Small-Scale Production of Cementitious Materials

by: R.J.S. Spence

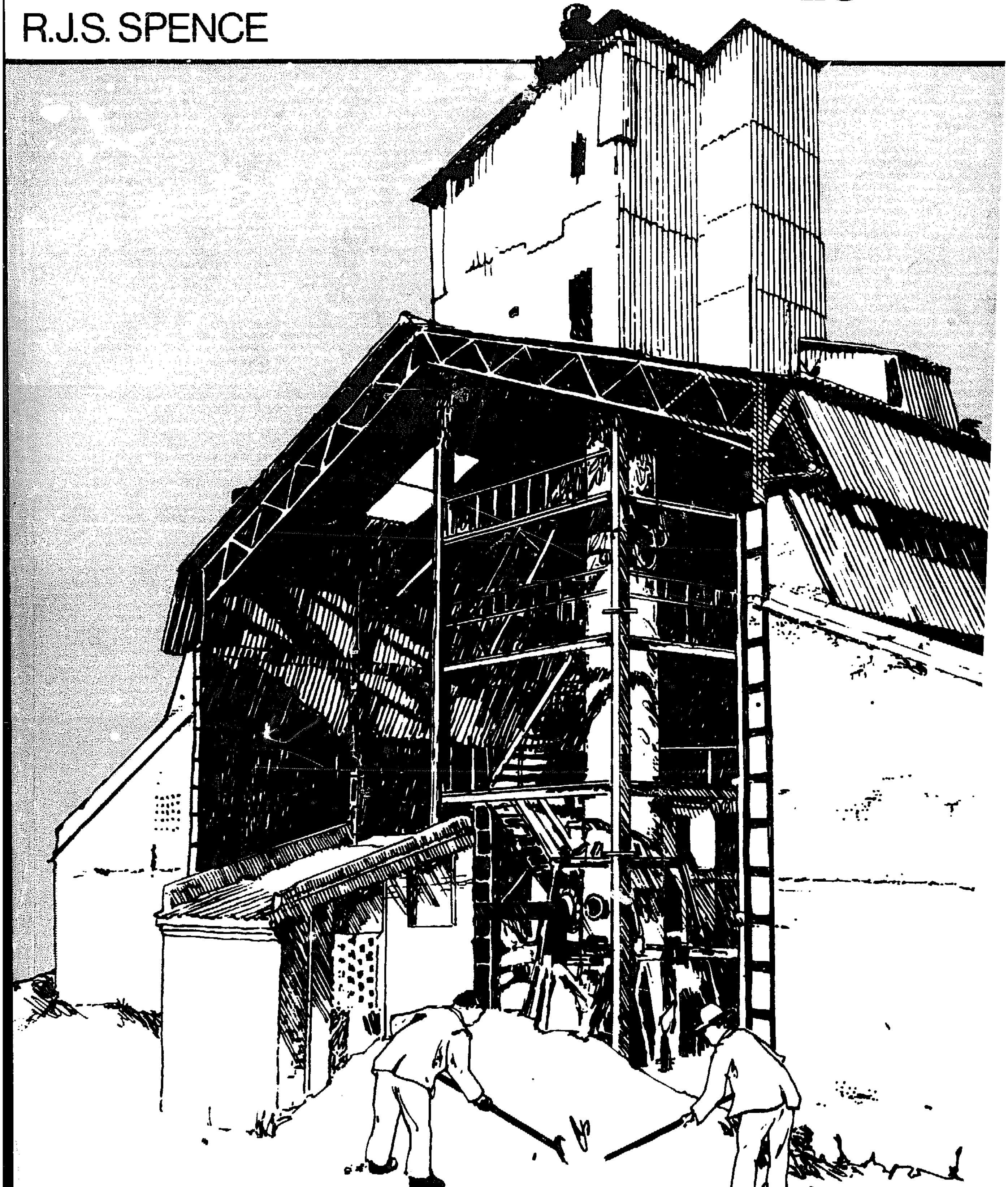
Published by:
Intermediate Technology Publications, Ltd.
9 King Street
London WC2E 8HN
United Kingdom

Paper copies are 4.25 British pounds.

