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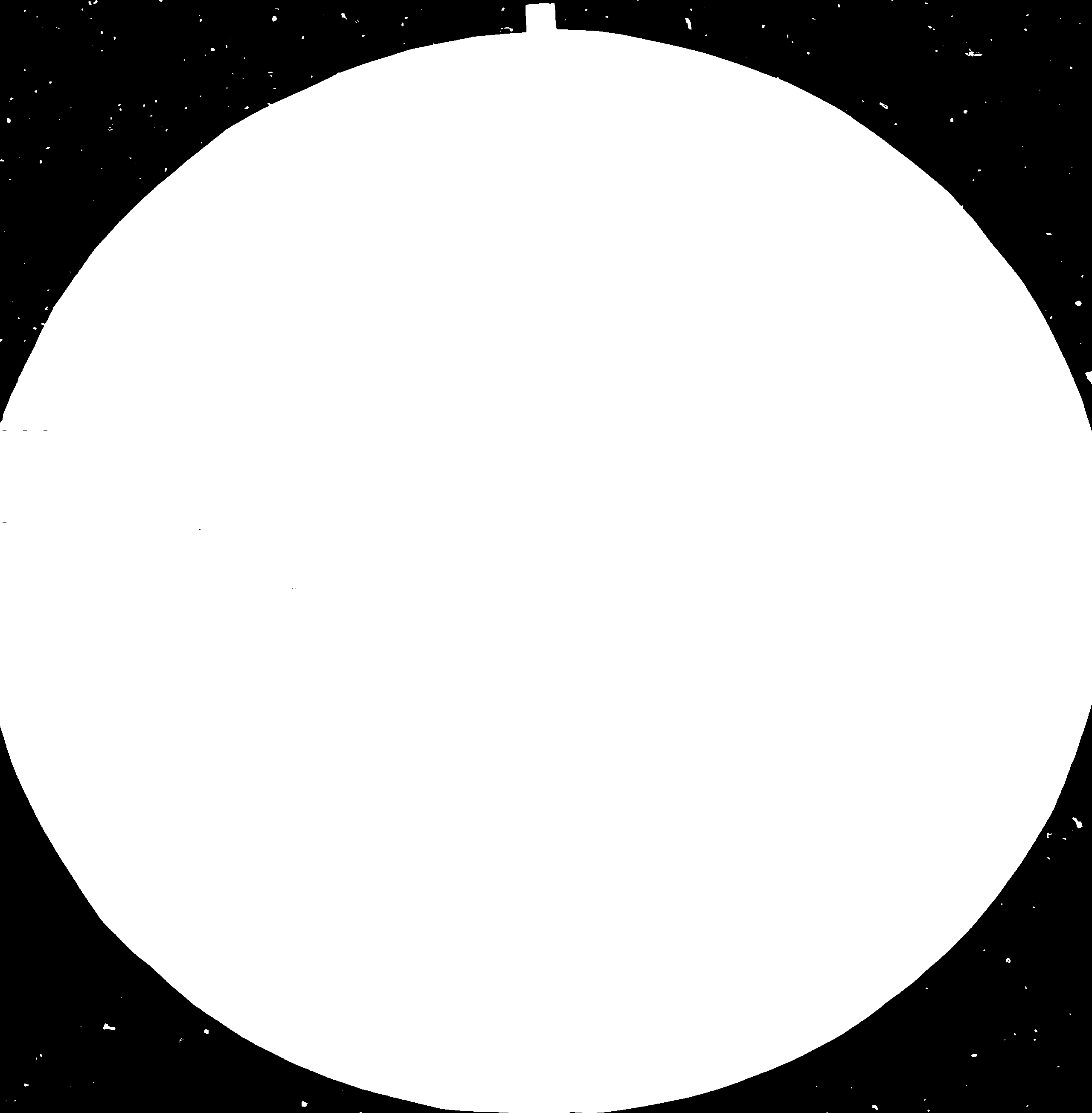

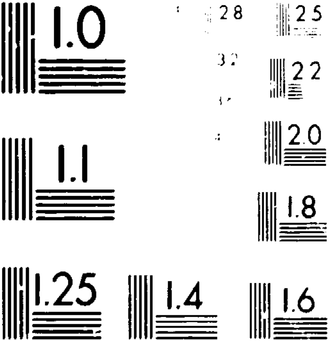

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INTERREGIONAL SEMINAR ON ENERGY SAVING IN THE CEMENT INDUSTRY,

Nancy and Paris, France, 13 June to 1 July 1983

Report,

Prepared by A.R. Marei, project co-ordinator

2722

Explanatory notes

The following abbreviations of organizations are used in this report:

ACTIM	Agence pour la coopération technique, industrielle et économique (Industrial and Economic Technical Co-operation Agency)
AFME	Agence française pour le management de l'énergie (French Agency for the Management of Energy)
CERIHL	Centre d'études et de recherches de l'industrie des liants hydrauliques (Research and Development Centre for the Industry of Hydraulic Binders)
CRIFIC	Centre de recherche, innovation et formation des ingénieurs et cadres (Centre for Research, Innovation and Education of Engineers and Executives)
ENSIC	Ecole nationale supérieure des industries chimiques (National College of Professional Education for the Chemical Industries)

The following technical abbreviations are used in this report:

mtoe	million tonnes oil equivalent
toe	tonnes oil equivalent

Mention of the names of firms and commercial products does not imply endorsement by the United Nations Industrial Development Organization (UNIDO).

CONTENTS

Chapter Page

Part two. Summaries of selected papers presented to the Seminar

Annexes

Tables

Figures

INTRODUCTION

The Interregional Seminar on Energy Saving in the Cement Industry was held at Nancy and in Paris, France, from 13 June to 1 July 1983.

The Seminar was sponsored by the French Ministries of Foreign Affairs and of Research and Industry, by the French Agency for the Management of Energy (AFME) and by the United Nations Industrial Development Organization (UNIDO). The Seminar was organized with the active co-operation of the Industrial and Economic Technical Co-operation Agency (ACTIM), the Research and Development Centre for the Industry of Hydraulic Binders (CERIHL), the Centre for Research, Innovation and Education of Engineers and Executives (CRIFIC) and French cement producers (Ciments français, Ciments La Farge and Ciments d'Origny) as well as French equipment manufacturers and suppliers.

The Seminar dealt with the problem of energy saving both in industrial processes generally and in the cement industry in particular. The production of Portland cement is an energy-intensive process and the cement industry is continually trying to develop more economical and efficient ways of operating. The investment and operating costs of cement plants are affected, among other factors, by the availability of raw-material deposits of suitable quality, the cost of complying with environmental-protection legislation, and the high cost of energy.

While in the past attention was focused on trying to reduce investment and production costs, the present high cost of energy has led to a separate evaluation of the contribution of energy-related factors to possible savings both in investment and in production. It is obvious that new factories would be the first to benefit from the new approach, but existing factories have also successfully improved their efficiency by combining energy-oriented plant modifications with a suitable increase of plant capacity.

France was one of the first countries to develop this new approach and the experience gained in France was made available to selected developing countries in 1982 when the first interregional cement seminar on this subject was organized by ACTIM and UNIDO in Paris and Nancy. The present Seminar was intended to make the same experience and information available in English to participants from developing countries. It is hoped that the dissemination of this information will arouse interest in the possibilities of energy conservation in the cement industry and lead decision-makers to seek further information on this subject.

It is envisaged that former participants in this programme, being more aware of the problems of energy management in the cement industry, will be in a better position to request from UNIDO any technical assistance related to energy management in the cement industry. More specifically, it is intended, after the completion of the series of training courses, to invite selected participants of each year's courses to a seminar to discuss any necessary follow-up procedures.

This report has been prepared under project TF/LIB/82/002.

Part one. Organization of the Seminar

The Interregional Seminar on Energy Saving in the Cement Industry was attended by 17 participants from developing countries. (See annex I.)

The first part of the Seminar, from 14 to 22 June, was held at CRIFIC in Nancy and consisted of morning and afternoon sessions of lectures on new techniques of energy management in industry, including the effect of energy factors on optimal choice and use of plant and equipment and on investment options. There were also exercises to put into practice the principles outlined in the lectures, an opportunity for participants to put questions and a visit to the CEDEST cement plant in Heming.

The second part of the Seminar took place in Paris at the headquarters of ACTIM (23 June and the closing session on 1 July) and of CERIHL (27-30 June). Lectures were given on the specific applications of energy-saving measures in the cement industry. There was a question-and-answer session, an opportunity for participants to meet cement producers, and a visit to the Lafarge Cement Plant at Frangy, 300 kilometres from Paris.

The list of lecturers and papers delivered to the Seminar is given in annex II. The visit to the Lafarge Cement Plant is described in annex III.

J.P. Meric (General Manager of CERIHL) and P. Bourgogne (Technical Manager of CRIFIC) were responsible for the technical programme of the Seminar. J.M. Meyour and Mrs. Kremer (ACTIM) were responsible for administration and coordination.

