OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

FAIR USE POLICY

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

14861

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

Distr.
LIMITED
UNIDO/IS.540
12 July 1985
ENGLISH

USE AND CONSERVATION OF ENERGY IN THE CEMENT INDUSTRY

Sectoral Working Paper Series

No. 31

V. Arakelov
H. Schaefer

Sectoral Studies Branch
Division for Industrial Studies

3??

V.85-29154

SECTORAL WORKING PAPERS

In the course of the work on major sectoral studies carried out by the UNIDO Division for Industrial Studies, several working papers are produced by the secretariat and by outside experts. Selected papers that are believed to be of interest to a wider audience are presented in the Sectoral Working Papers series. These papers are more exploratory and tentative than the sectoral studies. They are therefore subject to revision and modification before being incorporated into the sectoral studies.

Preface

The building materials sector has a particularly important role in contributing to socio-economic development in virtually all developing countries.

An analytical appraisal of the building materials industry in developing countries has been carried out in UNIDO s study "The building materials industry in developing countries: an analytical appraisal" (UNIDO/IS.512). Some considerations related to energy as a production factor for the building materials industry were also presented in that study.

The present paper contains a more detailed treatment of issues related to the use and conservation of energy in the cement industry which is one of the most important branches of the building materials industry. Energy issues for cement industry have a particular significance as this industry is a heavy energy consumer.

This paper aims at providing interested users in developing countries with up-to-date information on the use and conservation of energy in the cement industry based on experience from developed as well as developing countries.

The paper draws on contributions prepared by Dr. V. Arakelov (VNIPIENERGOPROM, Moscow, USSR) and Prof. H. Schaefer (Technical University, Munich, Federal Republic of Germany) and other information available from a number of published sources. One of these sources which contained valuable information was the proceedings of the APO Symposium on Energy Conservation in Cement Industry (1982).

Contents

Tables

Figures

1. INTRODUCTION: THE CEMENT INDUSTRY AND ENERGY

Cement, which is the most important representative of cementing materials, has found wide application in many sectors of the economy of virtually all countries. However, the major part of the cement production goes to the construction of buildings, industrial plants, infrastructure, etc. Among the different types of cement, the most important are hydraulic cements of which portland cement is the most widely used. National demand for cement is closely linked to the economic and social development of any country. The world production of cement reached about 900 million tons by 1981. During the period 1960-1981 the cement production in the developing countries rose 500 per cent, from 42 million tons to 213 million tons. Their share in the world production of cement increased from 13 per cent in 1960 to 24 per cent. However, developing countries need more and more cement as their development proceeds, for development projects in the field of industry, infrastructure, housing, etc.

The increasing demand for cement and the associated expansion of the cement production in the developing countries have important energy implications for these countries as production of cement is a heavy energy consuming technological process. In 1981 the energy bought by the United States' cement industry accounted for about 3.5 per cent of the total purchased by all manufacturing industries of the country. In India, the coal requirement in the cement industry accounted for 17 per cent and the electric power requirement accounted for 4 per cent of the total estimated demand in the industrial sector. An important feature of cement production is that different technologies require different amounts of energy for manufacturing a unit of finished product, i.e. the choice of technology is to a large extent affected by energy considerations. The history of cement making reveals another very interesting point - technological developments leading to the enhancing of productivity normally result in higher efficiency of energy use. Besides, this industry has a rather great scope for improvement of the efficiency of energy use through better housekeeping, implementation of various heat and electricity saving measures, particularly waste heat recovery.

The cement industry also appears to be responsive with respect to the types of fuels used in the production process and to the use of different types of combustible industrial and agricultural residues. The major fuel used for cement production in the world before 1950 was coal, but during the 1950s and 1960s fuel oil, which was available at low prices, became predominant. The adjustment of oil prices which took place in the 1970s forced many countries to start switching their existing and new cement plants from oil to coal and other fuels, and to implement various energy saving measures.

Thus energy matters which always were of importance for the energy conscious cement industry have become of primary concern during the last decade.

2. ENERGY REQUIREMENTS IN CEMENT MAKING

The manufacture of cement includes the following stages:

(a) Raw material winning;
(b) Raw mix preparation;
(c) Cement clinker making; and
(d) Cement clinker grinding and mixing.

All these production stages require energy but the major part of energy is consumed at cement plants where the raw materials used for cement production undergo mechanical and heat treatment.

Cement is made from an appropriate combination of calcareous and argillaceous raw materials. The most important calcareous material is limestone which occurs in a variety of forms, viz. chalk, other sedimentary limestones etc. The most common argillaceous materials are clays, shales and marls, but mudstones, slate, schist, some volcanic rocks and ash are also used. Some cement works are based on one calcareous and one argillaceous material, but it is more common to use three or more component materials, in order to get the required control of composition. Although the winning of raw materials and their transportation to cement plants require energy, their combined share in total energy use per unit of finished product - cement, is not high as compared to the energy used at other stages of the cement production chain. Energy consumption for the transportation of raw materials from quarries to cement works may be relatively high in cases when these bulky materials have to be delivered over long distances, but normally cement plants tend to be located close to raw material deposits.

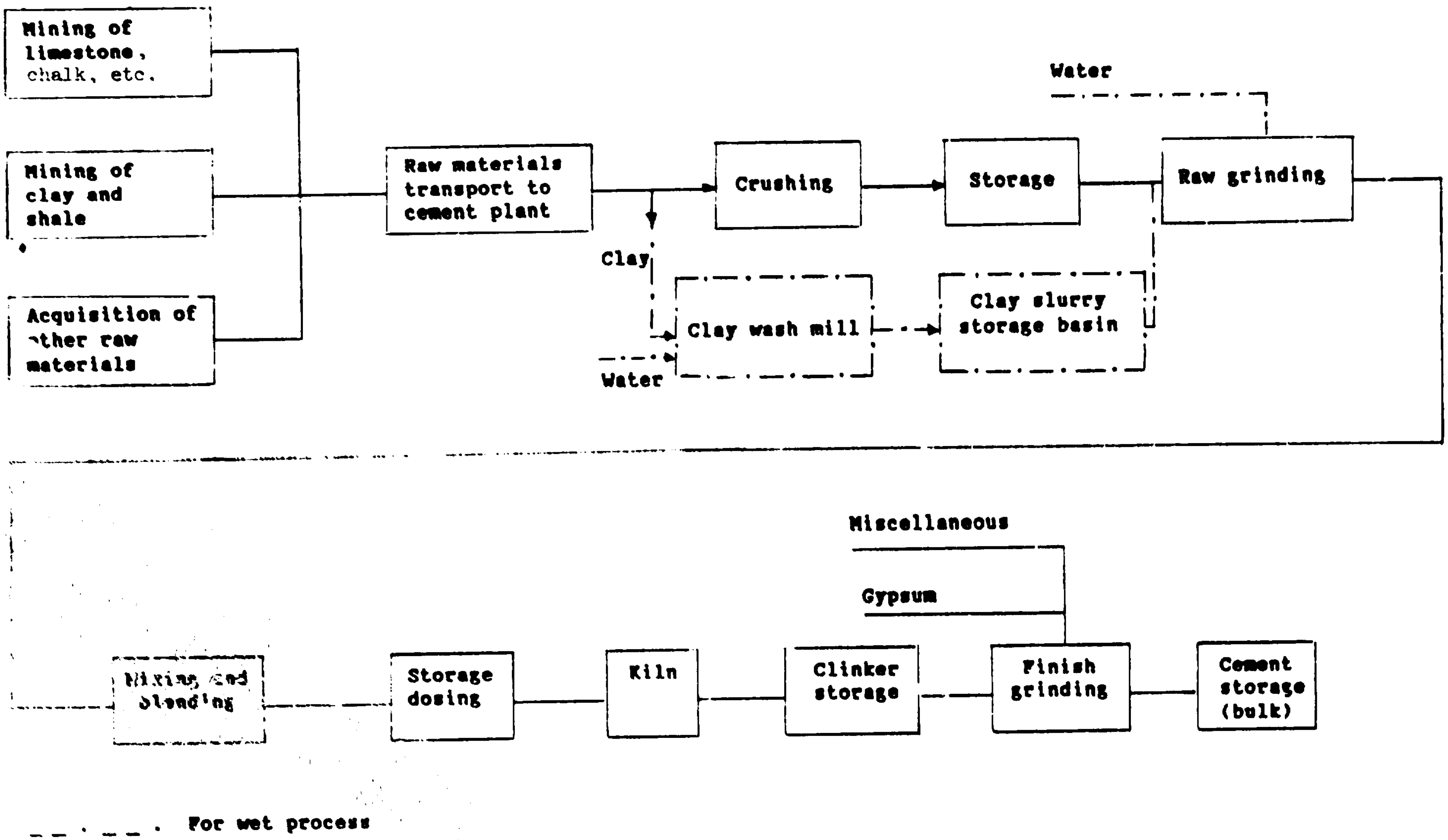
The raw materials delivered to the cement plants, which at present use primarily rotary kilns, are reduced in various crushers and then ground. Crushing is generally done in two stages: first, crushing into lumps of 15 cm size, then fine crushing to under 2 cm. Before grinding the crushed raw materials are blended in the required proportion to prepare a raw mix necessary for production of a cement with specific properties. There are two main different processes of cement production: dry and wet processes. But two intermediate processes are also used: semi-dry and semi-wet. In the dry process all raw material grinding and blending operations are done with dry materials and the resulting powder is fed into the kiln system. In the wet process the raw mix is wet ground and then in the form of slurry containing 30 to 40 per cent moisture is pumped to homogenization tanks where the final mixing is accomplished. The slurry is stored in storage basins from where it is fed into the kiln. The portland cement manufacture flowsheet for both dry and wet processes is given in figure 1.

