated in a sedimentation tank and a grease separator, and finally discharged into the River Armançon.</p>
Measure applied	<p>In January 2000, it was decided to install a closed-circuit water cooling system. The project required the fitting out of a number of disused tanks for use as water storage tanks, installation of a pumping planned and a cooling tower.</p> <p>Thus, the cooling water is currently collected and recirculated to the cooling tower where it is cooled by ambient air. The cold water is then pumped once again to the refrigeration circuit.</p>
Results obtained	<p>With this project, water consumption savings of 70 % were obtained, along with a reduction in the contamination associated with discharges to the River Armançon.</p>
Economic Aspects	<p>Investment costs of the measure applied: € 415.000</p>

Source: Lafarge

Practical Case 3	6.1.3. INSTALLATION OF A HYBRID FILTER
Country	SPAIN
Type of plant	Integrated
Environmental problems	High particle emissions.
Objective	End-of-pipe treatment. To reduce particle emissions in order to comply with future legislation.
Background	<p>The cement plant has a capacity of 1,850 t/d. In 1999 it was decided to substitute the existing electro-filter filter of the kiln with a hybrid filter, since emission levels implied exceeding the limits of future legislation.</p> <p>It should be pointed out that, from an operational perspective, the concentrated layout of the different installations of the plant offer many advantages, but it hinders any possible modifications.</p>
Measure applied	<p>Along with the objective of reducing particle emissions, the aim was to have the possibility of conditioning the filter gases with air or water, since the factories located in a semi-desert area.</p> <p>As a consequence of the high demand for cement, this transformation had to be carried out during the long shut-down of the kiln for the replacement of the refractory lining.</p> <p>Furthermore, the new project had to contemplate the extension of the kiln's production to 2.400 t/d.</p>

The measure implemented required the extension of the existing electro-filter casing for the installation of a baghouse, taking into account the increase in the production of the kiln. The filtering medium chosen was GORE-SUPERFLEX, as it endures a greater number of cleaning cycles than conventional ones. A total of 2,542 filter bags were installed, with active surface area of 7,779 m³.

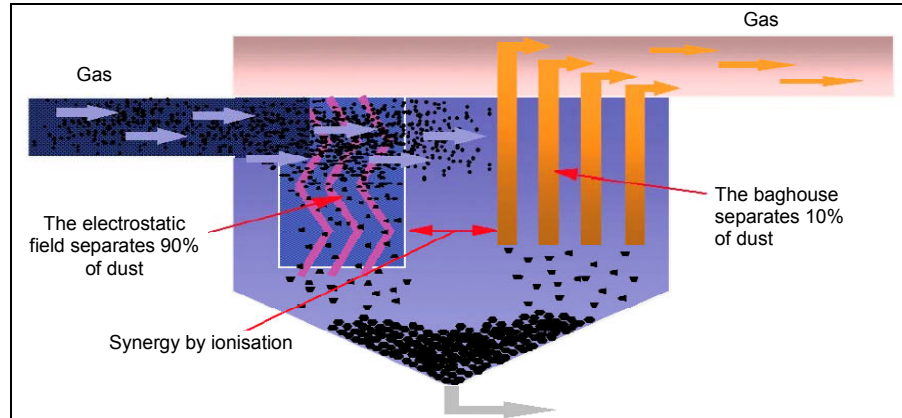


Figure 6.1.1. Diagram of the operation of a hybrid filter.

Results obtained

A year after the installation of a hybrid filter, the efficiency of this technology for removing dust from gases has been demonstrated. Emissions at all times are lower than 8 mg/Nm³.

	Particle emissions (mg/m ³)
Before the measure	60-75
After the measure	<8

The resulting fall in pressure was 6.5 mbar, well below the value guaranteed by the manufacturer of 7.5 mbar.

After the application of this measure, the possibility of completely replacing cooling water with fresh air without suffering any process restrictions with conventional fuels was verified.

During the small number of shutdowns of the electrostatic field due to CO triggerings, the baghouse functioned with no problems, i.e. with no excessive increase in pressure drop, and above all with no increase in dust emissions.

Economic Aspects

Costs under € 3 million have been estimated.

Fuente: Cemento y Hormigón, mayo 2004.