Available from:
Intermediate Technology Publications, Ltd.
9 King Street
London WC2E 8HN
United Kingdom

SMALL-SCALE PRODUCTION OF CEMENTITIOUS MATERIALS

R.J.S. SPENCE



Cement, or at least some form of cementing material, is an essential ingredient of virtually every type of construction. So a continuing and expanding supply of cement is vital to provide the infrastructure for development.

Until very recently, the means by which development planners in most countries have sought to achieve this end has been the establishment of comparatively large-scale factories, modelled on those in the industrialised countries. But this approach has undesirable consequences for the economies of the poorer countries, and the question is being increasingly asked whether there are not alternative approaches by which a greater degree of local self-reliance can be achieved.

Two such approaches are considered in this work: firstly, the manufacture of Portland cement, or material of comparable quality, in much smaller kilns, and, secondly, the upgrading of village-scale technology, based on lime and pozzolanas. In addition, other materials from which cements could be made under local circumstances are considered, together with the problems that can accompany their introduction. A comprehensive list of references and notes indicates how further information on the technologies referred to in this paper can be obtained.

ISBN 0 903031 74 4

Intermediate Technology Publications Ltd.,
9 King Street, London WC2E 8HN.

SMALL-SCALE PRODUCTION
OF CEMENTITIOUS MATERIALS

R.J.S. Spence,

The publication of this manual was made possible by a grant from the Overseas Development Administration whose assistance is gratefully acknowledged

Published by Intermediate Technology Publication Ltd
9 King Street London WC2E 8HN UK
Printed by the Russell Press Ltd Nottingham NG7 4ET, U.K.

ISBN 0 903031 612

Author's Note

This paper is based on an earlier draft presented to the UNIDO Forum on Appropriate Industrial Technology, New Delhi, November 20th–25th, 1978, and has subsequently been revised on the basis of comments made at the time, and to incorporate more recently received information.

The author is grateful to those who assisted in various ways in its preparation, and in particular to Harold Lee, Neville Hill and Jonathan Sakula who read and commented on the draft.

Cambridge
October, 1980.

Contents

1. Introduction

1.1 The place of cement in development

Cement, or at least some form of cementing material, is an essential ingredient of virtually every type of construction in developing countries and hence a continuing and expanding supply of cement is essential to provide the infrastructure for development. Indeed, the supply of cement is much more vital to construction in many developing countries than it is in the more developed European and North American countries, which are endowed with a wide range of alternative building materials — timber, steel and high quality bricks. Thus a temporary shortage of cement in a developing country can, and frequently does, completely halt crucial construction programmes. The Idikki dam in Kerala in South India is one major project delayed by months through cement shortages. In countries, where cement is imported, building activity often goes in cycles depending on the availability of the necessary foreign exchange. Throughout the developing world precious resources are wasted in half-completed projects which cannot be finished because there is no cement.

Thus cement must be counted among the basic commodities on which development programmes rely, with an importance comparable to water, energy and fertiliser supply; and consequently self-sufficiency in cement production is always given a high priority in development planning. Until very recently, the means by which development planners in most countries have sought to achieve an increase in the supply of indigenously produced cement, has been the establishment of comparatively large-scale factories, on the model of those in the industrialised countries. These factories produce Portland cement, and an associated range of products satisfying International Standards Organisation (ISO) standards. The factories have been either entirely imported, or in the countries with a more highly developed industrial sector, (e.g. India) locally manufactured in association with the European and American cement machinery companies.

Without any doubt considerable progress in cement supply has been made. But, as the next section will attempt to show, this approach has certain undesirable consequences for the economies of the poorer countries, and it is being increasingly asked whether there are not alternative approaches by which a greater degree of local self-reliance, not only in manufacture of cement, but also in the establishment of cement plants, could be achieved.

Two alternative approaches are being widely considered. The first is the manufacture of Portland cement, or a cementing material of comparable quality, in much smaller kilns which could be widely dispersed, and locally manufactured. This approach, already successfully adopted in China and under active consideration in India at the present time, is considered in Section 2.

The second approach is the upgrading of village-scale technology based on lime and pozzolanas in order to produce a standardised though comparatively low-grade cementing material which could serve as a partial or complete replacement for cement in a wide range of applications. This is considered in Section 3.

In addition to these two approaches, which depend on essentially the same raw materials as does Portland cement, and are thus of equally general applicability, there are a range of other materials or techniques by which cements could be made under particular local circumstances. Some of these are little known, and could profitably be more widely used than at present in developing countries. Such materials and techniques are considered in Section 4.

