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UNITED NATIONS INDUSTRIAL
DEVELOPMENT ORGANIZATION

DEVELOPMENT OF APPROPRIATE TECHNOLOGY FOR SMALL-SCALE PRODUCTION OF PORTLAND CEMENT IN LEAST DEVELOPED COUNTRIES AND REGIONS

RP/INT/76/021

Project findings and recommendations

Prepared by the United Nations Industrial Development Organisation

Based on the work of Harald C. Boeck, cement consultant

id. 76-4789

Explanatory notes

References to dollars are to United States dollars.

A full stop (.) is used to indicate decimals.

A comma (,) is used to distinguish thousands.

References to tons are to metric tons:

t	ton(s)
t/a	tons per annum
t/d	tons per day
WG	refers to water gauge

ABSTRACT

Increasing transport costs and modest cement consumption have emphasized the demand for small cement plants in some developing countries including the least developed countries and regions. In the past small cement plants have been represented both by rotary kiln and shaft kiln plants, but the cement from the latter was seldom of uniform quality.

The development of dry process technology, however, has resulted in an improved homogenization technique from which also shaft kiln plants can benefit. In the meantime also the shaft kiln technology has been significantly improved compared to the situation 20 years ago. The result is that small cement plants can be established with both the rotary kiln and the shaft kiln technology with the only difference that small rotary kiln plants may cost more to establish and operate than small shaft kiln plants. The only problem with the shaft kiln is that the technology can not be used unless the raw materials are suited for it.

Before this study was organized the situation was less clear and the shaft kiln technology had many opponents. This is why the United Nations Industrial Development Organization decided to evaluate the existing technologies, so clear advice could be available for the least developed countries and regions. Accordingly, a cement expert went on mission to various countries from 27 May to 7 August 1976 to examine and report on the situation.

The aims of the project were:

1. To organize and undertake an exploratory mission to producers of equipment for shaft kilns and cement manufacturers experimenting or working with shaft kiln installations.

2. To make observations and recommendations on the requirements for the establishment of shaft kiln pilot plant installations.

3. To assist in elaborating a plan of action for a mission to selected least developed countries for evaluation of the possibilities for the establishment of small-scale pilot cement plants and the tender specifications for such plants.

During his mission, the expert visited four shaft kiln plants and one cement plant with a test kiln for an oil-fired shaft kiln. Various consulting companies were also visited and information received concerning layout, design, pyro-technique, machine manufacturing, raw material handling, type of fuel, etc.

The expert makes recommendations in this report concerning shaft kiln operations. However, these should be considered indicative as it is impossible to make general recommendations to cover the entire world.

CONTENTS

INTRODUCTION

Recently increasing transport costs have created a demand for decentralization of cement plants in various developing countries, particularly the least developed countries and regions.

In order to produce low-cost cement it is necessary to build up big units as close as possible to the raw materials and either close to the market or to means of inexpensive transport, e.g. ship, train or long distance belt conveyor. Good public services are not widely available in the above-mentioned countries and therefore the United Nations Industrial Development Organization (UNIDO) decided to take a preliminary investigation of alternative solutions for a new technology for cement production by means of smaller units.

A cement expert went on mission for the project "Development of appropriate technology for small-scale production of Portland cement" (RP/INT/76/021), from 27 May 1976 to 7 August 1976, to examine the latest developments in shaft kiln installations (annex I). Various companies (annex II) were visited in the following countries: Australia, Austria, Denmark, Federal Republic of Germany, India, Kenya, Nepal, Papua New Guinea, Switzerland and the United States of America.

A new approach is emerging in this field and it is important to develop cement mini-plants in such a way that capital investment can be reduced as much as possible to keep down the fixed cost. The number of heavy casted parts should be reduced and a high degree of standardization enforced. Complex and sophisticated equipment should be avoided.

High investment costs for large-scale rotary kilns have resulted in the development of improved technology of interest for small- and medium-scale cement plants, including shaft kiln plants.

China has about 3,000 shaft kiln plants in operation in the ranges of 3,000-7,000 t/a and 10,000-50,000 t/a. Of a total production of 35 million tons of cement in 1975, approximately 20 million were produced by shaft kilns.