Energy requirements for the preparation of a raw mix to be fed into the kiln are rather substantial. Electric power is primarily used here for crushers, grinding mills and for transporting materials. In some cement plants using dry process production the moisture content of cement raw materials requires drying before grinding. Drying in such cases is done by hot air from special furnaces or using heat of the waste gas from the cement kiln. The amount of heat required for drying raw materials is low compared to the heat requirements of the cement kiln which is the major consumer of energy in cement plants.

The cement kiln is the place where the raw material mix undergoes heat treatment to become a cement clinker. The basic steps in the heat treatment of the raw mix are evaporation of water at up to 120°C, combustion of any organic matter and decarbonation of the calcium carbonate at up to 1,000°C, heating the decarbonated feed to 1,300°-1,500°C according to its composition and fineness, and maintaining this temperature sufficiently long for the sintering and for the cement compounds to form. The last step in clinker making is cooling.

Although vertical shaft kilns were the first kilns to be used for cement production, they gradually gave way to rotary kilns, since the latter permitted a significant rise in productivity to meet the growing demand for cement and reduce production cost. Vertical shaft kilns can be built in sizes from 20 to 200 tons per day. New more efficient designs were developed over the last 30 years. Innovations include interground fuel, higher air pressure (roots blowers) and efficient crusher grates. They have low fuel consumption owing to the direct heat transfer principle used, but nevertheless, the number

Figure 1. Portland cement manufacture flowsheet



of these kilns in operation in industrialized countries is on the decline whereas they still have a role to play in developing countries with modest or low labour costs and access to solid fuel (coal) at reasonable costs. The People's Republic of China and India are thus still for good reasons promoting the shaft kiln technology and are ready to share their experience with other developing countries. Nevertheless the majority of the world's cement plants are based on rotary kiln technology. In 1980, the vertical shaft kilns accounted for only 5 per cent of the world cement output.1/

A rotary kiln is a long cylindrical, refractory lined heat transfer chamber that rotates slowly around its axle and is slightly inclined. Today's commercial kilns of this type are 70 to 240 meters long and up to 7 meters in diameter. As a rule, the daily output is up to 3,000 to 4,000 tons of clinker, but capacities of 6,000 to 8,000 tons per day are known.

The raw material is fed into the upper end of the kiln and is moving slowly in a counterflow through the hot gases from the firing end of the kiln, while the kiln is rotating slowly. The burning zone is at the bottom end of the kiln. While moving through the kiln, the temperature of the material rises to the level required for the essential reactions to occur. The throughput of the kiln is monitored and the temperature of the raw material is raised to the level at which the lime CaO combines with silica SiO_2, and alumina Al_2O_3 to form the clinker minerals characteristic of portland cement. The typical retention time is 3 to 5 hours, during this time the raw material heats up to 1,400 or 1,450°C at the lower end of the kiln and undergoes all necessary reactions (table 1). The sintered material leaves the kiln in the form of coarse lumps or grains (clinker) of a diameter of between 2 and 30 mm. The clinker burning accounts for about 90 per cent of the heat energy used in the cement making.

The flame in the burning zone of the rotary kiln is maintained by injecting fuels together with primary combustion air through a burner pipe. Three different fuels can be used namely fuel oil, pulverized coal and natural

---

1/ R.J.S. Spence, "Small-scale production of cementitious materials", Intermediate Technology Publications Ltd., London, United Kingdom, 1980.

Table 1. Temperature cycle in clinker formation

Stage	Reactions	Temperature range
I Dehydration	(a) Evaporation of water that is not chemically or mineralogically bound (from raw meal, raw-meal grains, raw slurry)	Temperature to about 120°C
	(b) Removal of adsorbed water from clay minerals and intermediate layers	100-200°C
	(c) Removal of hydroxyl groups from clay minerals	250-700°C
II Decomposition of $CaCO_3$ CaO formation	(a) Early stage of CO_2 splitting in contact with SiO_2, Al_2O_3, Fe_2O_3	Over 550-600°C
	(b) Main reaction of CO_2 splitting by thermal dissociation, CaO_{free} 15 to 20 per cent	800-1,000°C very fast above 900°C (atmospheric pressure)
III CaO solids reactions	(a) See II(a); formation of $CaO \cdot Al_2O_3$; 12 $CaO \cdot 7\ Al_2O_3$ and 2 $CaO \cdot SiO_2$; free CaO content is 2 per cent	Over 550-600°C
	(b) Formation of more C_2S increases at 1,000°C max.; formation of C_3S; decrease of CaO_{free} and C_2S, rise of C_3S	600-1,000°C 800-1,000°C
	(c) C_2S lattice disorder, improved solubility in part-melt	1,400°C
IV Sinter reactions	(a) Part-melt in the presence of 2 per cent of alkali (max.)	Over 1,280°C
	(b) First part of the melt at invariance (eutectic: 54% CaO, 23% Al_2O_3, 17% Fe_2O_3 and 6% SiO_2)	1,338°C
V	Digestion of major mineral grains; steady-state	1,400-1,450°C

Source: Möglichkeiten zur Energieeinsparung in der Zementindustrie, Bundesministerium für Forschung und Technologie, Federal Republic of Germany, 1981.

gas. Coal which at one time lost its role as a principal fuel for cement kilns has recently come to the focus again and is now regarded as the most feasible fuel for use in cement clinker burning.

The resulting clinker is cooled down, and the waste heat being utilized to preheat the secondary combustion air. Various clinker coolers are commercially available. Some use a travelling grate, others are fitted with planetary arranged tubular coolers placed directly on the kiln shell at the clinker discharge point at the brim of the kiln. The clinker drops into the planetary coolers and rolls inside them towards the outlet. Air is normally drawn into the planetary coolers by induced draught. It is preheated and serves as secondary combustion air.

The thermal energy consumption of the rotary kiln ranges very widely depending on the type of process used, the quality and type of clinker required, the conditions of the insulation of and the kiln itself, the effectiveness of the operation control system, etc. As a result, the actual specific heat consumption varies from about 720 to 1,800 kcal/kg of clinker (3 to 7.5 GJ/t).

The last step in the production line is the grinding of the clinker with gypsum and additives to fine powder (the cement). Normally, clinker is ground in two chamber mills together with a small amount of gypsum (approxiamtely 3 to 5 per cent in weight). The purpose of adding gypsum is to control the setting time of the cement. Other substances are occasionally added to improve the grinding, or else to give the cement specific properties, such as improved frost resistance. Clinker grinding is currently done mainly in ball mills but roller mills seem to be an energy saving alternative. The clinker grinding mills are the major consumers of electric power in cement plants accounting for approximately 40 per cent of the overall electric power consumption. The specific electric power consumption for production of one ton of cement, depending on types of process, equipment used for milling raw material and clinker and other factors of different cement plants varies from 100 kWh/ton in modern plants to 150 kWh/ton of cement produced in earlier dry process plants.