The introduction of new materials and techniques is always accompanied by unexpected problems of a socio-economic as well as a technical nature, and this is likely to be particularly true of a material with such an enormously powerful status-value as cement has come to acquire in many of the poorer countries. Some of the social, economic and institutional problems which have been encountered, or are likely to be encountered in introducing new or different cement making technologies are considered in Section 5, which also sets out a number of policy recommendations for the guidance of planners and policy makers.

A comprehensive list of references and notes indicates how further information on the technologies referred to in this paper can be obtained.

1.2 Existing cement-production technology: characteristics and problems

Consumption of cement in developing countries has increased rapidly in the last 20 years as development expenditure has increased. Even more impressive has been the increase in the level of domestic production. Table 1 (cols 1 and 2) compares the figures for 1975 with those for 1966 for the major regions of the world and for selected countries. In all the developing regions of the world, Africa, Asia, South America, cement production doubled during this period, while much smaller increases were recorded in the developed regions. The increase in cement production in the developed regions has, in fact, been a great deal faster than that of average per capita income, reflecting perhaps the predominance of capital projects in the market for cement. Some particularly remarkable increases were those of Sri Lanka (up from 80,000 to 393,000 t/a), the Philippines (up from 1.6 to 4.4 million t/a) and China (up from 11 to 30 million t/a). Correspondingly, the imports of cement to developing countries have declined. A considerable number of developing countries are already, or soon will be self-sufficient in cement. Japan alone among the major industrialised nations is still a substantial exporter of cement.

Region	1966	1975	% increase
World Total	457	690	51
Africa	12	23	92
N. America	85	90	6
S. America	17	34	100
Asia	82	168	105
Europe	176	248	41
Oceania	5	6	20
USSR	80	122	53
China	11	30	173
India	11	16	46

Table 1. Comparison of domestic cement production 1966 and 1975, major regions and selected countries (million tonnes). *Source: U.N. Statistical Handbook 1976*

Details of the size and type of cement plant which have been established are not so readily available on a world-wide basis. However a recent report on the Indian cement industry[1] suggests that whereas the majority of kilns established in the 1950's and 60's were of 300–500 tonnes/day capacity, those established more recently are of 600 tonnes/day capacity and larger; although in 1975 there was no kiln larger than 1,000 tonnes/day capacity. A typical example, the Ndola Cement plant of the Chilanga Cement Company in Zambia, built in the late 1960's is shown in Fig.1.

In 1975 the Director of the India Cement Research Institute wrote:

> "It is time to consider single units of larger capacities. However, the type of plant which is most appropriate from the viewpoint of Indian conditions including transportation and availability of raw materials, has to be decided. In fact such an exercise of engineering

the first 2,000 tonnes/day single unit plant has begun, under the auspices of the National Committee on Science and Technology''[2]

If this is indicative of conditions elsewhere, it would appear that the current trend in conventional cement manufacture in developing countries, as elsewhere, is towards larger and larger kilns. Indeed, so long as the present dependence of so many developing countries on just a few European manufacturers of cement plants continues, it is inevitable that technological trends in the industrialised countries will be followed in the developing countries.

At first sight, the savings in capital cost and energy costs resulting from an increase in size seem to constitute a clear case for this trend. But, whatever the advantages of the use of increasingly large-scale cement plants in the industrialised countries, (and these advantages are by no means undisputed)[3] their appropriateness for all situations in developing countries must be, and is being, seriously questioned.

Problems associated with large scale plants are:

1) High capital cost per unit of output
2) Long time lag in construction
3) Difficulties over infrastructure (power, railway wagon) requirement
4) Cost of transportation to outlying areas
5) Dependency on imported machinery
6) Low capacity utilisation
7) Limited number of locations where raw materials are adequate
8) Difficulty in obtaining capital for new plants

Some of the problems are directly associated with the scale of production. The reserves of raw materials required to keep a plant in operation for a 30 to 40 year life are considerable, and the number of locations where reserves of sufficient quantity and quality are found is limited. In India a high proportion of the cement is produced in the south of the county, while the largest markets are in the north. The scale of the machinery required to be manufactured, transported and installed creates further problems. The larger the plant needed, the smaller the number of workshops capable of producing it. For most countries, this means the entire plant must be imported. But even in those countries which have their own heavy workshop capability, the unit cost of machinery increases as the scale increases. For instance, in India, according to a recent article in World Cement Technology by Bombay engineer A.L. Pastala