The performance of the shaft kilns, together with the cumulative costs, at the Bamburi Portland Cement Company Limited is shown in annexes III and IV.

In spite of limited time, the expert visited as many countries, manufacturers, promotors and small-scale cement plants as possible in order to compare different systems and methods.

I. SUMMARY OF FINDINGS AND RECOMMENDATIONS

As the investment cost in the cement industry is normally very high, it is important to determine the most economical and suitable size for small-scale factories in order to make savings through standardization. This seems to be in the range of a production of 80,000-120,000 t/a from two conventional shaft kilns or alternatively one kiln working on the newly developed REBA process if it proves technically feasible. This process may permit the use of any kind of fuel and the unit is split up into a vertical kiln and a vertical cooler. Although it has not yet been proved on an industrial scale, the technology appears promising and its further development should be of interest.

For the conventional shaft kiln, low volatile fossil fuel will have to be used. If not available the problem may be solved by charring high volatile fuel; the volatile gases emitted could be used for drying raw materials. Such a system has worked successfully since 1954 at the Gippsland Cement Plant in Australia which was designed by Steven Gottlieb. The plant is using charred brown coal briquettes as fuel for the shaft kilns.

For both of the above-mentioned kiln systems, it is necessary to produce pellets or nodules, which are small, one-half inch (12 mm) diameter balls, of uniform quality and high strength, consisting of ground raw materials plus 12-14% water and, for some technologies, fuel. If production of high-strength nodules is not possible, a rotary kiln process is preferable.

A small-scale cement plant producing 120,000 t/a would be the ideal size. The cost of machinery for the kiln and cooler would amount to approximately 4-6% of the total investment cost, whereas that of a rotary kiln plant would be approximately 8-10%. The advantages of a shaft kiln installation would be:

(a) Substantial savings in space;

(b) Simple construction with no heavy castings;

(c) Fewer problems with starting and stopping;

(d) High degree of reliability due to the durability of refractory bricks;

(e) The kiln and cooler are an integrated unit;

(f) Low-alkali clinker could be produced;

(g) A high degree of do-it-yourself construction could be developed which is important in order to bring down the total investment cost.

There are various processes of feeding the fuel to the shaft kiln. The most simple, and perhaps the most common is to feed the fuel (anthracite or petrol coke, coke breese, blast-furnace coke or similar), separately in sizes of 1.5-2.5 mm, directly to the pan pelletizer together with the raw mix. Other processes such as black meal, shell (black meal with white meal coating), and coke slurry should be considered depending on the type of fuel, especially if high content of ash occurs.

It is important, with shaft kiln operation, to have a good distribution of air in order to keep a "full moon" in the burning zone. The design of the outlet grate is also important and it has been proved that the so-called rocker grate, which is hydraulically operated, works satisfactorily with low maintenance costs.

Highly-developed equipment for the preparation of raw material makes it possible to produce good quality low alkali (semi-dry process) clinker in a shaft kiln. Pre-blending of the limestone is highly recommended. Shaft kiln clinker should not be stored for too long owing to its high porosity.

Small-scale cement plants may meet with opposition from large-scale cement producers as a network of shaft kilns in some areas could create competition for their markets.

II. CAPITAL INVESTMENT FOR NEW CEMENT PLANTS

Investment requirements are extremely important for all factories because it may be difficult to find the necessary financial support. Once this is found, the fixed costs required for amortisation will influence the price of the final product. In annex VI, the curves showing upper and lower investment costs of "mini-plants" are hypothetical but such values could be realized by means of an extensive standardisation and on-the-spot manufacturing which the latest welding techniques make possible.

Manufacturers of rotary kiln plants with preheaters and calciners prefer not to use kilns of a capacity below 500 tons per day (t/d). The reasons are:

(a) Cyclones become small, therefore jamming occurs more often resulting in low efficiency of the plant;

(b) The fuel consumption is too high because of numerous stops and starts;

(c) By-pass installations are necessary in order to produce low alkali cement and this is too expensive for small-scale units;

(d) Bricklayers are reluctant to make repairs in the preheater and calciner because there is very little working space.