Practical Case 4	6.1.4. INSTALLATION OF CYCLONES
Country	TURKEY
Type of Plant	Integrated
Environmental problems	Particle emissions.

Objective	End-of-pipe treatment. Reduction of particle emissions.						
Background	<p>This plant was built in 1911 with a capacity of 20,000 t. Later, in 1923, it was upgraded to a production capacity of 40,000 t.</p> <p>During the manufacture of cement, the raw materials (limestone and clay) are heated in a rotary kiln producing dust-laden gases. The gases are passed through a number of electrostatic precipitators before being emitted to the atmosphere. One of the plant's four precipitators did not allow acceptable levels of particle reduction to be reached.</p>						
Measure applied	In order to improve the efficiency of the electrostatic precipitators, a powerful cyclone separator was installed at the head of the dust removal unit. This device removes the coarsest particles so that the reduced quantity of particles reached the precipitators, guaranteeing their greater efficiency.						
Results obtained	<p>The following table compares particle emission before and after the installation of cyclones. As can be seen, they have been reduced by 72 %.</p> <table border="1"> <thead> <tr> <th></th> <th>Particle emissions (mg/m³)</th> </tr> </thead> <tbody> <tr> <td>Before the measure</td> <td>180</td> </tr> <tr> <td>After the measure</td> <td>50</td> </tr> </tbody> </table> <p>With this reduction, particle emissions are now below the level required by local regulations.</p>		Particle emissions (mg/m ³)	Before the measure	180	After the measure	50
	Particle emissions (mg/m ³)						
Before the measure	180						
After the measure	50						
Economic Aspects	Investment costs of the measure applied: € 620,000						

Source: Lafarge

Practical Case 5	6.1.5. INSTALLATION OF BAGHOUSES
Country	BOSNIA & HERZEGOVINA
Type of Plant	Integrated
Environmental problems	Particle emissions.
Objective	End-of-pipe treatment. Reduction of particle emissions.
Background	<p>The existing filter system, electrostatic precipitators (EP), has never run at maximum output since it was installed 30 years ago. The high concentrations of CO in the kiln exhaust gases (CO peaks) and the frequent cuts in the energy supply caused stoppages of the EP, which results in extremely high particle emissions various times a day.</p> <p>This problem gave rise to an increase in public awareness and harsh words with the local authorities, which ended up with production ceasing in the year 2000.</p>

<p>Measure applied</p>	<p>The company decided to make a large investment with the aim of modernising its installations. One of the largest projects in this investment was the improvement of the plants filtering system, which was carried out in 2002.</p> <p>It was decided to replace the existing EPs and the cyclone separator in the clinker cooler with baghouses. This new technology would reduce emissions by 96 %.</p> <p>Furthermore, the dust removal system involved a series of associated changes. The waste gas from the cooler is now piped to the preheating tower, where it is mixed with residual air coming directly from the kiln and the grinding of raw materials. Another option is to pipe the residual cold gas once again to the grinding of raw materials. The gas is then passed through the new filter before being emitted to the atmosphere.</p> <p>This is an innovative system with regard to the exploitation of the residual gases from the cooler for other purposes, and the cleaning of the mixture of gases in one common filter.</p>						
<p>Results obtained</p>	<p>The baghouses function satisfactorily, in line with that expected for the plant.</p> <p>Results obtained</p> <table border="1"> <thead> <tr> <th></th> <th>Particle emissions (mg/m³)</th> </tr> </thead> <tbody> <tr> <td>Before the measure</td> <td>150</td> </tr> <tr> <td>After the measure</td> <td><25</td> </tr> </tbody> </table> <p>Particle emission readings showed that values even below those guaranteed were being reached.</p> <p>This decrease resulted in a considerable improvement in air quality, creating a very positive image for the cement plant with the population and the government authorities.</p> <p>Additional benefits included:</p> <ul style="list-style-type: none"> Improved efficiency in the productive system. Reduced fuel consumption due to the re-circulation of warm gases. Noise reductions. 		Particle emissions (mg/m ³)	Before the measure	150	After the measure	<25
	Particle emissions (mg/m ³)						
Before the measure	150						
After the measure	<25						
<p>Economic Aspects</p>	<p>The investment costs for the filtering system were in the region of € 9 million.</p>						