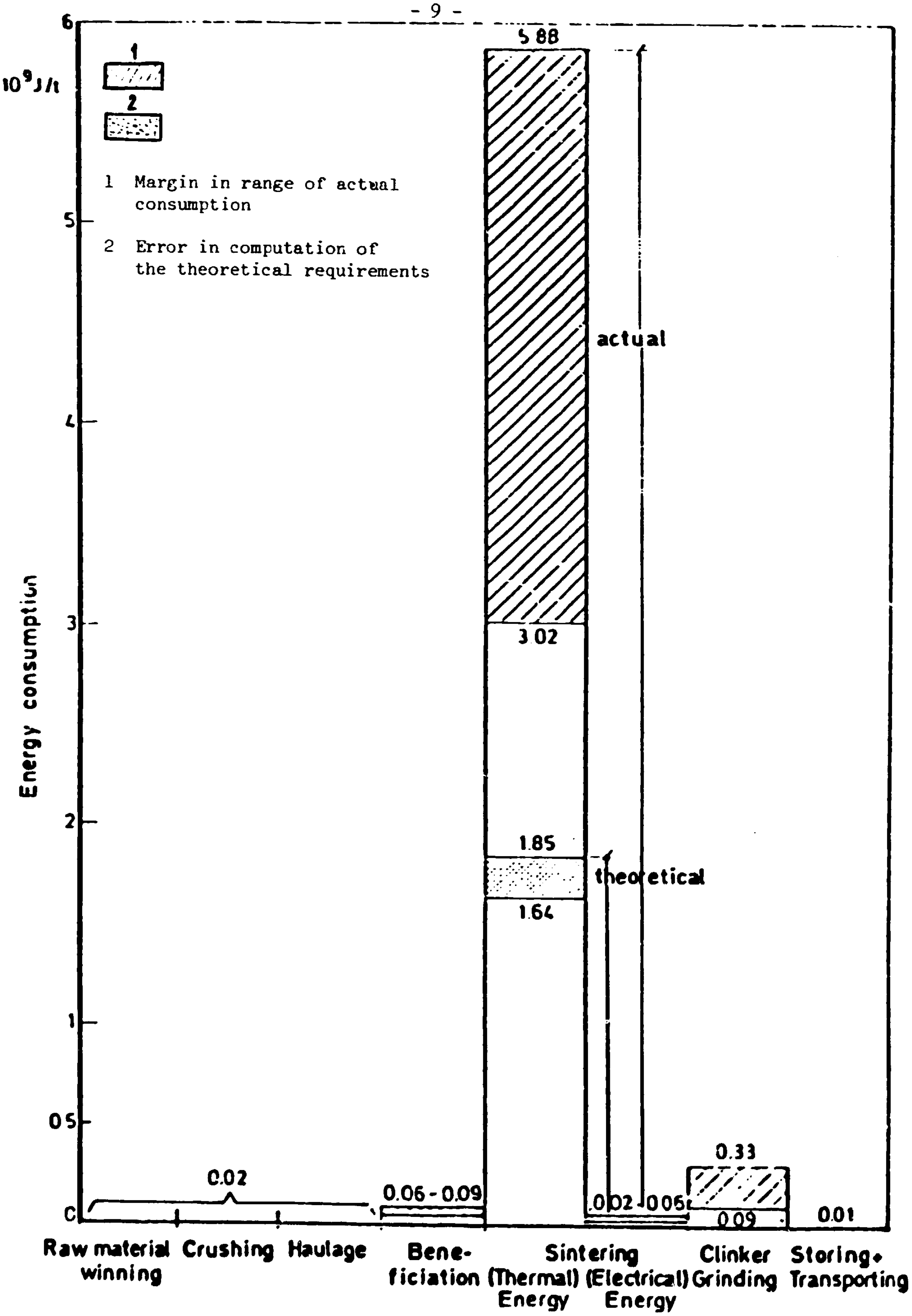


Figure 2. Energy consumption diagram of portland cement making

The distribution of energy consumption in cement making is illustrated in figure 2. Although it does not cover all possible cases, it gives a picture of energy consumption distribution between different stages of cement production and clearly shows that the fuel consumed in clinker burning has a direct bearing on the energy intensity of the product. It is also seen from the diagram that the actual consumption is usually double to, in many cases, triple that of the theoretical requirement. The minimum theoretical requirement of heat consumption for clinker burning is about 430 kcal/kg cl (1.8 GJ/t). This difference between theoretical and actual consumption of heat per unit of cement clinker produced at different cement plants is due to the various afore-mentioned factors related to the type of process used, design and conditions of the kilns, type of fuel used, requirements for clinker quality, operational routines, use of energy saving equipment, etc. Yet the type of process used influences most of all the energy consumption of a cement plant. Dry and semi-dry processes use on the average 40 per cent less energy than the wet processes. Table 2 contains data for modern cement plants on specific energy requirements broken down by process stages for the three processes mainly used at present: dry, semi-dry and wet.

However, it should be noted that it is not always possible to convert the process from wet to dry because some of the raw materials can only be treated in a wet process.

Table 2. Specific energy requirements by process stage and production method

Type of energy	Production method		
	Dry	Semi-dry	Wet
Thermal energy requirement			
Raw material preparation			
in GJ per ton of clinker	0.73	0.57	
in GJ per ton of cement	0.59	0.46	
Clinker firing			
in GJ per ton of clinker	3.14	3.38	5.44
in GJ per ton of cement	2.57	2.77	4.46
Electrical energy requirement			
Raw material preparation and clinker firing			
in GJ per ton of clinker	0.14	0.11	0.08
in GJ per ton of cement	0.12	0.09	0.07
Cement grinding in GJ per ton of cement	0.25	0.25	0.25
Total thermal requirement per ton of cement in GJ per ton of cement	3.18	3.24	4.46
Electrical energy requirement per ton of cement in GJ per ton of cement	0.37	0.34	0.30
Total energy requirement per ton of cement in GJ per ton of cement	3.54	3.58	4.78

Source: Möglichkeiten der Energieeinsparung in der Zementindustrie, Bundesministerium für Forschung und Technologie, Federal Republic of Germany, 1981.

3. ENERGY CONSUMPTION IN DIFFERENT TYPES OF CEMENT CLINKER MAKING PROCESSES. IMPACT OF TECHNOLOGICAL DEVELOPMENTS

3.1 Wet and semi-wet process kilns

Since the rotary kilns were introduced in cement making, two main processes, wet and dry, have found wide application in the cement industry. The advantages of the wet process, such as simpler technological scheme for raw mix preparations and its control, lower labour input and less pollution of the environment, led early to its extensive use in many countries.

The basic disadvantage of this process compared to the dry process has been a higher consumption of heat for clinker burning as the water added to the raw mix has to be driven off again in the kiln with additional energy being spent. However, until the beginning of the 1970s the prices for fuel oils were such that the overall economic considerations justified the use of a wet process. Nevertheless, various efforts were made to increase energy efficiency of the wet process kiln through design improvements, particularly by installing different types of heat exchangers in the kiln to improve the heat transfer, with for example chain systems installed at the back end of the kiln.

Another way to reduce the amount of heat in clinker firing under the wet process is to reduce the moisture content of the slurry, particularly through the use of thinners. Different diluents can be used for this purpose such as lignosulphorites, tripolyphosphates, etc. By adding thinners a substantial reduction of the water content can be achieved while maintaining the required slurry viscosity and pumpability. A decrease of slurry moisture from 36 to 31 per cent by using thinners leads to savings of heat and permits the raise of kiln capacity by 10 per cent. In general the heat consumption for clinker making for the ordinary wet process kilns has been in the order of 1,500-2,000 kcal/kg of clinker (6-8 GJ/t).

The lowest figures achieved in the world are about 5 GJ/t. But this figure was achieved at cement plants in developed countries (U.S.A., USSR, Western European countries) where a number of modifications were introduced and combined with the implementation of efficient operational control measures. In cement plants using the wet process in most developing countries the heat consumption is usually higher. In India, consumption of heat energy by wet kilns varied between 1,400-1,680 kcal/kg of clinker (5.8-7 GJ/t). Such kilns accounted for about 80 per cent of the total number of kilns in operation as of 1979 (103 out of total 134 kilns)2/. In Pakistan, where wet process kilns were dominant in 1979 (21 wet process kilns out of total 26 kilns), most of these kilns consumed as high as 1,670-1,770 kcal/kg of clinker (7-7.4 GJ/t) which was found to be higher by 20-23 per cent than the designed energy consumption.3/

In semi-wet process kilns, the water content of the slurry is reduced before feeding into the kiln. Different types of filters can be used to reduce the water content to about 20 per cent. The resulting cake is fed into the kiln which can be equipped with a preheater such as the Davis preheater. The nodules obtained by filter-pressing of slurry and a shaping process are fed into the kiln. The preheater-kiln system consumes 1,200-1,300 kcal/kg of clinker (5-5.4 GJ/t).4/

3.2 Dry and semi-dry process kilns

Dry process kilns came into existence along with wet process kilns. First they were used without any internal heat exchangers. But gradually in order to raise their capacities and improve energy economy, the length of the kilns was increased and internal heat exchangers were being installed. The major development in dry process kilns was the introduction of external preheaters installed before the kiln inlet. This has led to radically better heat economy, increase in kiln capacity and particularly in connection with the application of precalciners made it possible to make smaller

---

2/ Energy conservation in cement industry - some experiences, Asian Productivity Organization, Tokyo, 1982, p. 38.

3/ Ibid. p. 83.

4/ The chemistry of cements, V. 1, Academic Press, London and New York, 1964, p. 41.

kilns for the same capacity. The main advantage of dry process kilns with preheaters is that the kiln gases pass over the raw mix thereby transfering their heat to the raw mix before it enters the kiln. Thus the raw mix undergoes the final drying and partial calcination by using waste heat.

The Lepol preheaters, which were developed in the 1930's, found wide application in the world cement industry as they provided a drastic reduction in heat consumption for clinker burning compared with wet kilns bringing it to about 1,000 kcal/kg of clinker (4.2 GJ/t). Further improvement of these preheaters' design after 1959 resulted in the utilization of a so-called double gas circuit. This reduced the specific heat requirement per unit of clinker produced to approximately 800 kcal/kg (3.4 GJ/t).[5/]

The main application of the Lepol preheaters has been for dry process cement plants where the dry state of the raw material components is exploited to prepare the raw mix. After grinding 10-12 per cent of water is added. Then the raw mix is pelletized and put into the travelling grate where it is dried and partially calcined by the hot exit gases from the kiln before entering the kiln inlet. This process is known as a semi-dry process.

A decisive step in the improvement of the clinker making technology by using dry process was the invention of the four-stage suspension cyclone preheater, the Humboldt preheater. It became commercially available in the beginning of the 1950s.

The four-stage cyclone suspension preheater-kiln system (SP Kiln) reduced specific heat consumption to 780-850 kcal/kg of clinker (3.3-3.6 GJ/t) and allowed the creation of large-scale units of up to 5,500 tpd of clinker.

Both the operation and maintenance of the cyclone suspension preheater are relatively simple because it does not have any moving parts. At present many different makes of preheaters are commercially available with one feature being common to all of them: the heat transfer through a convection from

---

5/ W.H. Duda, Cement data-book, Bauverlag GmbH, Wiesbaden and Berlin, 2nd edition, 1977, p.375.

the waste gas to the raw mix or from the waste gas via the contact surface to the raw mix. The relatively high temperature of the raw mix entering the kiln permits a significant reduction of the size of the rotary kiln.

The size of a four-stage cyclone suspension preheater is of importance in connection with the specific heat consumption. Smaller systems have higher specific heat consumption than large units. The specific electric power consumption of the four-stage cyclone suspension preheater-kiln system amounts to 20-22 kWh/t of clinker.