The opening session of the Seminar was held on 13 June at the Centre culturel des prémontrés at Pont-à-Mousson, north of Nancy. Representatives were present from the Ministry of Foreign Affairs, the Ministry of Research and Industry, ACTIM, AFME, CERIHL, CRIFIC and the French cement producers. The Chairman of the opening session was Mr. Perrut of the Ecole nationale supérieure des industries chimiques (ENSIC), who welcomed participants on behalf of all the organizers and talked about the teaching and research work of ENSIC, one of the well-known French schools of chemical engineering.

In his opening remarks, A.R. Marei (cement expert and co-ordinator of the UNIDO project TF/LIB/82/002) thanked the host country and the organizers of the Seminar and spoke about the importance of energy conservation in the cement industry which is one of the largest energy consumers, using from 750 to 1,700 kcal (3-7 MJ) per tonne of clinker produced.

B. Kyon (Minister of State, Ministry of Research and Industry) gave the main outlines of French policy on energy saving. He mentioned the research work done by CERIHL and other industrial technical centres and the teaching work in this field carried out by the universities and the national colleges such as ENSIC. French energy policy is co-ordinated and implemented by the French Agency for the Management of Energy (AFME) and international co-operation in this field is promoted by ACTIM.

J.M. Meyour, Deputy Director of ACTIM, explained the role of this semi-private agency which links the private and public sectors in co-ordinating France's international technical co-operation programme. The programme includes both bilateral and multilateral co-operation and covers both the sending of French experts to other countries and the organization in France of high-level training programmes for foreign engineers and specialists.

P. Bourgogne spoke about the work of CRIFIC as an advanced education and research institute connected to and using the facilities of ENSIC. CRIFIC carries out research for French industry but also elaborates tailor-made training programmes for industries in newly-industrialized and developing countries in co-operation with those countries' educational establishments. CRIFIC does not specialize in cement technology but many methods developed recently for use in industry generally in the fields of thermodynamics, heat transfer, insulation, energy accounting and so on can be successfully applied to the cement industry.

J.P. Meric (CERILH), in his introductory speech, discussed energy consumption in various different parts of the cement-producing process and emphasized the need for cement producers to focus not only on reducing their fuel and energy consumption but also on optimizing the use of cement in concrete manufacture. Both would be needed to ensure a continuing development of the cement market despite the energy crisis.

Concluding the opening session, Mr. Perrut spoke about the world energy situation in 1983. The world energy consumption is approximately 7,000 million tonnes oil equivalent (toe) per year, with a great disparity in North-South consumption. Mr. Perrut discussed the world trade in energy between producer and consumer countries and the future development of energy consumption in the light of estimated reserves of fossil fuels and uranium, and stressed the urgent need for industrialized countries to save energy. As an example of how this can be done he described the French energy policy based on the development of nuclear energy and on energy-saving technology in industry.

Part two. Summaries of selected papers presented to the Seminar

Thermodynamic analysis of energy degradation: enthalpy, entropy and exergy balances

J. Houriez and P. Steranka

This paper presented the minimum basic material required for effective work in the field of energetic thermodynamics. The methodology of thermodynamic investigation was described, distinguishing closed systems, open systems and systems in steady state.

Special attention was given to those functions useful for the analysis of steady-state systems; that is, enthalpy, entropy and exergy. Simple rules were given for calculating these functions in the most common cases.

The principles were then presented in the form of enthalpy balances for the First Law and entropy or exergy balances for the Second Law. Special attention was given to two aspects of the Second Law:

(a) Heat energy may behave in the same way as other forms of energy with simple variations in the magnitude of the overall conservative heat content. This applies in the case of ideal, frictionless, reversible phenomena without loss of noble energy, which can be translated into the language of thermodynamics in terms of the conservation of entropy and exergy;

(b) Heat energy is the only form of energy in which the overall content may grow. This applies to real phenomena with friction, in the general sense of the term, which are irreversible and involve loss of noble energy and which are translated into the language of thermodynamics in terms of the destruction of exergy and the creation of entropy.

Friction results almost exclusively from six physical factors: mechanical friction, the joule electrical effect, viscous friction, homogenization of temperatures and of concentrations, and chemical reaction. These can be described and analyzed in terms of economic loss.

The Second Law is thus presented in terms of understanding and quantifying losses due to thermodynamic irreversibility, with the goal of reducing these losses to economize energy.

P. Steranka conducted an exercise to illustrate the application of the concepts of thermodynamic analysis described in the lecture. The exercise was to evaluate and compare the effects of several different industrial installations on national fuel-oil consumption. The installations considered were conventional thermal power plants, heat-force power plants and gas-turbine power plants.

Devices which diminish energy degradation

J. Houriez and P. Steranka

The paper began with a few words about the significance of several thermodynamic properties used in energetic analyses with emphasis on property exergy and its association with irreversibility and created entropy. Various systems now employed in industry to use heat energy more efficiently were described. For example, it was demonstrated from the exergy balances of several theoretical heat exchangers that a good recovery of heat (in quantity and in temperature) destroys less exergy than a poor one.

Other systems and devices discussed included:

(a) Heat-force power plants in industries which consume thermal energy, which give greater exergetic efficiency;

(b) The preheating of inlet water for a boiler by recirculating the steam being used in the turbine, which allows an appreciable increase in the efficiency of condensation in turbine installations;

(c) Thermal power plants in which a high-temperature gas turbine is combined with a steam turbine which allow gains in the energy produced;

(d) The advantages of heat pumps and their dependence on the quality of the external exchangers, since thermal gradients greatly reduce the coefficients of performance;

(e) Vapour recompression which provides an efficient method of heating with a small amount of mechanical energy (applications discussed included distillation and evaporation of solvents);

(f) Fuel cells which are ideal devices for producing much more electricity with a fuel than is normally produced, although unfortunately all the technological problems have not yet been solved.

Energy balances in flowing liquids

L. Le Bec

The total energy of each kilogram of fluid in a steady-state flow in a pipeline is the sum of its internal energy and its external (or mechanical) energy, itself the sum of three terms: static pressure, kinetic energy and gravitational potential energy.

First, the total energy balance in general cases was developed and then the partial energy balances for various special cases, i.e. the mechanical energy balance for liquids (Bernoulli's equation), the internal energy balance, the enthalpy balance, the heat balance for gases with or without chemical reaction etc.

A list was given of the modes of degradation of mechanical energy into heat, i.e. by a rotating agitator, by wall friction, by impingement of a jet, by sedimentation in a gravitational field, by dispersion of a fluid into globules (drops or bubbles), by vortices in a cyclone etc.

Finally, a dozen examples of the calculation of the equivalence among various forms of energy were presented as an exercise to demonstrate the above principles.

Drying of porous and damp particles by means of warm air
(Exercise)

L. Le Bec

The terminal velocity of a single particle falling in the hot drying air was calculated, using the balance of external forces (apparent weight and frictional force) acting on the particle.

The equilibrium conditions of the layer of water at the surface of the particle were calculated using the heat balance at this surface, with the help of the Chilton-Colburn relation between the efficiencies of heat and mass transfer, and the mechanical degraded energy.

Thus, it was possible to calculate the rate of water vaporisation and discuss how to improve the travel time of the particle in the dryer, i.e. through free fall, pneumatic transport, or fluidized bed.

Additional calculations were made in order to connect, if necessary, the results previously obtained with simplifying assumptions.

Optimization of transport and storage of energy

L. Le Bec

A rapid inventory of the various means of transport showed that the least costly is, where possible, continuous in-line transport. One of the rare exceptions to this principle is perhaps the transport of crude oil by giant tankers. In general, bucket conveyors, conveyor belts and the like are gradually replacing pneumatic and hydraulic transport. Without attempting to deal with the whole of this subject, two specific problems were examined.

The first problem discussed was the value of heating a viscous fluid before pipeline transport. Heating reduces the viscosity and therefore the friction giving a corresponding decrease in the mechanical power required at the expense of a certain consumption of thermal energy. Both energy sources and the costs involved in the heat exchanger must be taken into account in determining the optimum temperature for the fluid. It was noted that these calculations, together with those in the exercise conducted by E. Dietrich (see below), allow a simultaneous determination of the optimum pipeline diameter and the optimum fluid temperature.

In the theoretical example which was presented, it could be seen that the reduction in pressure drop obtained, can bring about a reduction in the mechanical energy required. This reduction may more than compensate for the investment in a heat exchanger and the thermal energy used. The annual saving resulting from operating at room temperature gives a pay-out time on the investment in the heat exchanger of one month, in the case of the example given.

The thermal insulation of ducts and pipelines is also an important factor. When the thickness of the insulation increases, the cost of the insulation increases, but the heat losses and the energy-operation costs decrease. It is possible to choose the optimum thickness of the insulating material to achieve the minimum total cost. These calculations were made using standard pipe diameters and the standard thicknesses of insulating material, under simplifying assumptions. A rigorous calculation in a particular case was used to show that the assumptions give a sufficiently good approximation for calculating the optimum thickness of the insulation.