III. ROTARY KILN WITH PREHEATER AND CALCINER

The present trend of building up large-scale cement plants will certainly continue where raw materials are suitable and they, and a market, are readily available.

The reliability of a rotary kiln mainly depends on its diameter and with a diameter of up to 5 m, the amount of refractory bricks that must be used is still at an acceptable level of 0.5-0.8 kg/ton clinker.

Operations and maintenance experience have shown that conventional high-economy dry-process kilns with a four-stage suspension preheater are highly reliable in the size range of 1,250-2,000 t/d, corresponding to a kiln diameter of 4.15-4.75 m.

The latest development in precalciners has made it possible to produce 4,000 t/d with a kiln diameter of only 4.75 m. Such an appreciable development will reinforce the trend to build up large-scale cement plants.

A newly-developed pellet-bed precalciner, similar to the shaft kiln, has been designed and promoted by Steven Gottlieb, Australia. The process is semi-dry consisting of a shaft precalciner equipped with a special oil or gas burner. The pellet-bed precalciner will be fed with pellets and after precalcination the pellets will pass through a conventional rotary kiln. The features of this calciner are:

(a) Simple construction;

(b) Low-alkali clinker can be produced without kiln by-pass;

(c) Fewer problems with stopping and starting.

The pellet-bed precalciner can be designed with a capacity of up to 60 t/h corresponding to about 1,500 t/d.

IV. SHAFT KILN CEMENT MINI-PLANTS

A great many developing countries, especially those considered as least developed countries, suffer badly from a lack of cement plants. In many cases, they cannot obtain enough financial support to build a medium- or large-scale cement plant owing to the high investment cost and insufficient local demand. In addition, rocketing transportation costs make it necessary to decentralize cement plants in order to maintain an acceptable consumer price.

For these reasons, efforts have been made to establish mini-plants suitable for such countries. The shaft kiln has been reviewed together with appropriate technology based on the latest development in cement plant layouts and machinery designs.

Conventional shaft kilns

The shaft kiln has been used for nearly a century. In the early 1960s the layout and design of a shaft kiln plant reached a fairly high level but at the same time, the introduction of the dry-process four-stage suspension preheater kiln made it possible to avoid drastically increasing cement prices by the use of big and economical production units. The shaft kiln then started to lose popularity, particularly as transport costs were still relatively low.

Clinker produced by a shaft kiln today can be as good as clinker produced by a rotary kiln provided the same care is taken in the preparation of the raw material. In order to produce shaft kiln clinker the following conditions will have to be fulfilled:

(a) Plasticity of the raw materials in order to make pellets of high strength. Without this, it is impossible to draw the necessary combustion air through the shaft and the shaft kiln is useless;

(b) Low-volatile fuel (max. 12%) of low reactivity. (Coke produced from low-ash coking coals and anthracite is the preferred fuel.)

A kiln diameter exceeding 3 m is inadvisable. Air distribution becomes difficult resulting in an unstable operation.

A common and effective kiln size is 180-200 t/d. Such a kiln would have an inside effective diameter of 2.4 m and a total height of approximately 8 m. Smaller kilns work even better because of improved air circulation.

The vertical shaft kiln is very simple. The upper part of the shaft (approximately 15–20% of the total height) is conical to correct for shrinkage of the nodules through drying, calcining and sintering. The rest of the shaft is cylindrical and this part serves as a cooler and heat exchanger as the heat from the clinker preheats the combustion air moving in counterflow.

The raw mix and fuel fed to the kiln are agglomerated in a nodulizer where 12–14% of water is added. By means of a "snow-ball action" nodules of one half-inch diameter (12 mm) are produced. These nodules are fed to the top of the kiln and distributed equally over the material surface by means of an air-locked rotating chute.

The feeding to the kiln is regulated according to the flue gas temperature, which should be kept at 80–90° C, and the material moves downward with a velocity of approximately 1.5 m/h. At the bottom, the kiln is equipped with a grate which can be either the rotative or rocker type. Clinkers are sluiced out through hydraulically-operated air-lock discharge gates.

Combustion air is drawn in in counterflow to the materials and the pressure needed is about 1,200 mm WG; for safety, a Roots blower, with a maximum pressure of 2,000 mm WG, is normally provided.