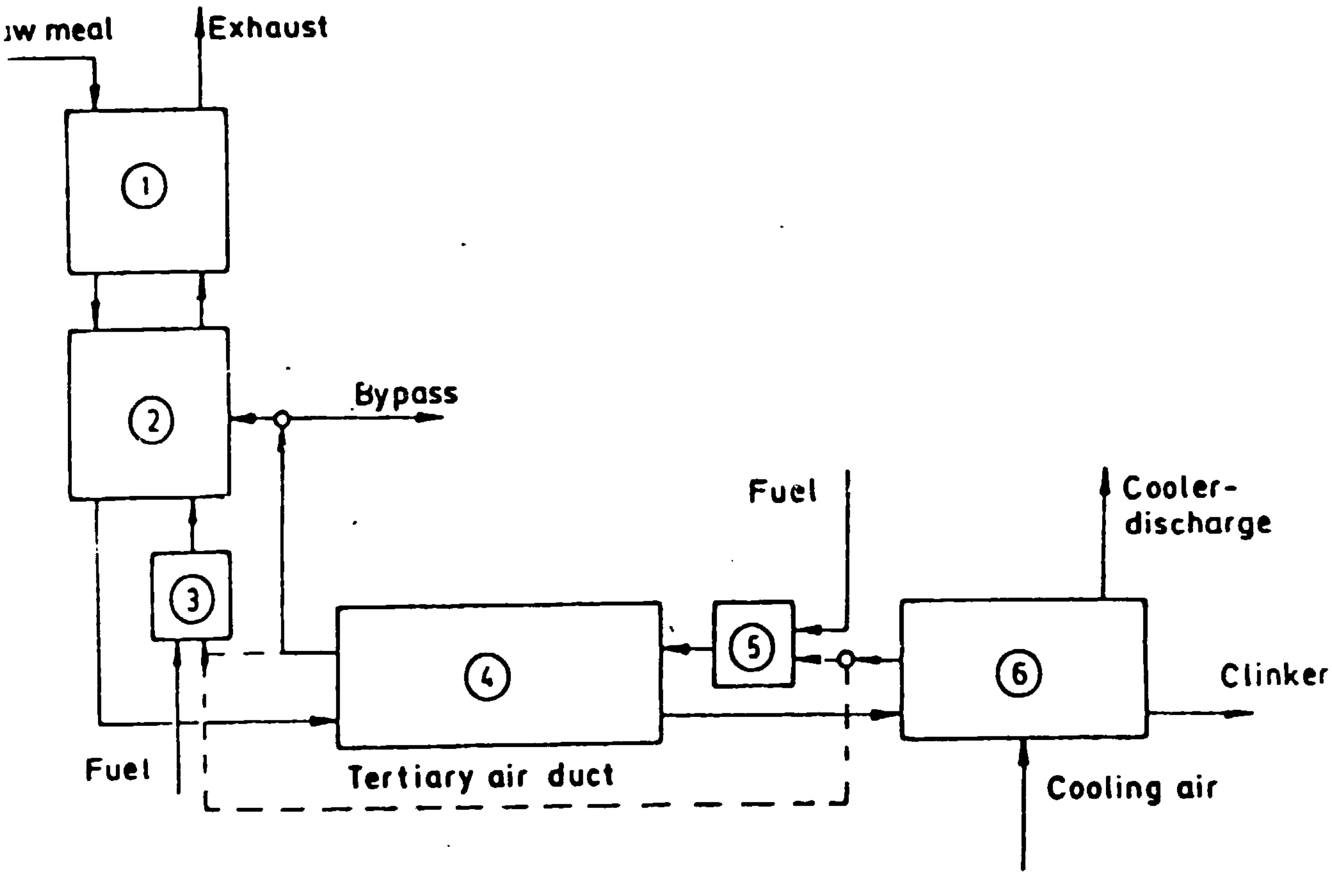
The four-stage cyclone suspension preheater-kiln system is today the most widely used conventional dry process kiln in the cement industry.

Further developments in clinker production has been achieved by the introduction of the cyclone suspension preheaters with precalciners. In this process, the firing stage is divided into two, according to the two different temperature levels applied during calcining and sintering. The primary firing, at the discharge end of the kiln, supplies only the heat flow that is required for sintering the neutralised material. The secondary firing takes place in the precalciner providing heat for the decarbonation of raw meal up to 90 per cent.

There are two ways of designing the kiln system for this type of secondary firing. In the first scheme the air required for combustion is guided through the rotary kiln to the precalciner. This requires the diameter of the kiln to be 20 per cent wider than in the second option, where the combustion air is taken through a separate air duct to the precalciner (figure 3).

In the first case where the air passes through the kiln to the precalciner, the specific volume load rises from 2 t/m^3 to 3.3 t/m^3; in the second case where the air is ducted outside the kiln, the specific volume load rises to 4 t/m^3. In spite of a higher volume load, the specific cross-sectional load is clearly lower than in rotary kilns without a precalcining stage. Therefore, the clinker output can be increased considerably when an existing kiln is fitted with a precalciner.

Figure 3. Burning of cement clinker with precalcination



1 Preheater
2 Precalcining stage
3 Secondary Firing
4 Rotary Kiln
5 Primary Firing
6 Clinker Cooler

Although the reduction in specific heat consumption by adding precalciners to the suspension preheater-kiln system, is modest namely about 20 kcal/kg clinker (0.084 GJ/t), this development has some important advantages which have led to its increasing use in developed and developing countries. The main advantage is increased output per unit of kiln volume. For a given capacity the volume of the kiln can be reduced by approximately 60 per cent as compared with the suspension preheater-kiln system, because the raw meal is decarbonized up to 90 per cent in the precalciner. Another advantage, which is particularly important from the energy point of view, is that low-grade fuels can be burned in the precalciner thus saving high-grade fuels such as fuel oil, gas and high-grade coal. A third positive factor relates to the environment: NO_x emissions are significantly decreased which is very important.

3.3 World-wide use of different types of clinker making processes and recent trends

The existing structure of the cement industry in different countries, particularly as related to the types of clinker making processes, has been formed under the influence of various factors such as the availability and type of raw materials, the developments in technology for clinker making, the availability and prices for fuels and labour. However, during the 1970s, a clear trend towards wider application of dry process kilns became apparent. This was a direct result from the increase in the world prices for energy and from new developments in the dry-process technology such as suspension preheaters and precalciners (see review in the preceeding section).

3.3.1 Developed countries

In Japan in 1980, practically all cement production was based on the dry and semi-dry method. The suspension preheater kilns and new suspension preheater systems which included precalciners became dominant. As a result the specific consumption of heat for clinker burning was on average 3.47 GJ/t as compared to 6.35 GJ/t in 1960. The Federal Republic of Germany's cement industry is currently using basically dry and semi-dry processes. Only about 3 per cent of all cement works use the wet process. The average specific consumption of heat for clinker production is one of the lowest in the world cement industry. In France the share of cement produced by the wet method decreased to 10 per cent by 1980 and the average specific energy consumption was 950 kcal/kg clinker (3.98 GJ/t).[6/]

In the United States the wet method of cement production has been dominant until recently. About 52 per cent of cement is produced here by the wet method technology. This situation was determined before the energy crisis by the availability of relatively cheap fuel and expensive manpower. The high content of alkalis in the clay components and the high demand for low-alkali cement delayed for many years the application of the dry method of cement production in kilns with cyclone preheaters. The problem of producing low-alkali cement is solved currently by installing kilns with precalciners and bypass systems for discharge of alkali rich dust. As the conversion of a wet process kiln to the dry process with preheaters and precalciners ensures a reduction in fuel consumption up to about 45 per cent, the high prices for heat energy in many cases made it feasible to implement such a conversion or even to shut down existing kilns and build up new ones based on modern dry-process technology. During past few years, 20 cement plants employing the wet method of production with a total output of 6 million tons have been put out of operation. During 1980-1982 about ten new kiln systems with precalciners were put into operation and several plants were modified with incorporation of precalciners in the kiln system.

Despite the great economy in fuel consumption of the dry process, the wet process is still widely used in Great Britain, because of the extensive use and the nature of the available deposits of chalk.

The wet process was at least up to recently rather widely used in the USSR cement industry where, as a result of various modifications, significant improvements in energy efficiency were achieved. To further reduce energy consumption in cement industry preference has now been given to the modern dry process technology and during 1981-1985 the production of cement by the dry method increased by 3.5-4 million tons.

6/ Report of the interregional seminar on energy saving in the cement industry (1983), UNIDO/IO.595, 1984, Vienna, p. 19.

The dry method of production has been introduced on an expanding level in the cement industries of the German Democratic Republic, the Hungarian People's Republic and the CSSR. In 1980 the proportions of cement produced in these countries by dry and semi-dry methods were 87.0, 82.1 and 69.2 per cent, respectively. The dry method of production is predominant in Hungary and the CSSR, while the semi-dry method is predominant in the German Democratic Republic. The average specific heat consumption for clinker burning in cement industries of Hungary and CSSR in 1980 was 4.96 and 4.86 GJ/t clinker, respectively. For some new plants in Hungary this index ranges from 3.28 to 3.47 GJ/t clinker. All these plants use modern dry-process technologies. The most efficient plant Ostrava in CSSR achieved the lowest figure for specific heat consumption: 3.15 GJ/t clinker. Preference for the dry and semi-dry process kilns has been given during recent years in most other developed countries as well.

3.3.2 Developing countries

The cement industries in developing countries use different types of processes and kilns. Table 3 contains information about the types of processes and fuel used for firing of cement kilns in most of the developing countries of Africa, America and Asia.[7/] Although this table cannot be regarded as strictly accurate, it does give the picture of the types of process kilns in use in developing countries. Furthermore, it can be seen from this table that the majority of planned kilns uses the dry process and in a number of cases the conversion of the wet process kilns to dry or semi-dry is planned or under consideration. It can be assumed that even more wet process cement plants would have been planned for conversion if the associated capital investments were not so high. In fact, this can be considered as the main constraint to the conversion of cement plants throughout the world, not only in developing countries.