Source: HeidelbergCement

<p>Practical Case 6</p>	<p>6.1.6. INSTALLATION OF A PROCESS CONTROL SYSTEM</p>
<p>Country</p>	<p>SPAIN</p>
<p>Type of Plant</p>	<p>Integrated</p>
<p>Environmental problems</p>	<p>Energy losses. Contaminating atmospheric emissions.</p>
<p>Objective</p>	<p>Prevention at source. Increasing efficiency in the productive system. Avoiding contaminating atmospheric emissions.</p>

Background	The cement plant was built in 1967, and subsequently extended on two occasions. It currently has an effective production capacity of 1,800,000 t/year. The manufacturing system is the dry process, and the fuel used is petroleum coke. The factory comprises three clinker production kilns (kilns with a preheater and precalciner with 4, 5 and 6 cyclone stages), three raw meal mills, two coke mills and three cement mills (closed-circuit ball mills).
Measure applied	In the year 2000, the company invested in updating the installations and installed a process control system for collecting and handling information, succeeding in optimising the production process and reducing the standard deviation in kiln feeding. The increased stability of the process and the energy performance of the plant's of kilns has resulted in reductions in a specific emissions of CO ₂ in clinker production.
Results obtained	Reduction of 16,000 tonnes of CO ₂ in the year 2000. Reduction of 18 kcal/kg of clinker in the plants average heat consumption. Now there is greater operational stability in the kilns, with increases in both efficiency and use.
Economic Aspects	Investment costs of the measure are insignificant. The economic benefits during the year 2000 were € 165,000.

Source: CEMEX

Practical Case 7	6.1.7. IMPLEMENTATION OF A MAINTENANCE PROGRAM
Country	EGYPT
Type of Plant	Integrated
Environmental problems	Energy losses. Contaminating atmospheric emissions.
Objective	Prevention at source. Increasing efficiency in the productive system. Avoiding contaminating atmospheric emissions.
Background	In 1994 the company decided to introduce the concept of cleaner production into the plant. Based on studies carried out beforehand in the plant, they decided to focus on the operation of the cement kiln. Production readings and data from laboratory were used to determine the input and output over the period of a year and to prepare a mass balance for the operation of the kiln. This balance showed that there was an imbalance of 136 tonnes of raw material per day, showing that there was potential for reducing emissions and waste.
Measure applied	The measure implemented did not consist in applying a new technology, rather reworking the maintenance program. Preventative maintenance was increased and small changes were made to ensure continuous operation and improve the regulation of metallic elements, to thus minimise losses throughout the entire process.

	A maintenance program was drawn up and its application was exhaustively controlled.
Results obtained	It was calculated that subsequent to the introduction of the measure, particle emission was reduced by 3,600 tonnes in the first year, reducing contamination of the surrounding environment.
Economic Aspects	Investment costs of the measure are insignificant. The annual savings made were € 132,000 (savings in consumption of 12 tonnes of raw material a day).

Fuente: UNIDO

7. GLOSSARY

accelerating admixture – ingredient which brings about an increase in the hydration speed of hydraulic cement, and thus reduces the setting time, increases the resistance development speed, or both.

addition / additive – material that is ground along with a hydraulic cement or which is mixed in limited quantities with it, either as 'process additive' to facilitate the manufacture or handling of cement, or as a 'functional additive' to modify the properties of the finished product.

agent – general term which is applied to a material which can be used either as an additive for the cement or as an ingredient of the concrete, for example, an air incorporating agent.

alite – name used by Törnebohm (1897) to identify tricalcium silicate with small quantities of MgO, Al₂O₃, Fe₂O₃ other oxides; it is a principal component of Portland cement clinker.

alkali – alkaline metal salts, principally sodium and potassium; specifically the sodium and potassium appearing in the components of concrete and mortar, which in chemical analyses are normally expressed as the oxides Na₂O and K₂O.

alumina – aluminium oxide (Al₂O₃).

asphalt cement – fluidised or non-fluidised asphalt specially prepared, with regard to its quality and consistency, to be used directly in the manufacture of bituminous surface course, and which has a penetration at 25 °C (77 °F) of between 5 and 300, under a load of 100 g applied for 5 s.

ball mill / tube mill – horizontal, revolving tube mill, in which balls are used as milling agents.