Current air pollution regulations call for an electrostatic precipitator for the dedusting of the flue gas. Dust production of a shaft kiln is very low, about 2% of the clinker production, but it looks worse due to evaporated water. The low temperature of flue gas makes it necessary to preheat the gas before the filter about 90°–120° C, which is the most suitable temperature for an electrostatic precipitator.

<u>Oil-fired shaft kilns</u>

One of the reasons why shaft kilns have not been installed in too many places is that it is next to impossible to make them oil-fired. Nevertheless, a German cement plant has carried out tests on a newly-developed process which is similar to the shaft kiln. The expert visited the plant and inspected the test unit during its erection.

The process in the kiln is more or less the same as in the famous Lepol kiln, which is still used successfully all over the world. The new process is called REBA after the group and the designer, Readymix and Bade.

The difference between the two processes is that the travelling grate has been replaced by two inclined fixed grates, one for calcining and one for sintering. As far as the material flow is concerned, nodules of a maximum of 10 mm are fed by air-lock to the upper part of the kiln which is a vertical shaft used only for drying the nodules. After drying, the nodules pass through the first inclined grate down to the upper push car situated in the second (calcining) chamber of the kiln.

The partition wall between the two chambers is one of the secrets of the process. The wall separates the chambers in such a way that the thickness of the layer of nodules will be permeable to flue gases passing through the second inclined grate in the sintering zone situated in the firing chamber.

The oil or gas burner is situated in the firing chamber at the front of the inclined grate.

After the second inclined grate the clinker proceed by means of the lower push car falling by gravity in a vertical cooler from where they are discharged by air-look to a clinker conveyor.

Secondary air for the burner passes through the cooler and after combustion flue gases, excess air and added fresh air pass through the kiln in counterflow by means of Roots blowers and fans.

The following significant features are noted:

(a) Investment cost for a total REBA plant, 120,000 t/a clinker, is in the range of $130-140 per t/a;

(b) Energy consumption is 730 kcal plus 14 kWh per ton of clinker for the kiln alone;

(c) Heat-up time is a maximum of four hours;

(d) Multiple application for cement and lime or similar materials.

The test kiln has a capacity of 75 t/d and is connected to a 500 t/d vertical cooler. Specially designed compact cement mini-plants could be installed to provide an output of 100-500 t/d; they could then be expanded, in modular form, to any size without risk. It is thus possible to adapt to market requirements at any time without increasing the variable costs. The short heat-up time also contribute to this as the plant can be switched off as often as required depending on the marketing situation or other factors.

If this innovation is successful it will open up possibilities of development of mini-plants in a large number of developing countries.

V. FINDINGS AND RECOMMENDATIONS

Findings and recommendations should be considered as indicative as it is impossible to make general recommendations to cover the entire world. However, it is hoped that they will be useful to governments trying to promote cement production in remote areas, especially in the least developed countries.

How to reduce capital investment

The total investment cost is divided among the following items:

	Fraction of total investment costs (%)
Mechanical equipment	25-30
Electrical equipment	6-8
Civil works	30-40
Transport (cif - fob)	10-25
Erection	15-20
Miscellaneous	6-10

The above-mentioned figures show where savings can be made. Civil works account for the largest percentage of the cost. Considerable savings can be made here, for instance by reducing storage capacities. However, such savings depend to a large extent upon local conditions, and advice should be sought from an experienced consultant.

The following recommendations are made for the erection of mechanical and electrical equipment:

1. A perfect layout will be necessary.
2. Intensive PERT (programme, evaluation and review technique) planning.
3. Intensive standardisation should be made.
4. The site should be provided with a well-equipped workshop especially for steel-plate work and welding.
5. Machinery manufacture and erection should be combined.
6. All steel-plate work up to, say, a 25-mm thickness should be done at the site.
7. The latest welding techniques should be applied.
8. Considerable time can be saved by co-ordinating the civil work and the erection of mechanical and electrical equipment.

In annex V is shown a graph with an upper and lower curve for cement mini-plants. The figures for the curves based on existent plants supplied by European manufacturers. The Indian total investment costs in general may be about 35% lower than those shown here.