7/ Compiled from World Cement Directory 1980, vol. 1 and II, CEMBUREAU, The European Cement Association, Paris, 1980.

Table 3. Rotary kilns in service at end 1978

Country	Process Dry	Fuels Oil	Coal	Gas	Process Semi-dry	Fuels Oil	Coal	Gas	Process Wet	Fuels Oil	Coal	Gas	Note
Africa													
Algeria	10			x	-				5			x	2 DPK[a/] burning gas were planned for 1983 and 1984
Angola	-				-				4	x			
Benin	-				-				-*				* One DPK was under construction
Cameroon	1	x			-				-				One DPK was planned to be added
Congo	1	x			-				-				
Egypt	-				3	x			18	x		x	(a) Some of the wet kilns were planned to be converted to dry process; (b) two DPK were under construction
Ethiopia	2	x			1	x			-				
Gabon	-				-				1				No information regarding fuel use
Kenya	2	x			-				2	x			6 vertical kilns using coal were in operation
Libya	9	x			-				-				One dry process kiln in 1983
Madagascar	-				-				1		x		It has been decided to build two vertical kilns in 1979 to be increased by a third kiln
Malawi	1		x		1		x		-				
Mali	-				1				-				(a) No information regarding fuel use; (b) one DPK was planned for construction for 1983

a/ DPK = Dry process kiln.

Table 3. Rotary kilns in service at end 1978 (cont'd)

	Process	Fuels			Process	Fuels			Process	Fuels			
Country	Dry	Oil	Coal	Gas	Semi-dry	Oil	Coal	Gas	Wet	Oil	Coal	Gas	Note
Africa (cont'd)													
Morocco	1	x			4	x			8	x			5 DPK were planned to be constructed during 1979/83
Mozambique	1		x		1		x		1		x		
Niger	1	x			-				-				
Nigeria	4	x			-				8	x	x		(a) Two rotary semi-wet kilns were in operation; (b) four DPK were under construction
Senegal	3	x			-				-				
Sudan	3	x			-				-				One DPK was under construction
Tanzania	2	x			-								Four DPK were under construction
Togo	2*	x			-								* Refers to 1979
Tunisia	4	x		x	-				3	x			One DPK was under construction
Uganda	4	x			-				-				
Zaire	3	x			1	x			3	x	x		
Zambia	2		x		-				3		x		
Zimbabwe	1		x		3		x		-				

Table 3. Rotary kilns in service at end 1978 (cont'd)

Country	Process	Fuels			Process	Fuels			Process	Fuels			Note
	Dry	Oil	Coal	Gas	Semi-dry	Oil	Coal	Gas	Wet	Oil	Coal	Gas	
America													
Argentina	29	x	x	x	3	x	x	x	11	x		x	One wet kiln was planned to be converted to dry process by 1980
Bahamas	-				-				2	x			Feasibility to convert to dry or semi-dry in 1982 was studied
Bolivia	4	x			-				-				
Brazil	42	x	x		3	x			51	x	x		(a) One vertical kiln fired with coal; (b) expansion by two dry kilns and construction of four DPK was planned
Chile	5		x		-				2		x		
Colombia	6	x	x	x	-				36	x	x		Several kilns were planned to be switched over to coal
Costa Rica	3	x			-				-				One DPK on stream in 1980
Cuba	19	x			-				-				Two DPK in service 1979
Dominican Republic	1	x			-				6	x			
Ecuador	6	x			-				2	x			Two DPK were planned to be constructed
El Salvador	1	x			-				3	x			
Guatemala	4	x			-				-				
Haiti					-				2	x			This cement works is self-sufficient in electric power

Table 3. Rotary kilns in service at end 1978 (cont'd)

Country	Process Dry	Fuels Oil	Coal	Gas	Process Semi-dry	Fuels Oil	Coal	Gas	Process Wet	Fuels Oil	Coal	Gas	Note
America (cont'd)													
Honduras	4	x			–				–				One DPK was planned for 1981
Jamaica	–				–				3	x			
Mexico	68	x		x	–				4	x			
Nicaragua	–				–				5	x			
Panama	1	x			–				3	x			
Paraguay	2	x			–				–				One dry process on stream in 1983
Peru	8	x			–				4	x			
Puerto Rico	–				–				8	x			
Trinidad and Tobago	–				–				3			x	
Urugay	1	x			–				7	x			
Venezuela	7	x		x	–				14	x		x	Two DPK under construction

Country	Process Dry	Fuels Oil	Fuels Coal	Fuels Gas	Process Semi-dry	Fuels Oil	Fuels Coal	Fuels Gas	Process Wet	Fuels Oil	Fuels Coal	Fuels Gas	Note
Asia													
Afghanistan	-				-				3		x		
Bangladesh	-				-				1			x	
Burma	1*				-				3	x			* No information regarding fuel
India	32	x	x		6	x	x		95	x	x	x	A number of DPK were planned
Indonesia	7	x		x	-				10	x	x		One DPK on stream in 1980, another plant expansion by DPK in 1982
Iran	34	x	x		-				10	x			One DPK expansion in 1980
Iraq	3	x			-				24	x			13 WPK will be closed before 1985
Jordan	1	x			3	x			-				One DPK in 1983 with possibility to add another
Republic of Korea	21	x			7	x			4	x			Expansion by four DPK
Lebanon	-				-				10	x			
Malaysia	3	x			2	x			4	x			One DPK under construction
Pakistan	-				5				21		x	x	Expansion by one DPK
Philippines	20	x			12	x			2	x			One plant to be converted in 1981 to DPK
Qatar	-				3			x	-				
Saudi Arabia	10	x		x	-				-				9 DPK were under construction
Sri Lanka	4	x			-				-				
Syria	4	x			-				9	x			2 DPK were planned for 1980
Thailand	7	x			2	x			9	x			Expansion by two DPK was planned
United Arab Emirates	4	x			-				1	x			
Viet Nam	-				6	x			-				2 DPK were under construction
Yemen, Arab Republic of	-				-				1	x			

In India the average specific heat consumption for the dry process cement plants is 900 kcal/kg clinker (3.77 GJ/t): for the wet process plants it is 1,480 kcal/kg clinker (6.2 GJ/t). With 65 per cent of the cement plants using the wet process and the remaining the dry or semi-dry process, there exists a great potential in the cement industry for energy saving through the conversion to dry process.[8/]

In Pakistan the wide use of the wet process kilns (21 of a total of 26 cement kilns) and other factors accounted for a high average specific consumption of energy in cement production (about 7 GJ/t clinker). All projects for new cement kilns are based on the dry process with suspension preheaters and the use of precalciners in future projects is also under active consideration.[9/]

In Kenya two major cement companies use different types of processes. East African Portland Cement Company's (EAPC) Athi River plant uses the wet process cement manufacturing process requiring some 75 per cent more process heat input per ton of cement than Bamburi Portland Cement Company in Mombasa using basically the dry process. The conversion to the dry process kilns has been under consideration by EAPC as an option to achieve energy saving in the production process.

Some developing countries have essentially modern cement industries employing mainly dry or semi-dry process kilns with relatively low energy consumption. These are Indonesia, the Philippines, the Republic of Korea, Sri Lanka, Thailand and some other countries. Energy consumption broken down by stages of cement production process for the most modern plant in terms of capacity, quality control and energy consumption in Thailand is presented in table 4.

8/ Sectoral reports - Energy audit studies. "Report on utilization and conservation of energy", National Productivity Council, New Delhi, India, 1983.

9/ Energy conservation in cement industry - some experiences, Asian Productivity Organization, Tokyo, 1982, p. 76.

Table 4. Energy consumption - Kaeng Khoi plant

Department	Capacity Ton/hour	Power consumption kWh/t	Heat consumption kcal/kg
1. Crushing			
Limestone		1.60	-
Shale		2.60	-
Laterite		5.30	-
Transport and storage		0.43	-
2. Raw material grinding and blending			
Raw mill 1	140	21.75	-
Raw mill 2	280	24.20	-
Homogenizing and transport		1.31	-
3. Kiln			
Kiln 1[a/]	1,500	13.00	860 (3.6 GJ/t)
Kiln 2[b/]	2,800	14.80	780 (3.26 GJ/t)
Transport		0.73	-
4. Cement grinding			
C.M. 1: Portland type I	70	39.70	-
Mixed Portland		37.10	-
C.M. 2: Portland type I	70	41.30	-
Mixed Portland	120	40.90	-
C.M. 3: Portland type I	120	37.60	-
Mixed Portland		34.40	-
Transport		0.39	-
5. Packing and loading			
Packer 1, 2, 3, 4		1.61	-
Bulk loading		0.16	

a/ One stage cyclone preheater long dry kiln.
b/ Suspension preheater dry kiln.

Source: Energy conservation in cement industry - some experiences, Asian Productivity Organization, Tokyo, 1982, p. 122.

Along with rotary kilns some developing countries use vertical shaft kilns for cement manufacturing. Shaft kilns are in operation in the People's Republic of China, India, Nepal and some other developing countries. Because of their limited production capacities and low productivity their number was dramatically decreased in developed countries with the introduction of production units of 1,000 ton per day or above . However, many experts believe that for the developing countries with low labour costs and suitable coal reserves the use of small scale cement plants employing vertical shaft kilns is a viable alternative, or complementing technology, to large scale cement plants. It is a technology which allows for a high degree of self-reliance, not only in the manufacture of cement, but also in the building of cement plants. An example of such an approach is the cement industry development in the People's Republic of China where several thousands shaft kilns have been built and put in operation during recent years and are now producing cement with a calorific consumption of about 950 kcal/kg clinker (3.98 GJ/t). In India the building of mini cement plants is actively promoted and 200 possible sites have been located all over the country.