> "While the castings in the range of 2 to 5 tons per piece can be obtained at a price of Rs. 8000 (£550) to Rs. 10,000 (£700) per ton, the price of heavier castings with a weight of 20 tons and over per piece, will not be less than Rs. 25,000 (£1600) to 30,000 (£2000) per ton depending upon the intricacy of the castings. This is also true of machine fabrication. Light and medium sized workshops are able to deliver fairly accurate machine fabrications at Rs. 6000 (£4000) to Rs. 8000 (£550) per ton. Heavy fabrications, which come within the exclusive capacity of heavy engineering shops are priced at Rs. 15,000 (£1000) to 20,000 (£1250) per ton"[4]

One reason for this difference is that for smaller items which can be produced by many workshops, there is keen competition leading to a lowering of price.

Further problems are created by the size of the infrastructural requirements, power, maintenance workshops, railways and the specialised skills needed for a large plant. Shortages or breakdowns can frequently result in plant shutdowns. In India capacity utilisation has commonly been high, above 80%, because of the large demand, but over recent years has been severely hit by coal shortages, power shortages and railway wagon shortages, causing a drop to 72% capacity utilisation in 1974. In other countries with less well-developed infrastructures, capacity utilisation is frequently much lower. If low capacity utilisation in large plants were calculated for at the planning stage, their economics would look far less attractive. Because of the large scale, high capital cost and long time lag in construction (between three and five years), the financial commitment in a large cement plant is immense. In developing economies there are few if any investors who have the resources for such an undertaking, leaving the expansion of the cement industry either to government or to foreign investors. This is one of the main reasons why expansion in production so frequently lags far behind demand, causing the almost universally experienced cement scarcity.

Another problem of growing importance associated with large scale plants is that of transportation and distribution of the product. The level of demand for cement in developing countries is typically such that any large scale plant must serve a very large geographic region. The 3.2 million square kilometres of India is served by 53 cement plants, approximately the same number as in the 230,000 square kilometres of the UK. Africa, south of the Sahara (excluding South Africa), an area of more than 16 million square kilometres is served by no more than 25 plants.

Thus transportation costs must represent a very substantial proportion of the price buyers pay for cement. In India, where most of the cement travels to district distribution centres by rail, distribution costs are equalised throughout the country, with a freight equalisation charge of approximately 15% of the consumer price. This arrangement, though advantageous to the consumer, does have the unsatisfactory side-effect that it reduces the incentive for new cement plants to be located near the large markets where transportation costs would be lower.

In many other countries, where railway networks are less highly developed and cement must be transported by truck, bullock cart, boat or even by air, transportation costs are much higher, particularly where these have to account for numerous handlings and for the inevitable loss and deterioration in transit. Thus the price of cement in up-country Tanzania can be as much as two or three times that in Dar es Salaam where the factory is situated; throughout Indonesia the price of cement is above $100 (£52) per tonne; and in parts of Sumatra as high as $500 (£156) per tonne. In oil-importing countries, this high transportation element in the price of such a basic commodity as cement must be a matter of serious concern.

Finally, the centralisation of production resulting from the use of large-scale cement plants is entirely inconsistent with policies of regional self-sufficiency which many governments are trying to pursue. In most countries it is only by planning and investment decisions at a national scale that cement production can be increased.

Because of these problems, there is now considerable interest in the possibility of smaller-scale cement plants which could

1) be widely distributed wherever there is a demand for cement and suitable raw materials are found,
2) be manufactured and assembled locally, avoiding the need for imports and reducing technological dependence on foreign firms,
3) be erected and brought into production quickly,
4) be cheap enough to be financed locally, and
5) make only a small localised additional burden on existing power and transportation infrastructure.

Such plants would also need to be of low capital cost per unit of output, and economical in their use of energy, otherwise the cost of the cement produced in them would not compete with that produced in conventional plants. The straightforward scaling down of existing technology based on rotary plants is unlikely to meet this requirement because of the economies of scale in such plants. Different technologies, more appropriate to the specific requirements of a small plant are needed. The next section looks at the possibilities for small-scale plants manufacturing Portland cements. Alternative cementing materials are discussed in Section 3.