Implementation time

In a plant, for example, of 120,000 t/a capacity, the civil works may involve about 5,000-6,000 m^3 of concrete and about 1,800 tons of mechanical and electrical equipment. The erection of civil works and the mechanical and electrical equipment would amount to approximately 120,000 and 140,000 man-hours respectively. Even on extremely difficult sites it should not take more than a year to erect a cement plant.

Economic size of plant

As shown in annex V, a plant producing 100,000-120,000 t/a would be the most economic size. However, this may not be the case as a high degree of standardisation and on-site manufacturing could bring down costs considerably. For instance, according to investigations made by the Cement Research Institute of India (CRI), New Delhi, the most economic shaft kiln would have a production of 25,000-33,000 t/a.

The CRI has also carried out extensive investigations regarding shaft kiln operations. Indian experts have designed, fabricated and successfully operated, for more than two months, a 2 t/d shaft kiln producing quality clinker (annex VI). It is interesting to note that solar energy is used for drying nodules.

Noduliser (pan pelletiser)

The production of high-strength nodules is indispensable for a shaft kiln or any kiln working on semi-dry process. The noduliser for production of nodules was introduced in May 1950 by Steven Gottlieb at Gippsland Cement Plant (visited by the expert) in Australia. Millions of tons of nodules have been produced by means of the noduliser (also known as the pan pelletiser), especially after introduction of the semi-dry Lepol kiln. It is thanks to the development of the noduliser that the shaft kiln can produce clinker of high quality.

Irrespective of whether the fueling process is normal, black meal, shell or coal slurry, the final nodules should consist of raw meal ground to a fineness of 6-8% retained on 4,900 meshes/cm^2 and 0.5% on 900 meshes/cm^2 in order to keep a free lime content of 2.5-1.5% or below. Their size should be kept at 10-16 mm diameter for a shaft kiln with a diameter of 2.4 m and down to 8-10 mm diameter for smaller kilns.

The water content depends on the raw materials (plasticity) and should be in the range of 12-18%.

Fueling process

Fueling processes for conventional shaft kilns are as follows:

Conventional
Black meal
Shell
Coal slurry

In the conventional process, which is the simplest, the fuel, for instance, petrol coke ground to size 1.5-2.5 mm, is fed directly to the noduliser together with the raw meal. The size of the fuel is important. Small sizes decrease and large sizes increase the height of the burning zone and thus the cooling zone will be respectively increased and decreased. A short burning zone results in a good thermal efficiency.

Black meal, shell and coal slurry processes require more equipment than the conventional process. These processes should only be considered if the fuel has a high-ash content or reactivity occurs in order to ensure uniform and good quality of the clinker. However, determination of a fueling system is complex and should be done case by case.

In all processes, the proper mixture of raw meal and fuel has to be controlled by instruments with alarm systems.

Discharge grate

Good air distribution is very important in a shaft kiln and a discharge grate is required which can cope with irregular clinker formation.

The expert visited a factory in the Federal Republic of Germany (Ilse, annex II) which consisted of five shaft kilns and one rotary kiln. During the visit, only the rotary kiln was working owing to the low demand for cement. Normally, four of the shaft kilns were working.

All four shaft kilns are equipped with a discharge crusher grid and have worked satisfactorily for more than 12 years ensuring a continuous output of cement of 200 t/d from each kiln. The following features were noted:

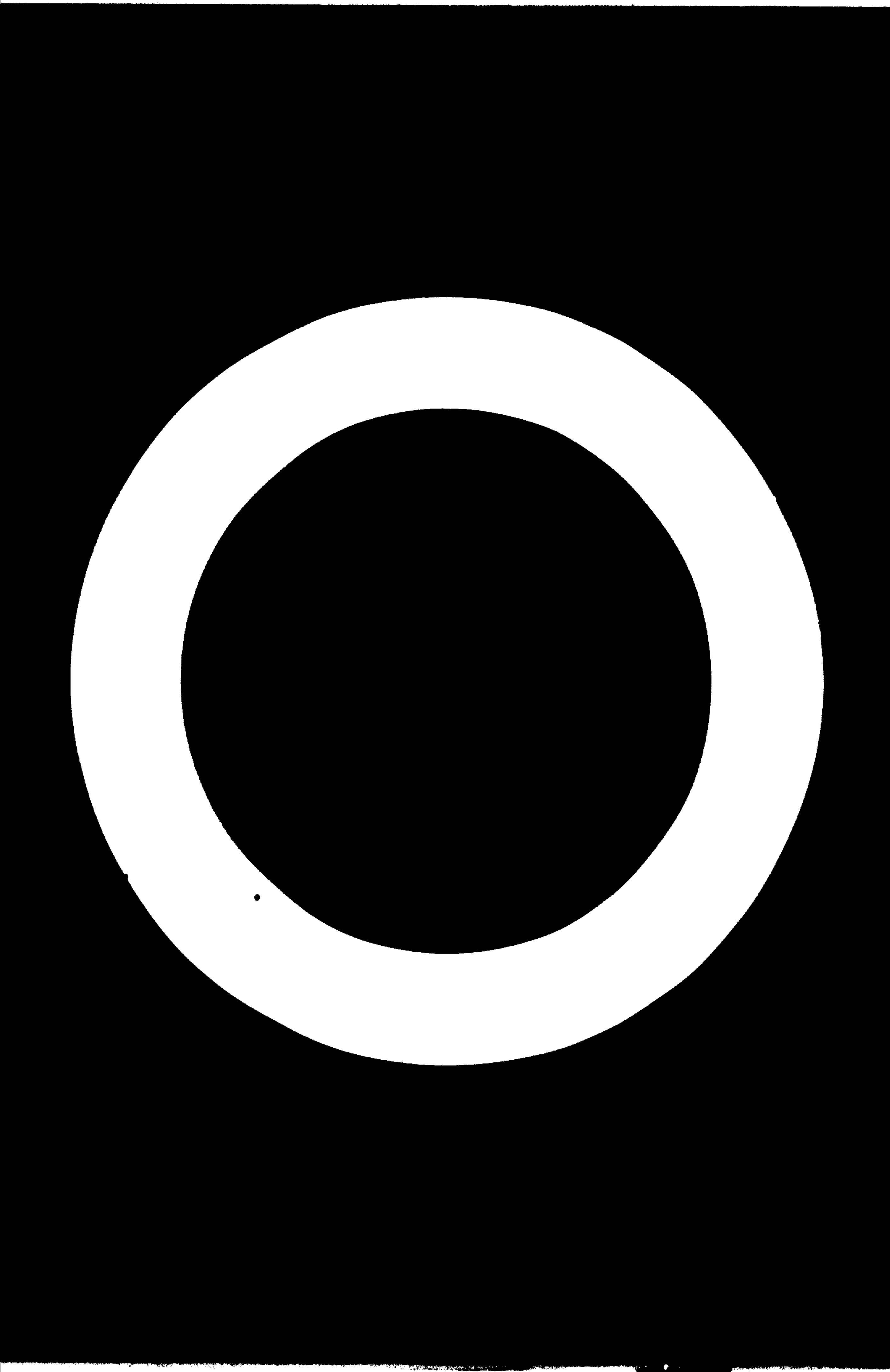
Simple and robust construction

Hydraulic drive

Low-cost maintenance

The discharge crusher grid, also called the rocker grate, consists of six water-cooled heavy shafts on which casted, toothed sections, similar to toothed roll crushers. The rocker grate is turned every two years to distribute the wear evenly. The distance between the shaft centres allows for the passage of clinker between the toothed sections.

The shafts rock, not rotate, which has a useful crushing effect and achieves good air circulation even when clinker lumps occur. The rocking movements are performed hydraulically and are activated from both sides.



Annex I

JOB DESCRIPTION

Post title:	Cement expert
Duration:	Two months and three weeks
Date required:	As soon as possible
Duty station:	Vienna, with international travel
Duties:	The expert will be attached to the Industrial Operations Division and will, in co-operation with the Least Developed Countries Section of the Division of Policy Co-ordination, assist in evaluating the technology available for the establishment and operation of shaft kiln plants for production of Portland clinker and cement.