The variations of the optimum thickness of the insulation under the influence of different technical and economic factors were shown and a simple and accurate method of calculating these variations was given.

The second problem dealt with was that of the optimum diameter of electric cables for carrying medium-power electricity over short distances. It was shown that it is often advisable to make the cables thicker than prescribed by the standard C 15-100 which is based on the criterion of the maximum admissible heating of insulation to limit joule-effect losses. The general application of this conclusion was shown by indicating the standard section and the economic optimum thickness for a given type of cable, as a function of the economic conditions and the useful power to be transported. The pay-out time of the extra investment incurred was also included in the calculations.

Choice of optimum diameter of a pipeline transporting a liquid

(Exercise)

E. Dietrich

The aim of the exercise was to apply P. Le Goff's new method giving a simple example in order to show the different monetary and energetic optima corresponding to the different sizes of equipment and taking into account the economic situation and the government policy in a country.

The monetary optima calculated were the minimum investment and the minimum total cost. The pay-out time on extra equipment was discussed.

The energetic optima considered were the minimum of energy investment and the minimum of fuel consumption. The minimum total energy consumption is the sum of energy investment and fuel consumption.

Participants were shown how to draw the Energy-Cost Characteristic (CAREC) diagram and how to choose the best equipment sizes with this new CAREC diagram.

Aging systems: optimization of regeneration and replacement cycles

L. Le Bec

The efficiency of an industrial system which transforms raw materials into useful products decreases after the running-in period. When the efficiency is very reduced, the operation is no longer profitable and the worn-out system is to be regenerated or replaced.

"Wearing down" is a process which can be reversed by regeneration. On the other hand, "using up" is an irreversible process leading to the death of the system and the need for it to be replaced.

The general problem for the manager is to optimize the regeneration cycle or the replacement of the pieces that are ageing.

Several examples of different kinds were given to demonstrate this optimization, i.e., cleaning of furnace, car servicing, regeneration of a catalyst and unclogging and replacement of a filtering membrane.

The figure below shows the curves of these two processes.

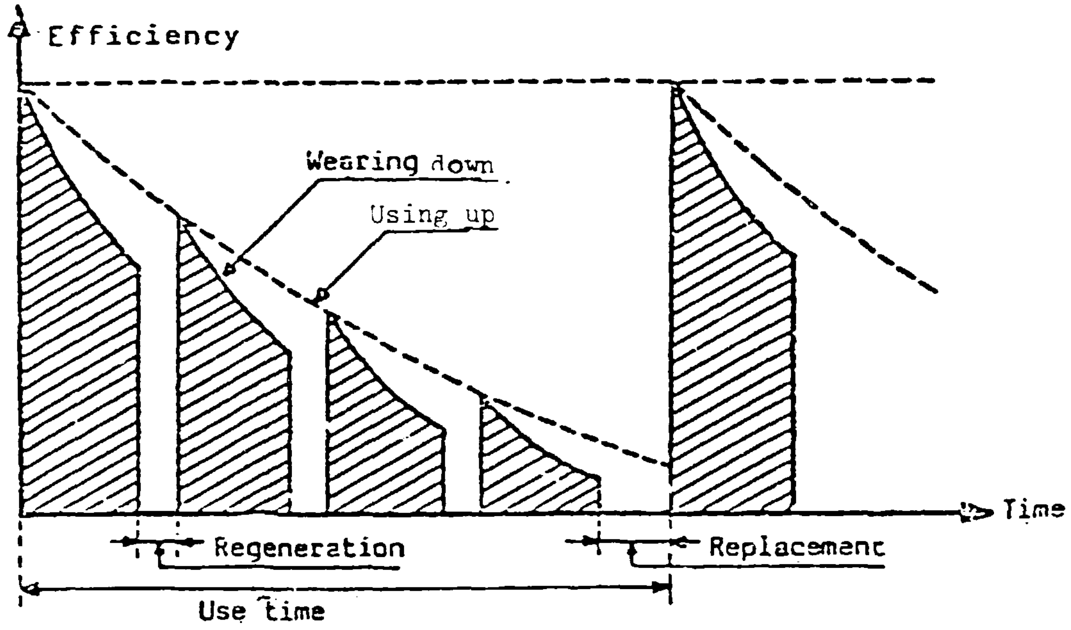

Figure I. Diagram showing the wearing-down and using-up curves of industrial systems

Industrial gas cleaning

Mr. Perrut

Removal of dust from dusty gases before disposal in the atmosphere, or before subsequent processing, is an important industrial operation, especially in the cement industry. This lecture gave a rapid survey of dust-removal technology.

In the first part, dust and dusty-gas characteristics were briefly described and the principles of the evaluation of efficiency in dust removal were outlined. The first important characteristic is the particle-size repartition. Other physical properties are also important, such as specific gravity, porosity, resistivity, and free-falling velocity. It is necessary to know how to evaluate the efficiency of a dust-removal system in order to avoid confusion when comparing several different processes.

In the second part, the various types of dust-removal systems were described and their average performances evaluated in order to guide the user's choice. After a short presentation of gravity settlers, multi-tray collectors and impaction separators, lengthier attention was given to cyclones which are very commonly used. Their basic design and extrapolation methods were described. Electrostatic precipitators and fabric filters were then presented in detail, with design rules and practical comments for their use in cement plants.

In conclusion, a general comparison of the main dust arrestors was given and the efficiency-to-cost ratio evaluated for the different types of equipment.

Industrial energetics

P. Le Goff

In several different presentations, P. Le Goff described the content of a course on industrial energetics which is composed of four main parts.

Optimum utilization of fossil-fuel energy

More than 90% of the energy used in industrial processes comes from fossil fuels (crude oil, coal, gas, lignite etc.). In order to best utilize this energy, the concept of "optimum thermal cascade" has been developed. This is a state in which the various thermal operations would be interconnected, the outputs of certain operations being the inputs of others. This maximum interconnection is an ideal state, impossible to realize from a practical point of view, but an objective towards which one should try to move. Various efforts in this direction were described, including storage and transportation of low-level heat energy, heat pumps, heat-transformers, and new uses of residual warm water. Actions to save energy can be classified on a time basis, according to their implementation periods: immediate (psychological action - no investment); short, medium or long term; and very long term (changing the process - very large investment).

Energy accounting compared to money accounting

For the economist, any industrial operation consists in transforming goods of little intrinsic value into more useful goods, that is to say with "added value". At the same time, it produces waste products of diminished value.

For the scientist in energetics, this operation consists in bringing available energy to raw materials containing little energy thus producing functional products with a higher content of energy. The operation increases the energy requirement of each kilogram of material. Simultaneously, some energy is lost in the waste products which also have an energy requirement larger than that of raw materials.

The different definitions of the energy requirement (net, gross, operating, capital) of a product were illustrated. Using a simple example, the pumping of naphtha, the method of calculating these different values was explained and, generalizing from this case, a method of calculation was presented which has the advantage of keeping only non-negligible terms.

Parallel to the classical concept of the pay-out time of invested capital, a new concept, the "time of equivalence" in energy of the energy requirement of the piece of equipment, has been developed for the converters of energy. It was demonstrated that this time-of-energy equivalence is considerably shorter than the monetary pay-out time.

Optimization of a steady-state industrial production system

An industrial production workshop, operating at steady state, has to produce a specified annual quantity of goods or services at the lowest "unit operating cost". The objective is to minimize the sum of the expenses for a specified production capacity. For a given productivity, some inputs can be substituted, at least partially, for others, for example, a raw material can be replaced by coal or by electricity.

The substitution of energy for raw materials was studied in detail, using as an example the treatment of ores by extraction through solvents. In every case, the best compromise must be sought which minimizes the unit operating cost.

Three kinds of decision-maker were then compared:

(a) The private decision-maker, who seeks to minimize the cost in national currency, in his own national market;

(b) The public decision-maker, who seeks to minimize the cost in terms of foreign exchange on the international market;

(c) An hypothetical planetary decision-maker, who would minimize the cost in energy, that is, the consumption of non-renewable fossil energy.

A new diagram called the Energy-Cost Characteristics (CAREC) diagram was explained, which enables a fruitful comparison of such various decision possibilities to be made.

Optimum choice of investments for saving energy

A design enterprise which is entrusted with the task of conceiving and producing a new plant suitable for manufacturing a product with prescribed characteristics, starting from specified raw materials, must usually adopt as the main target the minimization of the project's total cost, the latter being the weighted sum of the initial investment and the operating expenditure during a certain period taken as the plant's useful life. It often happens, however, that the decision-maker selects an option based on a minimum initial investment, because of limited capital availability or moderate trade competitiveness.

A mathematical model of the cost-function which allows a comparison of both decisions and their corresponding optima was described. Several theorems related to the properties of these optima and variations in their immediate neighbourhood were stated and demonstrated. An evaluation of the incremental investment and the higher or lower total cost, linked with a decision to save energy, was carried out. A general expression for the pay-back time of such incremental investments was established. In particular, the influence of various parameters was investigated: rates of actualization, inflation, energy-cost increase and the time of depreciation.