It is maintained that the low fuel consumption, owing to the direct heat transfer principle used, enables vertical shaft kilns to remain competitive with rotary kilns in spite of the difference in scale of operation.[10/]

10/ R.J.S. Spence, "Small-scale production of cementitious materials", Intermediate Technology Publications Ltd., London, United Kingdom, 1980.

4. ENERGY CONSERVATION IN CEMENT PRODUCTION

Effective measures taken to save energy in the cement industry in many countries, particularly developed countries, have helped to cut significantly the specific consumption of energy during the past two decades. This has been associated with the development and utilization of highly efficient large-scale production units.

The basic opportunities for energy saving in cement production relate to the improvement of the processes of clinker burning and grinding as well as to the utilization of low quality fuels. Of primary importance is the improvement of heat use efficiency and the reduction of heat losses.

4.1 Energy savings related to heat utilization

As shown above, the dramatic reduction of specific heat consumption in cement plants is achieved by using modern dry process kilns with suspension preheaters (SP) or more advanced kilns with both SP and precalciners where the heat of the exhaust gas of the kiln is used for preheating the kiln feed. This can be realized when building new plants and/or when expanding existing ones.

It should be mentioned that specific consumption of electric power in such plants is usually higher than that of the wet and semi-wet plants but nonetheless their overall energy efficiency is much higher since the heat consumption accounts for the major share of energy input to cement production.

Considerable attention is also given to such methods to economize on fuel as the changing of mineralogy in the cement and utilizing mineralizers. Low-melting slags, fluoride and calcium sulphate are a few of the numerous substances that render a mineralizing effect on clinker formation. A reduction of clinker formation temperature, when utilizing the latter, leads in the end to a saving of energy.

Available evidence suggests that the use of appropriate mineralizers opens a substantial energy savings potential. However, there are some difficulties with respect to choosing the best mineralizer for clinker burning as the quality standard, raw material base, technical facilities and ecological aspects have to be taken into account to prevent some possible adverse effects such as poor setting of the cement, delayed early and reduced final strength and environmental pollution through emission of fluorine and sulphur components.

It is expected that further research and development work in this field will result in a further evaluation of the applicability of various mineralizers in cement clinker production.

In the USSR significant attention is given to the development of industrial production of cement by low-temperature technology with the use of calcium chloride wherein the reaction in mineral formation is completed at temperatures lower than in currently utilized technologies. About 1 million tons of cement was planned to be produced by this technology in 1981-1985.

The basis for this low-temperature technology is the forming of such a melt during calcination of the raw material burden that the completion of clinker formation is ensured at 1,100-1,150°C (while the burning of portland cement clinker is performed at 1,400-1,450°C).

When the process of clinker formation has been completed, the clinker is desalted with the help of special equipment. The free calcium chloride in the clinker is decomposed in this case. Hydrogen chloride, produced in the process of desalting, interacts with the lime component of the burden, maintaining in it the required amount of calcium chloride for the production of a salty melt. When producing cement by low-temperature technology with the use of calcium chloride, the process of preparing the raw material mass is simplified, and the possibility arises for reducing the number of components in the mixture and for eliminating the introduction of pyrite cinder. The specific fuel consumption for calcining clinker is reduced approximately 10 per cent by changing the clinker mineralogy. Since the clinker produced by this process features a high grinding ability, the specific consumption of electric power decreases considerably and the capacity of the cement mills increases.

A catalytic complex technology for the production of effective types of cement is being currently developed in the USSR. It is planned to produce sulphoaluminate clinker by this technology that would make it possible to have a series of special grades of cement with unique building properties. Mineral formation is completed in the sulphoaluminate clinker at a calcining temperature 150-200°C lower than in the case of calcining portland cement raw material mixtures.[11/]

Among the measures widely applied for the improvement of heat use in rotary cement kilns are the use of internal heat exchangers, e.g. chain systems used in wet and dry process kilns and different thinners permitting reduction of the slurry moisture in the wet process that as described above.

Substantial reduction in heat losses from the kiln can be achieved by proper maintenance of the kiln seals and reduction of air leakages in the kiln system, control of combustion by continuous monitoring of CO and O_2 content in exaust gases, by improved refractories and cooling of the kiln shell to promote coating on the inside of the refractories.

Several commonly used ways of reducing heat losses have not been applied to the process so far. For example, losses from the wall of the rotary kiln make up a substantial share of total energy lost. The rotary kiln has a jacket temperature of up to 350°C. The heat transfer is reduced when the surface is insulated, but at the same time the temperature of both the metal jacket and the lining rises. This in turn reduces the mechanical strength and the life of the kiln. Moreover, there is the risk of the shell melting if the kiln is insufficiently insulated or if the lining fails. However, modern test facilities and monitoring of the jacket temperature seem to suggest that some kind of insulation can be considered.

The same kind of effect could be achieved by boxing-in the kiln. In this way convection heat losses can be minimized because high air velocities during wind are excluded.

11/ N.I. Fillipovich, "Rational and economic utilization of fuel-energy resources in industry of building materials", Materials of USSR-Federal Republic of Germany Symposium, VINITI, Moscow, 1983, p. 332-333.

By coating the kiln with aluminium bronze, for instance, radiation losses can also be cut. However, with minor radiation to the atmosphere, this kind of coating will make the temperature of the kiln jacket rise, which causes even higher convection and produces all the adverse effects mentioned above.

Thus, external insulation is detrimental to operating safety. One way of overcoming this is to utilize heat losses rather than minimizing heat transfer.

To this end, a recuperator is fitted at the top or on the side of the rotary kiln. It is heated by some of the radiation emitted by the kiln. Inside the recuperator flows a heat transfer medium, e.g. water which is heated. The key factors are the space between the recuperator and the kiln, and their respective temperatures. Some of the recuperator heat is released at its surface through free convection. However, this convection can be minimized by a top or side cover, or a screen.

Theoretical considerations have shown that a heat flow equal to 30 kg of fuel oil per hour can be saved with an optimized design and configuration of the recuperator, given mean wall temperatures of around 250°C, an outside diameter of the kiln of 5 m, and a heat exchanger surface area or 200 m^2. This amount of heat saved can be utilized to dry coal or raw materials, or to heat buildings. The practical application of these theoretical considerations will, however, require additional research and development.[12/]

The afore-mentioned measures aim at realizing the energy saving potential related to the kiln. Another opportunity for improving heat utilization in a cement plant is to use waste heat from clinker coolers. This waste heat can be used in a number of ways particularly to dry raw materials or coal, when it is used for firing the kiln and to generate steam and power if necessary.

12/ Tätigskeitsbericht 1978-1981, Verein Deutscher Zementwerke e.V., Forschungsinstitut der Zementindustrie, Düsseldorf, Federal Republic of Germany.

At one cement plant in the German Democratic Republic the heat given off by fresh cement clinker is used in two ways:

(a) Air heated by the cooling clinker is used in the rotary kiln as secondary combustion air, thereby increasing the efficiency of the combustion process in the kiln.

(b) Further cooling of the clinker yields waste air at a temperature of 200°C, which is used to heat water in four waste heat boilers. The hot water is fed into the factory water system. As a result, the fuel consumption of the factory boiler room is reduced. The capital costs associated with the above measures were recovered in 0.8 year.[13/] The use of hot air from clinker coolers as a combustion air in the kiln is an effective energy saving measure. An energy saving of about 50 kcal/kg clinker is achievable by reducing the amount of primary air from 30 to 10 per cent.[14/]

Effective systems for heat recuperation from clinker coolers have been introduced in Japan in plants with Air Quenching Coolers with a grate (A.Q.C.) when used in cement production systems with cyclone SP and precalciners. The hot air from clinker coolers is utilized as secondary combustion air in the kiln and the precalciner as well as for generation of electric power by using waste heat boilers.

Six cement plants generated electric power in Japan in 1981 by utilizing waste heat. A circuit with low-boiling (Freon type) liquids was exploited at a temperature of the waste gas up to 200°C, and a common steam power cycle at temperatures in excess of 400°C.[15/]

13/ Consolidated report on recovery and utilization of secondary energy sources in glass and building materials industries presented to the ECE Symposium on rational utilization of secondary forms of energy, Bukarest, 1983 (Energy/Sem.3/R 110).

14/ Energy conservation in cement industry - some experiences, Asian Productivity Organization, Tokyo, 1982, p. 88.

15/ K. Noguchi, Japan's cement industry today, "Rock products", 1982, N5, 64 E-64H.

One of the prospective trends in the reduction of energy consumption in the cement industry is the expanded production of blended cement.

The percentage of the replacement materials such as natural pozzolana, fly ash, slag, etc., normally ranges from 15 to 30 per cent. Blended cements with the addition of slag are produced in many countries. In Japan they are called special cements owing to their slightly lower strength indices. Slag portland cement is produced in some countries with separate grinding of cement clinker and slag and mixing them at the customer's site.

The utilization of additives in the form of blast furnace granulated slags and fly ashes of thermal power stations has contributed to reducing the consumption of energy resources in the cement industry. At the same time it allows the disposal of these industrial wastes in an environmentally sound manner. The amount of additives to cement in 1980 reached 16-18 per cent in Bulgaria and Hungary, about 22 per cent in the USSR and up to 29 per cent in Chekoslovakia. It is expected that the necessity of further reduction of energy consumption in the cement industry will lead to an increased use of additives.