Specifically, he will be expected:

1. To organize and undertake an exploratory mission to producers of equipment for shaft kilns and cement manufacturers experimenting or working with shaft kiln installations.
2. To make observations and recommendations on the requirements for the establishment of a shaft kiln pilot plant installation.
3. To assist in elaborating a plan of action for a mission to selected least developed countries to evaluate the possibilities for the establishment of small-scale pilot cement plants and to tender specifications for such plants.

Language:	English
Qualifications:	Industrial engineer with experience of the establishment and operation of cement plants
Background information:	The development pattern of least developed countries is characterized by very low consumption figures for cement and other commodities, making it practically impossible to establish economically viable industries. Supplier companies have concentrated on serving the big industrial units. The specialization of making big units has left the small units without improvements for the last fifteen years and the priority of big units on deliveries has made the cost of the establishment of small units prohibitive.

The above observations are based on the traditional rotary kiln technique which was only introduced at the turn of the century as a replacement for the original shaft kiln process. Before that, shaft kilns had been in use for 25 years and they continued to play an important role together with the rotary kiln for at least another 20 years, from 1900 to 1920.

The high investment costs for large-scale rotary kilns have led to a revival of shaft kiln techniques in an improved form for small- and medium-scale cement production.

Extensive development has already taken place and before further work is done and/or the possibility for establishing a small-scale cement industry is offered to the developing countries, UNIDO ought to evaluate the existing technologies so that the least developed countries can be advised of the technical and economic feasibility of the new shaft kiln technique with regard to the specific environment in different regions.

Annex II

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Annex III

SHAFT KILN PERFORMANCE (1972-1975)

Bamburi Portland Cement Company Limited, Kenya

Month	1972 Production rate (t/h)	1972 Energy consumption kcal/kg	1972 Energy consumption kWh/t	1973 Production rate (t/h)	1973 Energy consumption kcal/kg	1973 Energy consumption kWh/t	1974 Production rate (t/h)	1974 Energy consumption kcal/kg	1974 Energy consumption kWh/t	1975 Production rate (t/h)	1975 Energy consumption kcal/kg	1975 Energy consumption kWh/t	1976 Production rate (t/h)	1976 Energy consumption kcal/kg	1976 Energy consumption kWh/t
January	7.25	1 201		7.54	1 117		7.35	1 010		7.36	1 029		7.40	975	
February	6.75	1 173		7.37	1 110		7.26	1 004		7.24	968 a/		7.05	971	
March	7.41	1 189		7.50	1 126		7.14	1 052		7.13	975		7.08	967	
April	7.33	1 186		7.42	1 128		7.56	1 085		7.02	986		7.14	961	
May	7.23	1 188		7.56	1 108		7.25	1 044		6.97	987				
June	7.18	1 208		7.65	1 088		7.47	1 049		7.16	986				
Average	7.20	1 191	17.27	7.51	1 113	16.08	7.34	1 031	15.61	7.15	988	22.59			
July	7.36	1 174		7.45	1 088		7.30	1 058		7.25	985				
August	7.21	1 181		7.34	1 112		7.25	1 049		7.22	981				
September	6.85	1 186		7.32	1 080		7.38	1 084		7.37	981				
October	6.91	1 182		7.54	1 064		7.14	1 084		6.77	991				
November	7.15	1 184		7.62	1 038		7.02	1 057		6.87	923				
December	7.35	1 186		7.38	985		7.06	1 047		7.22	968				
Average	7.15	1 182	15.39	7.44	1 068	14.63	7.15	1 064	18.27 b/	7.12	973	...			

a/ Drop in fuel consumption due to new type of fuel.

b/ Electrostatic precipitator installed.

Annex IV

CUMULATIVE COSTS AT THE BAMBURI PORTLAND CEMENT COMPANY LIMITED, KENYA

A. Refractory Costs
(US cents/ton clinker a/)

	Shaft kilns	Rotary kiln I
1973	32.8	240.9
1974	48.4	333.4
1975	52.5	254.7
1976 up to April	3.1	365.1