Examples were used to point out the importance of psychological factors. A hasty intuitive decision may lead to the choice of a solution which does not correspond to the optimum one and which differs from the option which would be chosen on the basis of a logical and rigorous approach.

Investment choice in an uncertain future: formalization of a model for decision-making, evaluation and analysis of risks

M. Castagne

Deciding on an investment for economizing energy (IEE) means taking a certain risk. If this risk is defined as the possibility of ending with a result different from that initially expected, we find that this discrepancy may be attributed to three main causes:

(a) The state of mind of the decider;

(b) The fact of not having taken into account all the economic and financial parameters which could influence the result of the IEE;

(c) Changes in some variables in the economic environment of which the most important is obviously the rate of increase in the price of energy.

There are no means of dealing with the first source of error but the effects of the second may be limited by using a model for the economic evaluation of investment projects. This begins by determining the financial profit from an investment by means of a computer program. This program, known as ECO, can be applied in various economic situations. This result is then weighted to take into account effects other than those directly associated with the IEE, that is profits or costs which are not linked to energy saving, but which can bring about other benefits to the company such as improvements in working conditions or in reducing pollution. Thus, a weighted financial profit for the investment is obtained.

Finally, an attempt is made to define the risk of error arising from cause (c) by applying three types of risk-evaluation methods to the results of the economic evaluation, that is, to the weighted financial profit of the projected investment. These methods are: analysis by subjective probabilities, analysis of the intervals of variation of cash flow, and of the various decision methods for a non-probabilistic future.

The objective at each level of this work is to limit the possible error in a decision on energy saving. Nowadays, the reduction in profit margins in industry due to cost increases, which can be fatal to a company, has given a special importance to the science of decision-making. The loss incurred in an investment may not be covered by profits on other investments. All decisions must be taken with great care.

From the diagram of the decision-making process shown in figure II, it can be seen that a certain type of risk is involved at each level. At the end of the process, the decider makes a synthesis between a certain evaluation of the investment and the overall risk which corresponds to it. The evaluation is given by a methodological tool which gathers together a certain amount of data on the future of the investment. The overall risk is the sum of three main types of industrial risk. The decider's state of mind depends on his intuition, his professional experience, his desire to make the investment etc. According to these, the decider will take either a negative or a positive decision.

It seems useful to consider such a process with particular reference to investments for economizing energy, not just because of the increased interest in energy saving since 1973, but mainly because the overall risk associated with an IEE is especially high and therefore interesting to study.

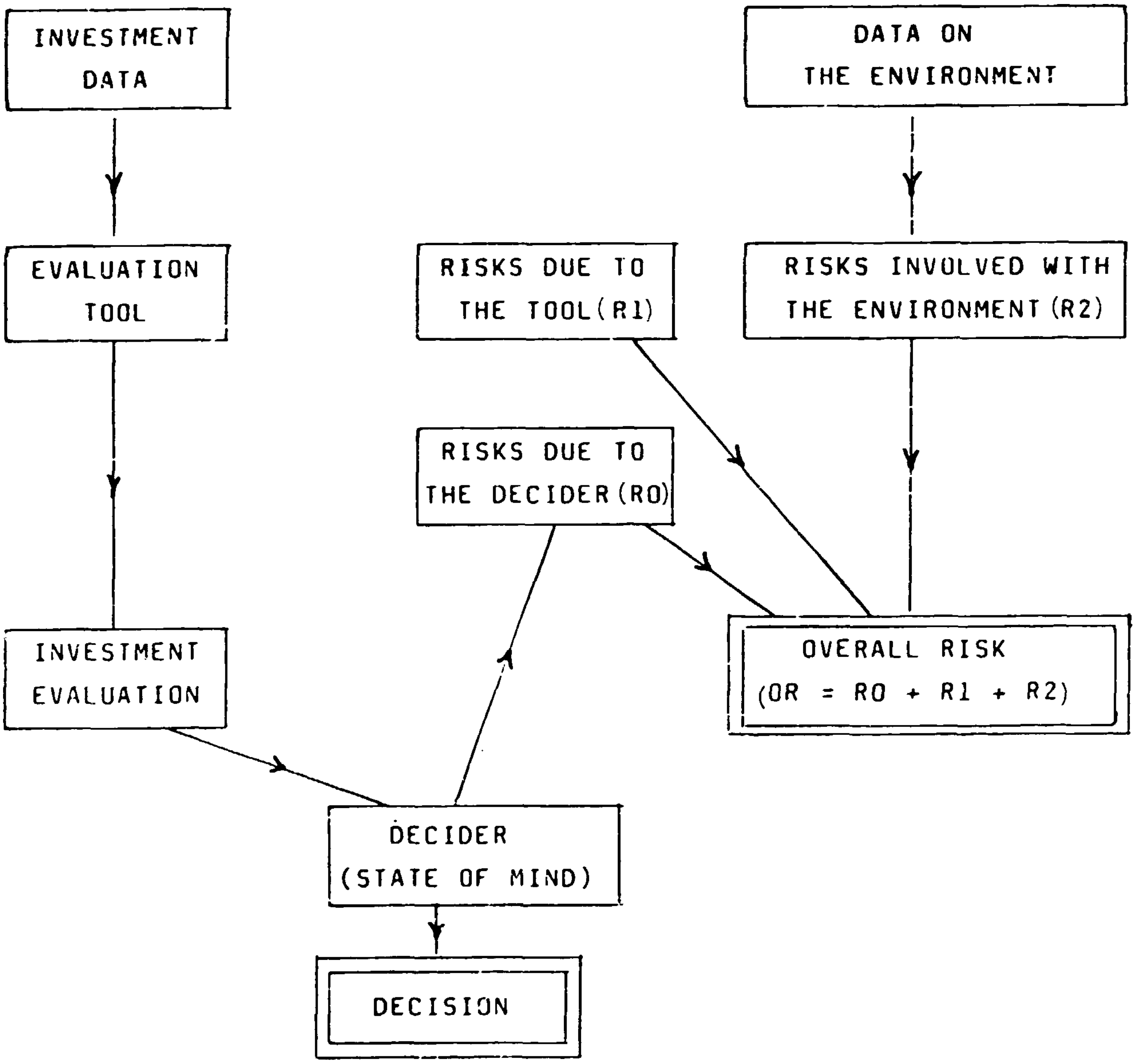

Figure II. Schematic diagram of a decision to make an investment for economizing energy

Looking at the diagram in figure II, it can be concluded that R0, the risk due to the decider, is inevitable. Only better education or information will enable him to modify his desire to make an IEE and thus act on his state of mind.

R1, the risk dealt with by the evaluation tool, can be reduced. An IEE depends on many economic parameters (overall rate of inflation, rate of increase in the cost of energy, energy-saving policies, method of financing the investment etc.). An evaluation tool which includes all these factors will help to reduce the risk inherent in the result.

The Department of Industrial Management at the National Polytechnic Institute of Lorraine has worked to develop a model of economic evaluation of investment projects for economizing energy which includes a maximum amount of data on the future of the investment and by this means to provide a precision tool for the industrial decider.

Finally, the environment of an IEE is naturally the rate of increase in the cost of energy. Whilst the model which is presented here does not directly involve R2 (risk due to the environment), it is in fact necessary to try to evaluate R2 in interpreting the results of the model. (This problem was dealt with in a separate paper.)

Macro-economic study of the calculation of energy requirements

F. Bollon

Energy analysis has two types of classical method for calculating energy requirements:

(a) The micro-economic or technical method, which consists of analysing in detail the process of manufacturing;

(b) The macro-economic method, which mainly uses the input-output tables of the system of national accounting.

The first method can easily be used to measure the energy requirement of a product which is clearly definable and which has an important energy requirement, such as aluminium or steel, but it is not suitable for complicated systems.

A more refined analysis can be made using the input-output tables of national accounting. This kind of approach gives the energy requirement of the aggregated products issuing from the national-accounting branches. A branch is defined as the collection of all the units engaged in similar production. The accuracy of the analysis depends on the classification of products used. In France, the most precise statistics available are those on level 90 of the National Accounting tables. Input-output tables are given for 90 branches of intermediate consumptions which together make up the composition of the final demand.

The economy is divided into a number of industries and these are listed as both the rows and columns of the input-output matrix. The entries in the column corresponding to any selected industry give the direct requirements from each of the other industries to produce one unit of that industry's output. If the input-output matrix is denoted by A, then the element A_{ij} gives the requirement from industry i to produce one unit of the output of industry j. It is important that the matrix is square, since, knowing these direct requirements, the same matrix can then be used to find out what was needed to produce them. These can be called the secondary requirements and it can be seen that they correspond to the matrix A^2. Similarly one can calculate the tertiary requirements corresponding to A^3 and so on.