bauxite – a rock made up principally of anhydrous aluminium oxides: the principal mineral of aluminium; raw material for the manufacture of calcium aluminate cement.

belite – name used by Tornebohm (1897) to identify a form of the component of Portland cement clinker which in its purest form is now known as dicalcium silicate (2CaO·SiO₂).

binders – cementing materials, either hydrated cements, cement products or lime and reactive silicic materials; the types of cement and the curing conditions determine the general type of binder that is formed; the term also refers to materials such as asphalt, resins and other materials which form the matrix of concretes, mortars and sandy lime washings.

blast-furnace slag – non-metallic product, made up principally of silicates and calcium aluminosilicates and other bases, which is produced simultaneously with the fusion of mineral iron in a blast furnace.

- 1.- *air-cooled blast-furnace slag* is the material resulting from the solidification of the slag smelted under atmospheric conditions; the subsequent cooling can be accelerated by applying water to the solidified surface.
- 2.- *expanded blast-furnace slag* is the light cellular material that is obtained by the controlled processing of the smelted slag with water, or with water and other agents, such as steam, compressed air or both..
- 3.- *granulated blast-furnace slag* is the granular, vitreous material that is formed with the smelted slag cools rapidly, such as with immersion in water.

bulk cement – cement which is transported and delivered in bulk (generally in specially designed vehicles) and not in sacks.

calcine – to alter the composition or physical state by heating and below the fusion temperature.

calcite – mineral which has the composition of calcium carbonate (CaCO_3) and a specific crystalline structure; principal component of limestone, chalk and marble; it is used as one of the principal components in the manufacture of Portland cement.

calciumaluminate cement (also aluminat cement, aluminous cement) – product obtained by pulverising clinker made up fundamentally of hydraulic calcium aluminates produced during the fusion or sintering of a mixture with a suitable dose of aluminous and calcareous materials; in the United Kingdom it is called high-alumina cement.

carbonation – reaction between carbon dioxide and a hydroxide or oxide to form a carbonate, especially in cement slurry, mortar or concrete; the reaction with calcium compounds to produce calcium carbonate.

cement – (see hydraulic cement).

cement kiln – kiln in which the raw mix is dried, metered, calcined and burned to obtain clinker at temperatures between 2,600 and 3,000°F (1,420 to 1,650°C); it may be revolving, cupola, fluidised bed or travelling grate; it may be fuelled by coal, petrol or gas.

cement rock – natural impure limestone which contains the ingredients for manufacturing Portland cement in roughly the correct proportions.

clinker (*occasionally breeze*) – sintered product which is ground to manufacture cement; also other vitrified or calcined materials.

composite (blended) cement – hydraulic cement which essentially consists of a tight, uniform mix of granulated blast-furnace slag and hydrated lime; or a tight uniform mix of Portland cement and granulated blast-furnace slag, Portland cement and pozzolan, or Portland cement with blast-furnace slag and pozzolan; it is produced by grinding the clinker and Portland cement together with the other materials, mixing the Portland cement with the other materials, or by combining joint grinding and mixing.

dicalcium silicate – compound whose composition is $2\text{CaO}\cdot\text{SiO}_2$, abbreviated to C2S; one of its impure forms (belite) is present in Portland cement clinker.

dolomite – mineral which has a specific crystalline structure and consists of calcium carbonate and magnesium carbonate in chemically equivalent quantities – 54.27 and 45.73 percent, respectively; rock whose principal component is dolomite

finish grinding – final grinding of the clinker to obtain cement, generally with the addition of calcium sulphate in the form of gypsum or anhydrate.

free lime – calcium oxide (CaO), as in clinker and cement, which has not combined with SiO_2 , Al_2O_3 and Fe_2O_3 during the calcining process, generally due to incomplete calcining, insufficient grinding of the raw mix or the presence of minimal quantities of inhibitors.

gypsum – mineral whose composition is calcium sulphate dihydrate ($\text{CaSO}_4\cdot 2\text{H}_2\text{O}$).

hydraulic cement – cement which sets and hardens due to chemical interaction with water, and is capable of doing so underwater.

hydrophobic cement – non-hydrated cement treated to reduce its tendency to absorb humidity.

lime – specifically calcium oxide (CaO); in general, a term which is applied to the physical and chemical forms of quicklime, hydrated lime and hydrated hydraulic lime.