Many developing countries use pozzolanas in varying amounts as additive to cement. A consideration of the possibility to grind a granulated blast furnace slag together with ordinary portland cement clinker in Pakistan has shown that the energy consumption per ton of cement will decrease by about 36 per cent as compared to the current level if the share of slag in blended cement is 40 per cent.[16/]

In India studies are going on to utilize steel slags - an industrial waste product from steel industries - as a major raw material for manufacture of super sulphate cement by blending it with calcined gypsum and hydrated lime in suitable proportions.[17/]

16/ Energy conservation in cement industry - some experiences, Asian Productivity Organization, Tokyo, 1982, p. 92.

17/ Ibid., p. 26.

One of the constraints to the wider use of slag in blended cements is the lack of slag granulation facilities in the steel industry in some countries.

4.2 Electric power savings

Rationalization of electric power consumption in the cement industry encompasses improved house-keeping measures with respect to electrical equipment as well as operational improvements and technological modifications leading to electrical power savings.

The cement mills are the major consumers of electric power at cement plants, accounting for some 40 per cent of total electric power consumption. Therefore, primary attention is given to improving efficiency in electric power utilization in these units as well as in the raw material grinding mills which are in second place in terms of consumption of electric power in cement plants.

The major part of the energy consumed in the grinding of materials is not used for the process proper but is released in the form of heat. Currently, cement is ground mainly in ball mills whose energy efficiency is low: only 5-9 per cent. This figure is 7-15 per cent in roller mills, 25-40 per cent in impact crushers, and 70 per cent in rolling crushers.

The basic method for reducing energy consumption in ball mills is their adjustment to establish an optimum operating regime and to ensure maximum output with minimum energy consumption while preserving the predetermined fineness of grinding. However, the possibility of reducing the specific energy consumption in cement grinding by adjusting the design and technological parameters of the mills is limited by the quality requirements of the cement, first and foremost the characteristics of setting and strength increase. It is possible to increase slightly the degree of energy utilization in ball mills by adjusting the parameters of the open and closed cycles but it is impossible to ensure a substantial increase in the efficiency of these grinding units at the current level of technical knowledge. The possibilities of increasing the efficiency in energy utilization in well adjusted grinding plants have been practically exhausted.

To further increase the efficiency of the grinding process, it is necessary to employ grinding units of other designs. But, when developing new methods of grinding, it is necessary to ensure that economy in energy use does not cause offsetting increases in capital and operating costs.

Experiments have been carried out in some countries on grinding cement in roller mills.18/19/ Thus, information was published in 1980 that the company Claudius Peters (FRG) used a roller mill of 110 t/h capacity for grinding cement at one of the cement plants producing portland cement. At first, the strength of the cement produced in the roller mill, was lower than when ground in a ball mill, but it corresponded to standards after 28 days. When compared with cement ground in a ball mill, this cement was characterized by a smaller specific surface area and steeper grain composition curve.

False settings are observed frequently for cement ground in a roller mill and its water requirements for reaching normal grout consistency increase considerably. This leads to the tendency of concrete made from such cement to form efflorescence. These phenomena are evidently explained by the narrow grain composition of the cements and the reduced content of fine fractions that cause an increased porosity in the produced cement stone. Water separation can be observed in the process of cement grout hardening. However, an improvement of the cement quality can be achieved by changing the configuration of the grinding elements and the conditions of separation.

The researchers at the companies Loesche and Polysius (FRG), who studied this problem, arrived at the same conclusions. According to published data, the energy consumption decreases in roller mills by 15-25 per cent compared with ball mills (depending on the grade of the cement being ground).

18/ Cement-Kalk-Gips, 1981-N11, p. 560-562, 1982-N2, Federal Republic of Germany.

19/ World cement, 1982, N2, p. 76-78.

Well-known advantages of roller mills as compared with ball mills are, for example, the short time the material is in the mill and the reduced cost of the dust separators (with consideration of the cost for the grinding bodies and the armoured lining). Besides, the capital expenditures are lower for their construction. Moreover, the Polysius company has developed a system that reduces the air rate in the roller mill. The large grains return through the holes in the circular channel at a low air rate and a bucket elevator is installed additionally to ensure their return to the cycle. The low air rate contributes to reducing wear of the spray injectors, reduces the pressure losses and permits the use of low power fan. The decrease in the part of fine fractions and the respective reduction in strength at an early age as a result of grinding the cement in a roller mill is explained by the fact that it is a ventilated-type crusher with a flow-type separator, wherein the fine fractions are removed immediately by the ventilating air flow.

Another possibility of reducing the consumption of electric power is to improve the technology of grinding in ball mills by pre-engagement of the crusher-drier. Preliminary crushing may save energy in grinding up to 6 kWh/t raw material or 9 kWh/t clinker.

Evidently, cement will be ground in the future mostly in vertical mills. The experience of grinding the raw material and coal at the plants of the British company ARSM has indicated that the utilization of vertical mills reduces the consumption of electric power for grinding by 50 per cent. The utilization of grinding intensifiers also ensures a certain energy saving. Investigations carried out by the ARSM company indicate that the specific consumption of electric power reduces by approximately 5 kW h/t when grinding ordinary portland cement, and by about 13 kW h/t when grinding high-early-strength cement.[20/]

At TSAB (Dessau, German Democratic Republic), a roller mill was re-equipped for operation with mechanical discharge in order to produce a wide range of cements. During the experiments, the specific consumption of electric power ranged from 20 to 23 kW h/t cement.

20/ "Cement, Wapno, Gips", Poland, 1977, 21 v.4.

Experiments have been carried out on grinding cement in pendulum mills of small capacity (from 0.5 to 30 t/h). These mills are simple in operation, need neither complicated maintenance nor frequent replacement of worn parts.

One of the main reasons for the reduction in grinding unit efficiency is the aggregation of the crushed material particles with the formation of agglomerates. In order to reduce the amount of agglomerates, formed in the roller mills, it has been proposed to decrease the rotational speed of the rollers but this requires a considerable increase in power consumption. Therefore, it is better not to return the middlings comprising a considerable part of agglomerates from the separator to the roller mill but to crush it additionally in a common ball mill.

During recent years many cement plants have started using grinding aids for clinker grinding as a means of reducing electric power consumption and achieving increased throughput in the cement mill.

Scientific research organizations of the USSR have developed and tested on an industrial scale new effective types of grinding aids. Their subsequent utilization in practical applications confirmed their high efficiency: the specific energy consumption was reduced by 10-15 per cent.

The use of grinding aid when grinding clinker has contributed to reducing the consumption of electric power and improving the grade of the cement. About 44 per cent of the total output of cement in the German Democratic Republic, and 16 per cent in the USSR, is produced with the use of grinding aids. Grinding aids are also used on a wide scale in grinding of cement in Bulgaria.

Proper clinker cooling can make clinker grinding easier and contribute to the reduction of electric power consumption. Another means to improve the electric power utilization in cement mills is to use classifying liners.

At present, roller mills appear to have some basic advantages in raw material grinding, particularly in kiln systems with SP or precalciners. The use of a roller mill in raw material grinding can reduce electric power consumption by about 20 to 25 per cent compared to that of a tube mill. However, a roller mill is in general not suitable for processing of abrasive raw materials.

4.3 Substitution of fuels

Energy conservation means not only reduction of specific energy consumption per unit of finished product but also preservation of scarce fuels such as fuel oil.

The basic technological fuel before the 1960s was coal. Then fuel oil and natural gas became predominant. This was associated, on the one hand, with the energy market situation, and, on the other, with the simplicity of preparing, easy control of supplying and delivering of the fuel. Beside that, the trend to increase the capacity of the kilns required increasing of the calorific value of the coal to 27 MJ/kg.

However, many countries started reversing to coal after sharp increase in prices for oil-based fuels in 1970s. Thus, it is planned to bring the proportion of coal in the fuel balance of cement production to 90 per cent in the United States, while a programme of complete transfer of the cement industry to coal is approaching its end in the Federal Republic of Germany today. Only 2 per cent of the fuel spent in the cement industry in Japan in 1973 was coal, but by mid 1982 the proportion of coal and different types of fuel with a low heat of combustion reached about 90 per cent. During 1978-1982 in France, the cement industry carried out a massive conversion from hydrocarbons to solid fuels so that today they represent almost 80 per cent of total thermal supplies.

The cement industries in many developing countries are now reversing to coal and other alternative fuels in order to reduce their reliance on mostly imported energy resources. This can be seen from table 3. Even countries possesing significant oil deposits like Indonesia are aiming at switching their cement plants from oil to coal and other low grade fuels.

Widescale opportunities for using low-grade fuels for clinker burning were opened by the development of systems with cyclone preheaters and precalciners. Precalcining or secondary firing, apart from the possibility of achieving higher outputs, has also opened a way for saving of high-grade fuel such as fuel oil, gas or high quality coal and substituting them by low grade fuels and combustible industrial wastes such as wood chips and bark, waste tires, urban wastes, etc.

This is possible because the precalciner operates at a temperature of about 900°C which is needed for the reaction of decarbonation of the raw mix. Only about a quarter of the total amount of heat used for clinker burning is consumed in the kiln itself. Therefore, it is possible to feed up to 75 per cent of the fuel into the secondary furnace in kilns with precalciners (in practice normally up to 60 per cent is burnt in the precalciner). This allows the differentiation of fuel for calcining the clinker: higher calorific fuel for ensuring high temperatures in the sintering zone of the rotary kiln and less calorific fuel for ensuring decomposition of the carbonate component in the precalciner.