Finally, the total-requirements matrix, B, which represents all these indirect and direct inputs is given by:

$$B = A + A^2 + A^3 + \ldots. = (I - A)^{-1} - I$$

Thus a matrix inversion is all that is needed to obtain the total-requirements matrix from the direct-requirements one, and this inverted matrix is usually published along with the matrix A. This macro-economic method is very useful for energy analysis of complex systems.

The difficulties that must be overcome when calculating the energy requirement and the applications which have been made in France in the field of heating power stations and in other fields such as petroleum products, agriculture etc., were described.

It was also pointed out that, far from being opposed to the micro-economic or technical method, the macro-economic analysis used in conjunction with the first method, makes possible an exhaustive calculation of the energy requirement and a mutual validation of the results obtained by each of these methods separately.

The French policy of energy management

J.P. Suteau

France is extremely dependent on outside supplies of energy. In 1973, France imported 75% of its energy requirement (67% for oil products). In 1981, energy imports were reduced to 65% (48% oil), and the aim of the Government is to reach 50% (30-35% for oil) by 1990. In 1982, the cost of imported energy was about FF180,000 millions, requiring the equivalent of four months of the country's exports to pay for it. Because of this dependence, the 50 public authorities have had to develop a voluntary energy policy to deal with the problem and the French Agency for Energy Management (AFME) has been charged with the implementation of this policy.

The components of the French energy policy are:

(a) To improve energy savings;

(b) To diversify energy sources (essentially from oil to coal and high-yield electricity);

(c) To develop the contribution of renewable energy sources (solar, biomass, geothermy etc.) in the national balance.

The Agency supports this policy by:

(a) An extensive research and development programme;

(b) Dissemination of methods and techniques of rational use of energy.

Industry is responsible for 30% of the national energy consumption, using 60 mtoe. AFME gives assistance to industry in several different ways intended to promote energy conservation:

(a) Aid is given for innovation (R and D programmes of equipment manufacturers) and for demonstration (first appliance in industrial pattern of a new piece equipment or process). Such operations can be subsidized up to 50%;

(b) Important energy consumers (5,000 toe per year) may negotiate pluriannual contracts with the Agency. The company appoints an energy manager, sets up an energy accountancy with all the measurement equipment required, and above all programmes investments for the rational use of energy. The Agency grants financial aid;

(c) Industrial sectors whose energy consumption is lower and more spread out may still negotiate similar contracts through their professional organizations;

(d) Financial aid for preliminary studies is also given;

(e) Preferential-rate loans, specifically leasing systems (with public-guarantee, accelerated fiscal depreciation) may be given to facilitate the financing of investment.

As well as these forms of assistance, the Agency has a programme to motivate, inform and train through the publication of technical guides, through a Technical Association of Energy Managers and through informative visits and demonstrations.

With respect to the cement industry in particular, this industry signed a contract for energy savings with the public authorities for the period 1973-1980. The aims and achievement of this energy-saving contract were as follows:

	1973	Contractual aim 1980	Achieved 1980
Energy consumption (kcal/kg clinker)	1 130	980	950
Percentage of production by wet process	30	15	10

In a second phase (1978-1982), the cement industry has operated a massive conversion from hydrocarbons to solid fuels which today represent almost 80% of their thermal supplies.

The co-operation between the cement industry and the Agency continues now in the field of new techniques (research on new types of clinker-cooler, precalcinators, clinkerization in fluidized beds, and so on) and also in utilization of low calorific fuels (refuse, biomass etc.).

Energy consumption in cement manufacturing: a general survey of production processes

C. Douvre

This paper dealt with the energy aspect of the cement-manufacturing process and described the different systems used at present and the energy requirements for each system. The energy required for producing clinker depends upon:

(a) The type of pyroprocessing system used;

(b) The quality of the raw materials;

(c) The conditions of operation.

The cost of this energy depends upon:

(a) The energy required for kiln burning (fuel and power consumption);

(b) The energy required for raw-material preparation (handling, drying, grinding, crushing, filtering, pelletizing);

(c) The impact of the quality of the raw materials and fuels used (burnability of raw mix, reactivity of raw mix, ash content of the coal, percentage of volatile matter in the coal). This factor can be quite substantial and could lead to differences in energy consumption as high as 100 kcal/kg (420 kJ/kg) between very good and very poor raw mixes;

(d) The impact of the local conditions of operation such as the type of seal arrangement used at the firing hood, the type of coal grinding and drying system used, the importance of air-leakages in the system etc. This factor is also quite important and could explain differences as large as 100 kcal/kg with the same pyroprocessing system and the same raw materials.

Energy required for kiln burning and raw material preparation

Based on a cement plant with a capacity of 1,500 t/d, the energy requirements for all the pyroprocessing systems available today were calculated.

Type of process	Energy requirement	
	Fuel (the pyro-processing system only) (kcal/kg)	Electrical power (from quarry to clinker storage) (kWh/t)
Wet process (32% H_2O)	1 250	44
Semi-wet process: (wet preparation of raw mix)		
Lepol kiln (19% H_2O)	900	51
Long kiln fed with nodules (19% H_2O)	990	48
2-stage preheater with flash drying of filter cakes (18% H_2O)	835 +35 (drying)	54
4-stage preheater with flash drying of filter cakes (18% H_2O)	780 +90 (drying)	57
Semi-dry process: (requires drying and grinding of raw mix)		
Lepol kiln	780	61
Long kiln fed with pellets	860	58
Dry process: (requires drying and grinding of raw mix)		
Long dry kiln	900	59
2-stage preheater kiln	835	62
4-stage preheater kiln without precalciner	780	65
4-stage preheater kiln with precalciner	780	67
5-stage preheater kiln with precalciner	750	68

The following points should be noted in connection with the figures given above:

(a) The wet and semi-wet process could require grinding of the raw materials. The electrical power requirements could therefore be modified. The present calculation was based on the use of a relatively soft limestone requiring rather little grinding energy. The electrical power used in the wet and semi-wet processes could be 4-5 kWh/t less in cases where no grinding is required and 4-5 kWh/t more where rock harder to grind is used;

(b) For dry and semi-dry processes, the electrical energy required for grinding is larger than in the wet process, even when processing the same rocks. It is estimated that grinding requires 15 kWh/t of raw mix in a dry process, and only 9 kWh/t in a wet process (with the same raw materials);

(c) The semi-wet process could require additional energy for filtering, depending upon the raw-material characteristics. Energy could also be used to heat up the slurry before filtering to speed up the filtering process (20 to 50 kcal/kg);

(d) It was considered that it would be possible to reduce the water content of the filter cakes in the case of 2- or 4-stage preheater kilns (18% versus 19% in Lepol kiln) because the quality requirements for pellets do not exist any more;

(e) It was estimated that, in the wet process, the slurry had 32% moisture. It could vary substantially, depending upon the nature of the raw materials. If the moisture goes up by 1%, the fuel consumption goes up by 25 to 30 kcal/kg of clinker;

(f) In the dry process, the raw materials have to be dried. The heat required for drying could be found in the kiln-outlet gases or in the cooler exhaust gases or both. However, the temperature and quantity of gases available in each system are not the same and the drying capabilities vary. Given below, for each system, is the maximum moisture in the raw materials that can be dried (assuming that the drying operation takes place for only 90% of the kiln operation);

Type of equipment	Maximum moisture to be dried (Percentage)
Lepol kilns	4-5 (with cooler exhaust air in the case of a grate cooler)
Long kiln fed with pellets	10-11 (with cooler exhaust air in the case of a grate cooler. Also use of kiln-outlet gases at 220 or 250°C, which requires however a particular design of the mill as the temperature of the drying gases will be quite low and the quantity of gases quite large)
Long dry kiln	18-19 (use of kiln-outlet gases around 500-530°C and cooler exhaust air)
2-stage preheater kiln	15-16 (use of kiln-outlet gases around 430°C and cooler exhaust air)
4-stage preheater (with or without precalciner)	12-13 (use of kiln-outlet gases around 350°C and cooler exhaust air)
5-stage preheater	11-12 (use of kiln-outlet gases around 320°C and cooler exhaust air)

(g) When the cooler is either a drum cooler or a planetary cooler, the figures should be reduced by 4-5%;

(h) For moisture levels higher than these figures, the fuel consumption should be increased by 20 kcal/kg for each additional percentage point;

(i) If coal has to be dried, the energy requirement for this should also be included in the calculation.

Quality of fuels

There could be large differences in the cost of the various fuels and also in the capacities of all these systems to burn these fuels properly. The following points should be noted:

(a) The wet kilns are known to be relatively trouble-free with all kinds of fuels;

(b) The Lepol kilns are known to be capable of eliminating alkali and sulphates. However, they are quite sensitive to high-ash coals (ash-ring formation);

(c) The long dry kilns are known to be difficult to operate with chloride contents in excess of 150 ppm in the raw mix and with high SO_3 contents in the clinker;

(d) Four-stage preheaters could be plagued with build-up problems in the riser duct and the bottom cyclone (sulphate problems).

Each case should be studied separately. However, the choice of a kiln system is very important as a well-chosen system could result in large savings whereas a poor choice is likely to lead to operational problems. (See below for criteria for selecting a kiln system.)