2. Small scale Portland cement plants

2.1 Background

The earliest nineteenth century Portland cement kilns were not unlike the lime kilns in use at the time. They consisted of a conical or bottle-shaped shaft and were operated intermittently. One of the reasons why shaft kilns were superceded, early in the 20th century, by rotary kilns, is that the rotary kiln could be operated continuously, thus considerably improving fuel efficiency, and making it possible for a better quality, more uniform product to be produced. As demand grew, so longer and larger kilns came into use, and with each increase in scale came a reduction in fuel consumption and in unit capital costs. Shaft kilns could not be scaled up in this way, and so they ceased to be economical for situations where there was a large concentrated demand.

The reasons for this have been explained by M.K. Garg:

> "The main difference between the vertical shaft and rotary types of kiln is that in the vertical shaft kiln the principle of heat transfer by conduction plays a more important role than radiation, whereas in the rotary kiln radiation is more important than conduction. Heat transfer by conduction can be efficient in a relatively small space; beyond a certain size heat transfer efficiency drops due to high radiation losses. On the other hand, heat transfer by radiation is progressively more efficient in a larger space due to lower heat losses. This basic fact led to the development of larger and larger plants based on rotary kilns. The vertical shaft kiln can be efficient with a capacity of as low as 1 ton per day, and has a maximum efficient capacity of 200 tons per day. The rotary kiln, however, has a minimum efficient capacity of 300 tons per day and nowadays capacities of 3,000 tons per day and more are preferred".[5]

Vertical shaft kilns went completely out of use, until the 1930's when, according to Garg, certain limitations and problems of large-scale rotary kiln plants led to the revival of interest. New designs with continuous, as opposed to batch operation were developed. These kilns were widely used in Germany during the second world war, and have continued to be used in Europe for a small proportion of the cement produced. Approximately 5% of world cement output is today produced in vertical shaft kilns.

Because of the heat transfer principle used, these kilns tend to have lower fuel consumption than rotary kilns. A recent report on the European cement industry[6] gives average specific fuel consumption for the main processes used (Table 2).

Representative Energy Consumption (Fossil Fuel Only)*

Process	kcal/kg Cement
Dry (long kiln)	860
Wet (long kiln)	1300
Semidry (grate preheater, Lepol type)	850
Dry (suspension preheater)	790
Shaft kiln	750

Table 2. Representative energy consumption (fossil fuel only) of common processes of cement manufacture in Europe. Source: NATO/CCMS-46, 1976

It is this lower fuel consumption which enables vertical shaft kilns to remain competitive with rotary kilns in spite of the difference in scale of operation.

There are differing views both on the scale and on the technology best suited to small Portland cement plants in developing countries. Some recent work is summarised in the following section.

2.2 Indian development work on small-scale vertical shaft kilns

Between 1965 and 1970, Dr. M.S. Iyengar working at the Regional Research Laboratory, Jorhat, Assam, developed designs for small shaft kilns with capacities of 2, 30 and 100 tonnes per day. Pilot kilns of 2 and 30 tonnes per day were installed. The technology has been summarised as follows[7].

> Limestone, clay and coal, after primary crushing, are proportioned and finely ground in a ball mill and then nodulised in a disc noduliser. The nodules then fall by gravity into the vertical shaft kiln. The kiln itself is divided into two portions — the conical portion at the top which is the clinker formation zone and the cylindrical portion at the bottom which is the heat exchange zone. As the nodules travel downwards in the conical portion, they come in contact with the pre-heated air. The fuel in the nodules ignites, providing the necessary heat for clinker formation. And by the time the materials leave the conical portion and enter the cylindrical portion, they have already been converted into cement. The clinkers are discharged through the rotary grate and an air-locking discharge gate, mixed with gypsum and finely ground in a tube-mill to give

---

*Electricity consumption of 100 kWh/metric ton of cement is not included in the figures in table 2.

Portland cement, conforming to Indian Standards Specifications, both in chemical and physical characteristics.