There are basically two good reasons for using low-grade fuels, especially fuel substitutes, in the precalcination of cement. First, there is no limitation to the minimum calorific value because ignition is ensured due to high meal and gas temperatures of 700 to 1,000°C. Secondly, many of the substances harmful to the environment are introduced into the process together with the fuel and are bound almost completely in the cement clinker without impairing its quality. What is more, low-grade fuel can normally be used in the process directly, i.e. without pretreatment.

The experience of the Genstar Recycling Cement Plant in the USA illustrates the broad possibilities for using different combustible wastes as a substitute to commercial fuels in cement production.[21/] Since 1980, when a modernization of the plant took place and the long dry kiln was replaced with a suspension preheater-precalciner kiln system, the rice hulls and wood

---

21/ R. Segal, "Kiln fuel: rice hulls, waste oil", Rock products, April 1984, p. 42-43.

waste material from mills have been used in conjunction with gas without any problem. Both waste materials were used to meet up to 50 per cent of heat requirements of the plant. Tests with old rubber tires were also made and the kiln ran with no problems. However, indications are that the availability of waste materials on a regular basis is the most important factor in switching a cement plant to this type of fuel.

The use of precalciners opens another opportunity for substituting energy, that is to use solar energy. According to one concept which has been presented recently, solar energy is deflected by plane mirrors, standing in a field next to the cement works, onto a concave mirror. This mirror is fitted on a pole high up above the works. It bundles the light and directs the beam through a window into the combustion chamber. The focal length of the mirror is long enough to place the focus exactly in the centre of the flame. However, many of the questions that determine the realization of the concept have remained unanswered so far.[22/]

The utilization of electric power in the production of cement clinker is of doubtless interest in the long run. The basic advantages of electric technology in cement production are the sharp decrease of heat losses to the ambient environment and the solution of many ecological problems. The amount of waste gas in modern kilns is approximately 1.7 m^3/kg clinker at a heat content of 2,800 kJ/kg, while in electric kilns these figures are 0.3-0.4 m^3/kg and 670-690 kJ/kg respectively. However, widescale utilization of electric power for these purposes is restrained by the lack of industrially approved electric cement production technologies and by the shortage and cost of electric power in some countries.

Research has been carried out in the USSR to determine the possibility of producing portland cement clinker when exposing the raw material mixture to a powerful beam of runaway electrons (radiation-chemical method).[23/] The

---

22/ Kesselring, Durisch, "Limestone calcination", Swiss Federal Institute for Reactor Research, Würenlingen, Switzerland, 1984.

23/ Scientific-technical reference collection, Cement industry, Moscow, VNIIESM, 1981, issue 8, pp. 22-25.

process of clinker formation is completed in this case in 5-15 seconds. Effective transmission of energy simultaneously to the entire volume of the irradiated material, overlapping of the decarbonizing and clinkering stages in time as well as radiation stimulation of the processes of decomposition and synthesis contribute to fast clinker formation. The consumption of energy is 10-15 per cent lower as compared with the best indices recorded in the production of similar clinker, all while producing a high-grade cement product. Beside that, a 30 per cent decrease in the capital expenditures may be expected as compared to those in the case of the dry method.

Several electric technologies have been patented in the United States but the consumption of electric power at 0.48 kWh/kg clinker seems uneconomic though the advantages stated earlier are stressed.[24/]

The use of electric arc for burning clinker is also under consideration in a number of countries.

4.4 Potentialities for energy saving in cement production

The potentialities for saving energy in the production of cement by utilizing energy-saving technologies, equipment and measures are given in table 5.

Of particular importance for promoting energy conservation in the cement industry are training programmes. To assist the developing countries in this field UNIDO has designed and conducted during recent years several group training programmes in energy saving and conservation in the cement industry.

24/ World cement, 1982, N5, p. 200-205.

Table 5. Potentialities for saving energy in the production of cement

Energy-saving technologies, equipment and measures, for	Potential savings
1	2
Calcination of clinker	Fuel, percentage
Utilization of predehumified slurry, including the use of diluents a/	1-1.2 per one per cent of moisture content reduction
Production of cement by dry method in kiln with decarbonizer: b/	
as compared to kilns with cyclone heat exchanger	5-7
as compared to the wet method	40-50
Intensification of calcining process, including by reducing suction of ambient air, utilizing mineralizers, automatic control systems, efficient heat exchangers, fuel combustion systems, etc.	10-15
Utilization of ashes, slags and other materials, containing CaO, calcium silicates or aluminates c/	10 and more (depending on additive)
Utilization of combustible industrial waste and domestic garbage	equivalent to amount of waste used as fuel
Utilization of fluidized kilns for calcining clinker (as compared to rotary kilns) d/	25-35
Utilization of secondary energy for electric power generation, raw material drying	8-20
Clinker grinding	Electric power, percentage
Milling cement in roller mills (as compared to ball mills) e/	15-25
Utilization of milling intensifiers, optimization of granulometric composition, etc.	10-15

a/ Increase of kiln capacity by 1.5-2 per cent of moisture content decrease.

b/ Increase of specific capacity by 2.5 and 7.5 times, respectively and decrease of specific consumption of refractories by 4 and 5 times.

c/ Savings in raw materials components.

d/ Reduction of capital investments by 20-30 per cent, potentiality for burning shale and low-grade coal.

e/ Reduction in capital investments for construction, potentiality for additional cooling of clinker in milling processes.

5. CONCLUSIONS

The cement industry belongs to a group of industries which manufactures products with high energy intensity. Consequently the industry for a long time has paid attention to problems related to the use of energy. However, only after the dramatic increase in the prices for oil in the 1970s these problems have become of primary concern for the industry since the share of the energy input exceeded 40 per cent of the production cost and energy became a major production factor.

This study addresses the main issues related to the use and conservation of energy in cement production. Some of the main findings are summarized below.

A comparison between data from developed and developing countries shows a great difference in specific consumption of energy in the production of portland cement, which is the the principal product of the cement industry. This indicates the existence of broad possibilities for energy saving in the cement industry which can be realized through technological modifications, operational improvements and housekeeping measures.

Since about 90 per cent of the energy consumption in the production of cement goes to the process of burning the cement clinker the basic opportunities and the highest potential for energy saving relate to this part of the production chain.

The utilization of the suspension preheater-rotary kiln systems with the dry method of raw mix preparation leads to a significant reduction of specific energy consumption compared to the dry kiln systems without preheaters and wet process kiln systems (up to 40-50 per cent). This advantage has been one of the main reasons for the wide application of this type of technology in the cement industry in many countries. It is shown in the study that the majority of cement kilns which have been put into operation and planned for construction in the world during the last decade employ the dry method of cement production and use suspension preheater-kiln systems.

The most advanced dry process kiln systems include precalciners along with suspension preheaters. The use of precalciners ensures not only further reduction of specific energy consumption but what is more important provides a possibility to use low grade fuels and various combustible industrial and other residues.

However, the cost of conversion of the existing wet process kilns to dry or semi-dry process kilns generally amounts to around 60 per cent of the cost of a new unit and is therefore not always feasible or affordable. Besides, at some locations the wetness of raw materials may make the use of wet process kilns necessary. In such cases a reduction of specific energy consumption can be achieved by preliminary dehydration of the raw mix, by utilizing different thinners, etc.

Prospective trends for reduction of the specific energy consumption related to the technology used in the production of cement include: calcination of clinker in a fluidized bed kiln; changing the mineralogy of cement by using mineralizers; low-temperature technology of clinker making with the use of calcium chloride; improvement of the existing grinding tube mills and application of roller mills as well as grinding aids to reduce consumption of electric power when grinding the clinker.

Considerable energy savings can be realized by using secondary energy for heating purposes, drying the raw materials, generating electric power etc.

Besides the possiblities mentioned above for improvement of energy utilization of cement plants which require capital investments there also exists a considerable potential for energy saving through improved housekeeping measures at no or little cost. These include improved fuel handling and preparation, improved combustion and draft control as well as improved housekeeping in respect of electric power utilization.

An analysis of the developments which have taken place in the cement industry of different countries also reveals the following two important trends related to the use and conservation of energy in this industry:

a) Production of blended cements with the use of various pozzolana materials including fly ash and slag is now considered by many countries as a way to reduce energy consumption in the cement industry;

b) In many countries coal is regaining its position as a basic fuel used in cement plants. Some countries have almost accomplished the process of switching their cement plants from fuel oil to coal. A great deal of attention is given to the use of different low grade fuels and combustible residues in clinker burning. This has become possible with the introduction of precalciners.

For the guidance of our publications programme in order to assist in our publication activities, we would appreciate your completing the questionnaire below and returning it to UNIDO, Division for Industrial Studies, D-2119, P.O. Box 300, A-1400 Vienna, Austria

---

QUESTIONNAIRE

Use and conservation of energy in the cement industry

	(please check appropriate box) yes	no
(1) Were the data contained in the study useful?	/_/	/_/
(2) Was the analysis sound?	/_/	/_/
(3) Was the information provided new?	/_/	/_/
(4) Did you agree with the conclusion?	/_/	/_/
(5) Did you find the recommendations sound?	/_/	/_/
(6) Were the format and style easy to read?	/_/	/_/
(7) Do you wish to be put on our documents mailing list?	/_/ If yes, please specify subjects of interest	/_/
(8) Do you wish to receive the latest list of documents prepared by the Division for Industrial Studies?	/_/	/_/

(9) Any other comments?

Name:
(in capitals) ....

Institution:
(please give full address) ....

Date: ....