Quality of raw materials

The mineralogy of the raw materials has a big effect on kiln operation and performance. Important factors are:

(a) The burnability of the raw mix, the ability of the raw-mix compounds to combine to form C_2S, C_3S, C_3A and C_4AF. Between a poor-burning raw mix (made for instance with pure limestone and pure sand and alumina) and an easy-burning mix (natural cement rock requiring no addition or correction), the difference in fuel energy required could be 50 kcal/kg;

(b) The ability of the raw mix to be calcined. Calcination takes place at 850-900°C usually. However, there is a certain amount of calcination done at lower temperatures (as can be seen by thermo-gravimetric analysis). The difference between extremes could be around 30 kcal/kg;

(c) Clinker granulometry. The granulometry is a function of the process and the raw-material quality. The cooler's behaviour is very sensitive to the clinker granulometry. This could represent variations in fuel consumption up to 30 or even 50 kcal/kg.

These parameters can be evaluated and the impact on kiln operation and performance estimated.

Criteria for selection of a kiln system

There are several technical criteria to be taken into account in choosing a kiln system:

(a) The energy requirement. This includes fuel and electrical power and must take into account the moisture of the raw materials;

(b) The quality of the raw materials. If a semi-wet or semi-dry process is used, the pellets should have adequate properties (strength, resistance to thermal shock etc.). If their quality is poor, the performance in terms of production and fuel consumption will be quite low;

(c) The quality of fuels. The parameters to be looked at are ash content, volatile matter and impurities (sulphur, alkalis, chloride etc.);

(d) The operational problems expected. This is related to the items mentioned previously (quality of fuels and raw materials);

(e) The quality of clinker to be produced (e.g. is a low-alkali clinker needed?);

(f) The flexibility of the system with variable fuels and raw-material qualities.

The main non-technical factor is the cost of the investment and in this there could be large differences.

Criteria for selection of a precalciner system

There are, today, 14 types of precalciner available on the market. They have different shapes and work differently. Using fuel oil or natural gas, all precalciners appear to be equally good. Using solid fuels (coal, waste fuels etc.), there are some important differences and their performances are not equal.

The most important point related to the choice of the precalciner is the quality of the fuels to be used, not only today, but tomorrow, i.e. 5 years from now, 10 years from now. If the quality of fuels is likely to be poor (low-volatile coal, coarse materials) the choice of the precalciner should take into account the following criteria:

(a) The average residence time of the material in the precalciner (the longer, the better);

(b) Ability to retain the coarse particles longer;

(c) Turbulence (the more turbulent, the better);

(d) Heterogeneity of temperatures (to allow the start up of the ignition process for the solid fuel).

Each case should be studied separately as the manufacturers are able to modify their systems to suit particular needs.

Evaluation of raw materials. Sequential analysis and gitological variations: an aspect of applied sedimentology

Y. Champetier

Facies disposition in sedimentary series is neither random nor scattered. Hence, it can be quantified by means of a sequential interpretation.

This requires the determination of a type-sequence which will be used as a work-sequence to analyse thickness evolutions of facies and their contents of SiO_2, Al_2O_3, Fe_2O_3, MgO and CaO.

The representation of sequential histograms allows:

(a) Some correlation between bore-holes;

(b) The definition of variation limits of sampling;

(c) Characterization of homogeneous sedimentation.

These studies permit an automatic cartography of the evolution of characterization parameters and finally make it possible to work out the optimal definition of exploitation blocks.

Transformation of cement plants to increase capacity and reduce energy consumption

M. Champonnois

The precalcination process has been one of the major improvements introduced during the last twenty years into the dry-process production of clinker. The classical dry process uses only one heat source to supply the energy required for the whole unit. As the decarbonation reaction absorbs about 50% of this energy, it seems logical to provide an independent energy source making it possible to control directly the progress of the reaction. This is one of the bases of precalcination. The decarbonation of the materials in suspension in the gaseous flow also considerably increases the exchange factors. It thus makes it possible, for a given production rate, to reduce the dimensions of the rotary kiln, resulting in savings:

(a) In the investment;

(b) In the operating expenses, by:

  (i) Reducing the specific consumption of the refractories;
  (ii) Increasing the availability of equipment;
  (iii) Reducing the average consumption of fuel following the low inertia of the system in the start-up or restart-up periods after shutdowns;
  (iv) Increasing the regular production of the kiln.

The precalcination technique was first introduced in the construction of new, large-capacity units. Other possible applications then appeared for the transformation of existing cement plants which had the disadvantage of limited capacity combined with a specific, rather high, calorific consumption resulting from the process initially used, whether it was a wet or half-wet process or a dry process in long kilns.

The transformation of existing units into precalcination kilns makes it possible, with a limited investment cost, to increase the production capacity and to reduce the specific energy consumption of the units.

For a dry-process operating plant, the introduction of a recirculating suspension precalciner (RSP) and the possible addition of a second cyclone line also makes it possible to achieve an increase in capacity.

The possible applications of precalcination can be illustrated by some of the results achieved by Creusot-Loire Entreprises in this type of transformation of cement plants with RSP precalcination.

For example, the transformation from wet into dry-process production with precalcination was achieved for the first time in Europe in the Lexos plant of the Societé des Ciments Lafarge. It resulted in a reduction of energy consumption from 1,350 to 800 kcal/kg of clinker and the production of the same quantity of clinker, i.e. 1,500 t/d, as that obtained with the two previous wet kilns, with only one dry-process rotary kiln which re-uses the greatest part of the old wet-process kiln.

The cement plant of Le Teil of the Societé des Ciments Lafarge was also converted by Creusot-Loire Entreprisés from wet to dry process with precalcination. It was the first plant in the world to produce white cement by using precalcination. The plant capacity rose from 350 t/d to 850 t/d and the calorific consumption was reduced from 2,200 kcal/kg of clinker to 1,270 kcal/kg.

In Somalia, transformation is in progress of a wet-process plant to convert it into a dry-process plant and to boost its capacity from 300 to 600 t/d by adding a precalciner.

The same type of transformation is going on in the Alhandra cement plant in Portugal. Its capacity will rise from 1,700 t/d to 2,300 t/d.

There are also some good examples of the transformation of dry-process operating plants. In two 2,400-t/d burning units previously supplied in France by Creusot-Loire Entreprises, the addition of precalciners and related equipment raised the capacity of each unit to 3,600 t/d. At the Loule plant in Portugal, the previous capacity of 1,000 t/d was increased to 1,500 t/d after transformation. In Italy, the increase in capacity of the Friulana cement plant was achieved in two stages, from 750 t/d to 1,240 t/d, then to 1,900 t/d.

Two other transformations with precalcination are presently in progress: the Loutete plant in the Congo in which the capacity will increase from 300 t/d to 900 t/d and the Rufisque plant in Senegal which is to produce 2,300 t/d (previously 750 t/d). An example of a new cement line equipped with a RSP is the Catatumbo plant in Venezuela (capacity 1,800 t/d).

It must also be said that the use of precalcination makes it possible to spread the investment. In some countries, the present cement consumption is still limited, but an important increase in this consumption can be anticipated. It is possible to design production units with a limited capacity, but with elements which allow the later addition of a precalciner and a second line of cyclones, while still retaining the advantages of having only one burning workshop. Creusot-Loire Entreprises is at present installing in Pakistan two plants designed to allow such an extension later on. The production lines have been designed with an initial capacity of 1,100 t/d, which is likely to be increased later on to 2,300 t/d each. The cash flow obtained from the operation of the first implementation stage will provide the financing of the extension.

There is now a tendency in current research to use low-grade fuels. The related calcination equipment is at a semi-industrial prototype stage, based on the recirculating fluidized bed which enables high combustion times and combustion of fuels with a high ash content. The results already obtained are extremely encouraging.

Dry processing in the cement industry

J.P. Henin

The study presented was limited to the conventional dry-process calciner, i.e. a short kiln plus four-stage preheater, with or without precalcination.

On the basis of a given heat balance, the different savings obtained by decreasing the heat requirements or losses, or by burning inexpensive fuels, can be calculated. For a plant with a 3,000 t/d capacity, a balance may be drawn up as follows:

Heat balance
(kcal/kg of clinker)

Fuel-oil input	760	Δ H raw meal	430
Sensible heat of fuel	3	Clinker at 1370°C	354
Sensible heat of raw meal	10	Radiation losses:	
		kiln	45
		preheater	14
Secondary air	239	Exhaust fumes	169
	1 012		1 012

This is with a new kiln (new brick lining with low air inlets into the preheater) processing a raw meal which has a low heat requirement. The kiln consequently has a low total consumption.

Heat requirements of the raw meal

These depend mainly on the different contents of $CaCO_3$, $MgCO_3$, moisture, chemically-bound water and organic materials in the raw meal. The two last components are sometimes omitted from calculations and can be very important.