Refractory price: approximately $US 325/ton

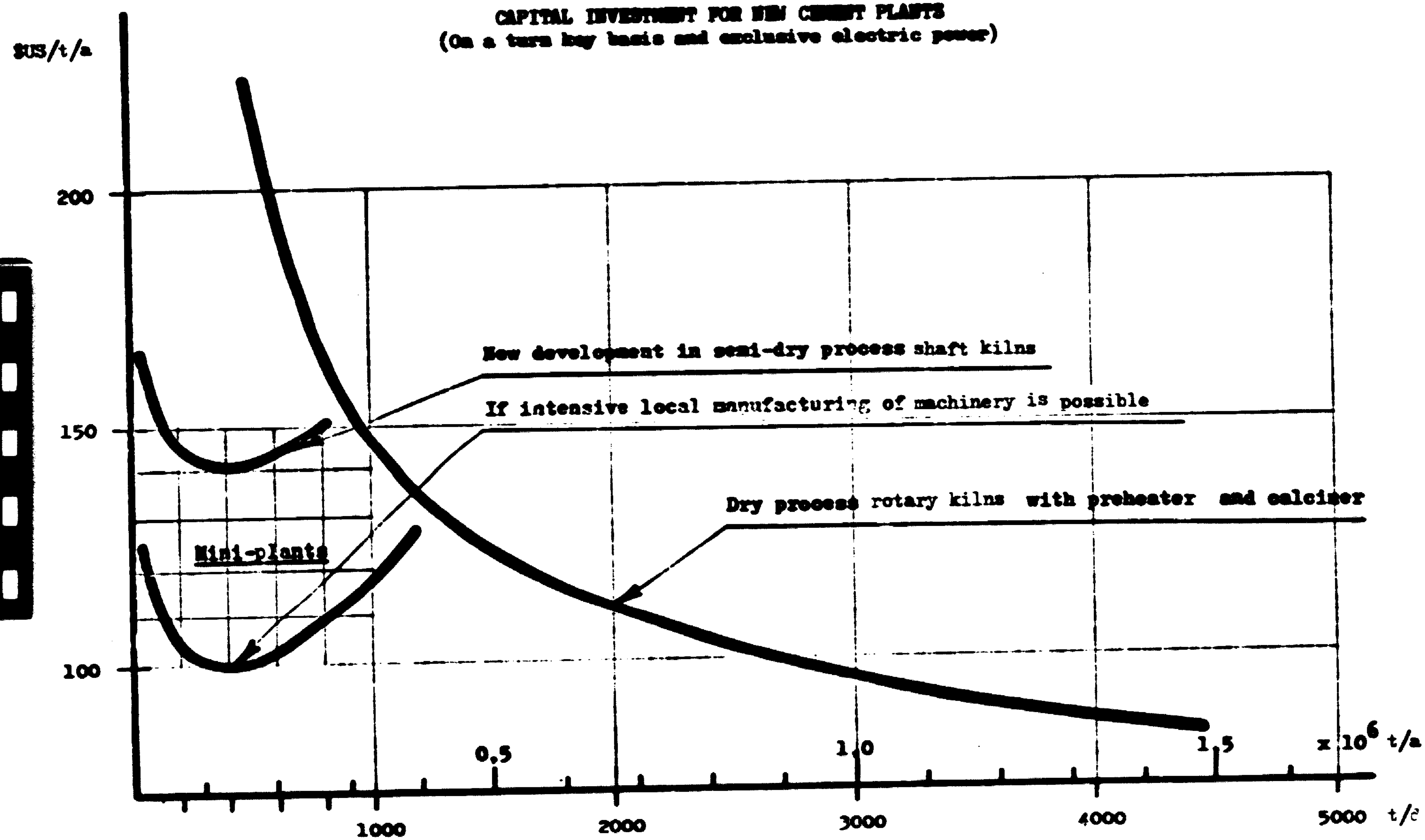
B. Fuel costs
(KSh/ton clinker a/)

	Shaft kilns Coal	Rotary kiln I Fuel oil
1973	21.69	11.27
1974	29.84	39.33
1975	37.50	48.11

a/ The monetary unit in Kenya is the shilling (KSh). In June 1976, at the time of the expert's visit, the value of the shilling in relation to the United States dollar was $US 1 = KSh 8.35.

Annex V

CAPITAL INVESTMENT FOR NEW CEMENT PLANTS
(On a turn key basis and exclusive electric power)



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