limestone – sedimentary rock made up fundamentally of calcium carbonate.

melt – portion of the mass of raw material that melts during the burning of the cement clinker, the calcining of light aggregates or the expansion of blast furnace slag.

modified Portland cement – Portland cement which has moderate hydration heat; from 1960 on this term was replaced by "Type II" cement.

natural cement – hydraulic cement which is produced by calcining a clay limestone at a temperature below the sintering point, and then grinding the calcined product to obtain a fine powder.

natural pozzolan – natural unprocessed or calcined material which has pozzolanic properties (e.g., volcanic ash or pumice, opaline chert and shales, tufa and diatomaceous earths).

normal cement – Portland cement for general uses; in United States this is called Type I sticky cement: a finished cement which develops low or null fluidity during or after storage in silos, or after being transported in bulk recipients, tanker trucks, etc.; this phenomenon may be due to: (a) interlocking of particles; (b) mechanical compacting; (c) electrostatic attraction between particles. (see also - warehouse set).

NSP- *New suspension preheater*- cyclone preheater with precalciner.

ordinary Portland cement – term used in the United Kingdom and other countries to designate the equivalent of the American normal or Type I Portland cement; the abbreviation OPC is frequently used.

PC – *precalciner*.

periclase – crystalline mineral, MgO, whose equivalent may be present in the Portland cement clinker, Portland cement, and other materials, such as Siemens Martin furnace slag and certain basic refractories.

Portland blast-furnace slag cement – hydraulic cement which consists of a finely ground mix of Portland cement clinker and granulated blast furnace slag, for a tight uniform mix of Portland cement and finally granulated blast furnace slag in which the quantity of slag is within specified limits.

Portland cement – hydraulic cement which produced by pulverising Portland cement clinker, and which generally contains calcium sulphate.

Portland pozzolan cement – hydraulic cement which consists of a tight uniform mix of Portland cement or Portland cement with blast-furnace slag and fine pozzolan, produced by grinding Portland cement clinker and pozzolan together, mixing Portland cement or Portland cement with blast furnace slag and finely divided pozzolan, all-weather combination of joint grinding and mixing, in which the pozzolan is within specified limits.

pozzolan – siliceous material or siliceous and aluminous material which in itself has little cementing value, but which, in finely ground form and the in the presence of humidity, reacts chemically with calcium hydroxide at common temperatures forming compounds with cementing properties.

pozzolanic – characteristic of pozzolan or related with pozzolan.

pozzolanic activity index – index measuring the pozzolanic activity in the basis of the resistance of cement mixes containing hydraulic cement with and without pozzolan, or which contain pozzolan and lime.

retarding admixture – ingredient which gives rise to a decrease in the hydration speed of hydraulic cement and extends the setting time.

roller mill – horizontal or vertical mill, in which the raw material is ground by the pressure exerted by revolving rollers.

SF & NSF – suspension furnace / new suspension furnace. These are two successive versions that differ in the position burners and the feeding of the material into the fire chamber.

slate – fine-grained metamorphic rock which has well developed cleavability (shaley cleavage) which is generally not parallel to the stratification of the rock.

slurry – mixture of water and any finely divided insoluble mixture, such as Portland cement, slag or clay, in suspension.

SP – Suspension preheater.

supersulphated cement – hydraulic cement which is made by finely grinding a mixture of granulated blast-furnace clinker, calcium sulphate, and a small quantity of limestone, cement or cement clinker; it

is called thus because its equivalent sulphate content is higher than that of Portland cement with blast-furnace slag.

tricalcium aluminate – compound whose chemical composition is $3\text{CaO}\cdot\text{Al}_2\text{O}_3$ and which is abbreviated as C3A.

tetracalcium aluminoferrite – a compound from a series of aluminoferrites whose composition is $4\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot\text{Fe}_2\text{O}_3$ (abbreviated as C4AF) which is generally assumed to be the aluminoferrite present Portland cement.

tricalcium silicate – compound whose chemical composition is $3\text{CaO}\cdot\text{Si}_2\text{O}_3$ and which is abbreviated to C3S; one of its impure forms is a principal component of Portland cement.

white cement – Portland cement which hydrates forming a white slurry; it is manufactured on the basis of raw material with a low iron content whose clinker is calcined with a reducing flame.

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