About 1,100 kcal/kg of chemically-bound water are generally required. The efficiency of the heat input supplied by the organic materials depends on their nature and consequently on their combustion temperature. Fly ash from power plants used as a raw material can bring a saving of up to 80 kcal/kg of clinker because it burns in the hottest cyclone. On the other hand, very volatile organic materials will only overheat the fumes.

Besides the conventional moduli, the knopicky modulus should also be used to determine the coating values of components in order to ensure a protective insulating layer in the hot zone. The effect of fuel ashes as a raw-meal element should also not be forgotten.

Use of slags as a raw material in cement factories

Mr. Galibert

Slags can be used in cement production:

(a) As a raw material used for clinkerization in a kiln to produce Portland clinker;

(b) As an important additive with Portland clinker in different preparations (see French standard NFP 15301, December 1981).

The qualities of cement made with slag and clinker are:

(a) Hydraulic setting and mechanical strength;

(b) Low heat of hydration;

(c) Resistence to aggressive agents like acids, sulphates, chlorides etc.;

(d) Stability in cool as well as hot conditions. In the case of reactive aggregates, slag cements block the alkali-aggregate reaction;

(e) Good behaviour of steel reinforcement in reinforced concretes.

The main uses for slag cements are in:

(a) Domestic, industrial and agricultural buildings;

(b) Underground work in galleries, roads and railway tunnels etc.;

(c) Hydraulic works such as dams, locks, wharves and piers in tidal areas;

(d) Special construction work such as the cooling towers of nuclear and thermal power stations, factory chimneys and waste towers;

(e) Normal road works.

Slag cements are economical from the point of view of energy consumption. Figures were given to show that, with 10% moisture, only 339 kWh/t of slag were needed for drying and grinding, compared to 1,169 kWh needed for the manufacture and grinding of one ton of clinker.

It is recommended to choose a granulated slag of low moisture suitable for use as an additive in cement production.

There are a range of slag cements graduated according to the percentage of granulated slag used (from 1-80%). The percentage is determined by the quality of the concrete needed (as specified in the standard NFP 15301).

Use of fly ash in cement factories

M. Venuat

CERILH has been carrying out research on pulverized fly ash (PFA) since 1953. In 1951, the French engineer, Fouilloux, took out patents on cements blended with PFA and slag. The French standardization steps were:

1959: CPA-C (up to 20% of PFA)

1979: CPJ (up to 35% of PFA)

1982: CLC (20 to 45% of PFA and also slag)

Two types of fly ash are used:

(a) Mainly from coal (SiO_2 = 50%, Al_2O_3 = 30%);

(b) From lignite. This fly ash is called "hydraulic" (high percentage of CaO).

PFA is added in cement works:

(a) As a raw material (dry or wet process);

(b) As an additive to cement.

The cement industry in France uses about 1 million tonnes of PFA a year. PFA is also added to concrete, mainly to improve workability (30 to 100 kg/m^3).

The consequences of adding PFA to cement are the following:

(a) Better rheological behaviour;

(b) Increase of setting time (hardening is slower). It is possible to accelerate this by temperature control (precast industry) or by chemical admixtures (winter concreting);

(c) Reduction of heat of hydration and shrinkage;

(d) Mechanical strength is lower during the first days but becomes greater and greater after 28 days.

In general, the result is an improvement in soundness and durability.

The crystal chemistry of Portland cement phases

Mrs. Regourd

Portland cement clinkers are composed of calcium aluminates and calcium silicates. The crystallization of the four principal minerals C_3S, C_2S, C_3A, C_4A is a function of the composition and the fineness of the raw mix, the thermal treatment (the clinkering temperature), and the nature of the burning and cooling system. Some characteristics of Portland cement, such as grindability, hydraulic reactivity and durability, depend on the microstructure of the clinker which is a non-equilibrium, multicomponent system of solid solutions.

On a polished clinker surface, C_3S appears as well-defined pseudo-hexagonal crystals, more or less micro-cracked. C_2S occurs as rounded crystals with a smooth or striated surface. Between these grains there lies an interstitial phase in which it is sometimes possible to identify "prismatic" crystals of C_3A, but in well-quenched clinkers, the interstitial phase is so finely crystallized that the individual grains are not visible. Beside the main constituents of Portland cement clinker, there exist some minor phases such as free lime and periclase, sodium and potassium sulphates. Fillers introduced up to 5% can be calcite or calcite+dolomite and can contain a few grains of quartz and feldspars.

The quantitative phase analysis can be done directly by x-ray diffraction or by optical microscopy. Results can differ substantially from the Bogue calculation, which is an indirect method.

Tables 1 to 4 show four different analyses of Portland cement clinker.

Table 1. Bulk chemical analysis : x-ray fluorescence

CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	K_2O	Na_2O	TiO_2
66.6	21.9	6.3	2.5	1.0	0.8	0.2	0.2	0.2

Table 2. *Phase analysis : x-ray diffraction*

C_3S	C_2S	C_3A	C_4AF	free CaO
62 ± 1	17 ± 2	15.0 ± 0.5	5.5 ± 0.5	0.3 ± 0.

Table 3. Phase determination : Bogue calculation

C_3S	C_2S	C_3A	C_4AF
57	19.9	12.5	7.7

Table 4. Elemental analysis of the four Portland clinker constituents : electron probe microanalysis

Oxide	C_3S	C_2S	C_3A	C_4AF
CaO	74.2 ± 0.6	64.2 ± 0.6	57 ± 2	50.7 ± 0.5
SiO_2	24.5 ± 0.3	30.9 ± 0.8	4.4 ± 0.1	3.8 ± 0.2
Al_2O_3	1.5 ± 0.2	2.2 ± 0.4	25.2 ± 0.9	17.4 ± 0.6
Fe_2O_3	0.57 ± 0.07	0.63 ± 0.06	6.9 ± 0.6	18.5 ± 0.7
MgO	0.34 ± 0.02	0.16 ± 0.02	0.56 ± 0.01	1.96 ± 0.09
SO_3	0.30 ± 0.06	1.2 ± 0.2	0.4 ± 0.1	0.09 ± 0.04
K_2O	0.03 ± 0.01	0.30 ± 0.05	0.10 ± 0.04	0.03 ± 0.01
TiO_2	0.18 ± 0.03	0.13 ± 0.05	0.5 ± 0.1	2.0 ± 0.2

Use of pozzolana and other local materials

J. du Moulin

Pozzolanas are defined as being materials reacting with lime in the presence of water to form compounds with hydraulic binder properties. They are basically composed of silica (SiO_2), alumina (Al_2O_3) and ferrous oxide (Fe_2O_3).

Natural pozzolanas are either of volcanic or sedimentary origin. Artificial pozzolanas are achieved by thermal treatment of clays (and sometimes shales) at 500° to 700°C. Natural pozzolanas and basic materials liable to show pozzolanic properties after activation are widely spread throughout the world. The elements of silica, alumina, ferrous oxide and calcium sulphate make up 80% of the earth's crust whereas limestone covers only 5%.

Pozzolanas have slow setting and hardening properties in the early stages of hydration. To improve their reaction, the fineness of the cement is increased by more thorough milling. During tests on selected pozzolanas, it has been found that, when these are milled with clinker in a maximum proportion of 30%, the strength of the cement obtained only falls by 40% compared with a reference Portland cement at 90 days, and only 20% after one year. It then stabilizes at this value.

Beneficial influences of pozzolana on shrinkage, cracking and the rheological properties of concrete and mortars have been observed. The use of natural pozzolanas gives an extensive energy saving, directly linked to the proportion of these materials which are blended with the clinker.

In the case of artificial pozzolanas, account must be taken of the energy needed to heat the clay. For example, a category B. clay, heated to 750°C to make it pozzolanic and mixed after processing with clinker in the proportions 30/70, gives the following comparative balance expressed in kilojoules.

Normal Portland Cement	3,200 kJ
Compound Portland Cement (70% clinker, 30% artificial pozzolana)	2,740 kJ

This represents an energy saving of 15%.

It should be stressed that, when there is a possibility of using natural or artificial pozzolanas, the first things to do are to take samples, analyse their physical and chemical characteristics, determine their degree of activity by tests on mortars and concrete and evaluate the deposit (output, distance from the plant location).

Lime pozzolana blends, known since the beginning of our era, behave like cement without clinker, but the strength of these hydraulic binders are naturally lower than those of blended Portland cements. They are however sufficient for certain types of construction such as masonry, one-family houses, water pipes, roads under light traffic etc. After 28 days, their compressive strength can reach 100 bars (20% slaked lime, 80% pozzolana).

Certain industrial countries are using fillers as additives in limited quantities (30% of additives in Portland cement are permitted in the French standards.) These products are obtained by milling of certain rocks (limestone, basalt etc.). These fillers are either inert (no chemical action on cement in the presence of water) or active if they have hydraulic or only pozzalanic properties.

Other experiments on waste products with pozzolanic properties have been successful. One case is the use of rice husks. Certain types of laterites are presently in the process of being tested as secondary constituents in cement.

Grindability

J.P. Bombled

Grindability is the relationship between the state of fineness of the material (specific surface, Blaine, for example) and the energy consumption needed to obtain the fineness (according to Rittinger's Law).

As a rule, the grindability coefficient is related to the mechanical properties of the material (tensile strength, modulus of deformation, brittleness, hardness, density etc.). But in practice, we have to consider not only the materials' characteristics (mineralogical components, heterogeneity, porosity), but also the factors connected with the making of clinker (quenching, porosity, vitreous phase) and the grinding conditions. To these numerous parameters, we have to add the tendency to reagglomeration of the smallest particles and their shapes.

The hardness of the materials to be ground is classified as:

(a) Between 3 and 4 for gypsum and calcareous stones;

(b) Between 5 (apatite) and 7 (quartz) for clinker and slag.

As far as clinker is concerned, C_3S is brittle but has a tendency to agglomerate. It is the opposite with C_2S, and the vitreous phase is between the two. Seven methods can be used to measure grindability. They are divided into two categories:

(a) Low speed/strain (Harugrove, Cerilh test, Wickenmicro hardness);

(b) High speed/strain (Joisel's satellite, Cerilh mill, jet Cerilh mill, and work index).

There is an empirical relationship both between the several grindability testing methods and between grindability and some characteristic values of the materials' compressive strength and hardness.

The paper demonstrated the relationship between grindability and clinker composition.

To save energy during the milling process, we must have:

(a) An optimal speed of $32/\sqrt{D}$ turns per minute (D in metres);

(b) A good percentage of loading (more than 35%);

(c) A good size distribution of the balls;

(d) A clinker with a high percentage of C_3S, a low vitreous phase, well quenched and porous;

(e) Less agglomeration (using small balls, adding a little water or grinding aids).

The influence of different types of mills on grinding and of grain size on cement hydration

Mr. Le Jean

The different modes of grinding are by slow crushing, by impact crushing and by jetting. The principles of jet grinding were described and the operation of ball mills and jet mills compared. This comparison dealt with the following factors:

(a) The influence of the grinding mode on the grading spectrum;

(b) The inadequacy of the specific-surface parameter;

(c) The influence of the grindability of the gypsum materials in the clinker;

(d) The influence of gypsum grading;

(e) The influence of the quantity of gypsum.

A study was made of the reactivity of alite as a function of the grinding mode and of the grain size.

Cements ground in a jet mill were discussed, including artificial Portland cements, cements with inactive additives, fillerization, grading-range "filling" and the Fereti law.

The rheology of mortar and fresh concrete was described including the measurement of rheological behaviour, the comparison between ball-mill and jet-mill cements as regards water requirements and the factors influencing rheological behaviour.

It was concluded that the high increase in reactivity of cements ground in the jet mill is due to the quasi-separation of the clinker crystalline phases and to the size of grains between 0 and 20 μm. The Blaine specific-surface measurement becomes an inadequate parameter to characterize a milled material. Moreover, a material's grading becomes a complementary factor, if not the principle characteristic.

Cement hydration

C. Vernet

Looking into the future, it is likely that the Portland cement of the next century will not be radically different from that of today, but it is also likely that more of its hydraulic features will be taken into account in the manufacturing process itself.

During a century of research, the cement makers have discovered the nature of the clinker's constituents and have learned how to optimize the proportions of these constituents.

The nature of cement hydrates is quite well known today, but it is still not possible to foresee or control their amount and their efficiency. This will doubtless form the subject of future research and improvement. If cement users are to be provided with cements suited to their specific needs, it will be necessary not only to be able to produce mechanical strength but also to master other features such as the setting time, the rheology, the heat of hydration, the shrinkage, and the resistance to various physically or chemically aggressive conditions. These features are governed by the inner mechanisms of hydration and by the evolution of the speed of reaction. Therefore, the kinetic aspect of hydration is becoming more and more important in present research.

The study of cement hydration is also essential in connection with energy saving. Much research has been done during the past ten years on increasing and improving the utilization of the hydraulic-reactivity potential of the clinker and the cement manufacturers have been doing their utmost to modernize and automate their plants and to use the cheapest fuel.

Two main lines have been followed. The first one includes all the research on improving the grinding technique by making it more selective, assuming that only some of the clinker grains contribute significantly to forming mechanical strength. The second line has been to try and optimize the amount and type of the additives. This involves a good knowledge of their behaviour during the hydration process. This research is hard and long, for hydration involves complex mechanisms with numerous variables.

In this short paper, it was only possible to introduce hydration in a general way, trying to summarize the best-known elements of present knowledge.

The first part described the nature and the microstructure of hydrates.

The second part studied the evolution of the cement/water system over the course of time and the sequence of Portland cement hydration reactions.

The third part discussed cements with additives such as slag, fly ash, pozzolana and calcareous fillers.

The fourth part summarized briefly the mode of action of admixtures.

The final part dealt with the applications to be made of the knowledge gained to date.

Annex I

LIST OF PARTICIPANTS

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Annex II

LIST OF LECTURERS AND PAPERS

Mr. Perrut:

The world energy situation in 1983
Industrial gas cleaning

J. Houriez and P. Steranka:

Thermodynamic analysis of energy degradation: enthalpy, entropy and exergy balances
Repercussion of different industrial installations on heating-oil consumption (exercise)
Devices which diminish energy degradation

L. Le Bec:

Energy balances in flowing liquids
Calculation of equivalences among the usual forms of energy (exercise)
Ageing systems: optimization of regeneration and replacement cycles
Drying of porous and damp particles by means of warm air (exercise)
Optimization of transport and storage of energy

P. Le Goff:

Industrial energetics
General principles of energy accounting: micro-economic approach to the calculation of energy requirements of products and equipment
Influence of the economic and financial factors on technical choices

Mr. Du Peloux:

Utilization of coal in the cement industry: the French policy

M. Castagne:

Investment choice in an uncertain future: formalization of a model for decision-making, evaluation and analysis of risks

J.P. Suteau:

The French policy on energy management

F. Bollon:

Macro-economic study of the calculation of energy requirements

E. Dietrich:

Choice of optimum diameter of a pipeline transporting a liquid (exercise)

Y. Champetier:

Evaluation of raw materials. Sequential analysis and gitological variations: an aspect of applied sedimentology

C. Douvre:

Energy consumption in cement manufacturing: a general survey of production processes

R. Belair:

Mineralogy and quarry investigation

M. Champonnois:

Transformation of cement plants to increase capacity and reduce energy consumption

Mr. Devillers:

Adapting new methods to wet processing

J.P. Henin:

Dry processing in the cement industry

Mr. Gilbert:

Sampling and prehomogenization

Mr. Galibert:

Use of slags as a raw material in cement factories

M. Venuat:

Use of fly ash in cement factories

J. Bosc:

Cement factory kilns and energy balances

Mr. Minerbe:

Automation of kilns: the contribution of automation in energy saving during the firing process

Mrs. Regourd:

The crystal chemistry of Portland cement phases

J. du Moulin:

Use of pozzolana and other local materials

J.P. Bombled:

Grindability

Mr. Le Jean:

The influence of different types of mills on grinding and of grain size on cement hydration

Mr. Chone:

Grinding agents

J.P. Meric:

Cement production in developing countries: capacity optimization and extensive use of mineral admixtures

C. Vernet:

Cement hydration

Annex III

VISIT TO THE FRANGY CEMENT PLANT

On 24 June, participants were taken to visit the cement plant of Ciments Lafarge at Frangy, 300 kilometres south-east of Paris.

Production of hydraulic binders started in Frangy shortly after 1865 with the establishment of shaft kilns for cement and lime production. Later, the Hoffmann kiln was used for production of clinker bricks which were ground into cement.

Modern cement production started in 1931 with a wet-process unit which was in operation till 1970. In 1970, the factory was modernized into a semi-dry process plant of 300,000 t/a capacity (Lepol grate type) and the main changes were introduced in the quarry, prehomogenization, raw mill and kiln departments. Installations of the old plant which continued to serve in the new factory were the clinker storage, cement mills, cement storage, packing and distribution units.

The operation of the factory can be described as follows; after the limestone is loosened from the quarry face with explosives (dynamite), it is transported with front-end loaders to a mobile crushing plant (weight 300 t, power 700 hp (525 kW), capacity 300 t/h). The crushed material is transported by belt conveyers to the prehomogenization hall which has a capacity of 7,000 t.

The prehomogenized material is taken out by a bucket-wheel excavator and fed to a conventional horizontal raw mill. Directly from the raw mill, the corrected raw mix is fed to the nodulizer pan which discharges directly onto the Lepol grate.

The kiln is 54 m long and has a diameter of 3.6 m, a capacity of 950 t/d, and is equipped with a grate cooler. Two years ago (1981), a vertical coal mill was installed and coal firing introduced instead of oil firing. The cement mills were recently adjusted and the energy consumption reduced from over 40 kWh/t to 30-32 kWh/t, partly due to the use of grinding aids.

The storage, packing and distribution of the cement is conventional and was not inspected.