These modern kilns have the following features:

(i) the feed is in the form of uniform nodules,
(ii) since the raw meal has the fuel interground, fuel efficiency is high;
(iii) clinker formation which is mainly a sintering operation is confined to the top portion of the kiln;
(iv) the lower portion of the kiln acts as a heat exchanger where the sensible heat of the clinker is recovered by the air;
(v) air for combustion is supplied through rotary grate at the bottom of the kiln by a blower;
(vi) clinker discharge is controlled by the rotary grate and
(vii) the clinkers obtained are porous and need less energy for grinding.

All these improvements have led to a fuel efficiency as high as 750 K cal/kg of clinker against about 700–2,000 K cal/kg for rotary kilns. The shaft kilns also have a much bigger output per cubic metre than the conventional rotary kilns — 2.3 to 2.4 tons per day per cubic metre against 0.5 tons (wet process) to 1.3 tons (dry process) for rotary kions. They are simple in construction and can be installed in less than one year.

Some of the other advantages of the shaft kilns are that they occupy only about 1/7th the space for rotary kilns. The kilns can operate on solid fuel with a high ash content, even as high as 50 per cent. They can work on a variety of wastes like press mud waste from the sugar industry, lime sludge from the paper industry or acetylene sludge. Besides, they can be located in areas where transport bottlenecks prevent the setting up of large plants. Also they can be located near potential markets saving transportation and packaging costs.

In 1965, the U.P. State Planning and Action Research Institute decided to design, build and operate a 25 tonne/day plant on which the design of future commercial plants could be based. The work was directed by M.K. Garg, PRAI Rural Industries Specialist. The design is in many respects similar to the Jorhat design, based on a disc noduliser feeding a vertical shaft kiln. The kiln was designed to use as raw material a mixture of kankar (impure secondary limestone found in the plains of northern India) and rock limestone. The fuel was coke breeze with some coal added.

Production trials took place in 1970/71 during which 10,000 tonnes of cement was produced most of which satisfied the Indian Standards

Institution specification for Portland cement, except for expansion ratio, which was somewhat high. After a lapse of five years, further work to develop this design has now (1978) been initiated, again under the direction of M.K. Garg, working with the Appropriate Technology Development Association (ATDA) of Lucknow.

A third similar project is that of the India Cement Research Institute at Tiruchirapalli in Tamil Nadu where a 20 tonne/day plant has been developed,[8] and this is now said to be in commercial production (53).

2.3 Medium-scale vertical shaft kilns

During 1976, cement consultant Harol Boeck undertook a mission for UNIDO whose main aims were:

1. To organise 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.

Boeck[9] recommended the use of vertical shaft kilns with a size considerably larger than the Indian designs described above. He proposed a plant with an annual output of 80,000–12,000 tonnes, from two conventional shaft kilns of about 180 to 200 tonnes/day or alternatively one kiln working on the newly developed REBA process. Such a plant would be large enough to take advantage of highly developed existing kiln designs yet small enough to be fabricated locally and to make substantial savings through standardisation. He lists the advantages of a vertical shaft kiln installation as follows:

(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.

Boeck points out that conventional shaft kilns may not be suitable for all raw materials, as high strength pellets are essential; also that for the conventional plants low volatile fossil fuel would need to be used. The REBA process, however enables a shaft kiln to be oil fired.

He also warns that the use of 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.

2.4 The compact cement plant

A different approach is suggested in a recent article in World Cement Technology by the Indian engineer A.L. Pastala.[10] Pastala recognises the need for small cement plants in order to achieve dispersal of industrial activity for local economic development. He argues, moreover, that in developing countries the smaller the plant, the lower the unit cost, because of the increased competition among the much larger number of workshops able to produce it.

He does not, however, accept that the vertical shaft kiln is the answer, except at the level of what he calls the mini-plant of 10 to 50 tonnes per day. Above 100 tonnes per day, he argues that it has major disadvantages.

> ''Nodulisation of cement raw mix and fuel (coke breeze only can be used and this normally has to be brought from steel plants at comparatively high cost, when compared to low/medium grade coals normally used in the cement making process) in the correct proportion is necessary for charging the nodules to the vertical kiln. This process requires additional equipment and auxiliaries which increase costs. Adequate control of the burning process, once the nodules are charged to the kiln (to achieve uniformly burnt clinker) is difficult to achieve in a shaft kiln and results in an uneven quality of clinker which after selective screening does not produce a good quality clinker cement. In view of the additional equipment necessary in a shaft kiln plant the operational costs are also relatively higher when compared with an SP kiln system''.

Pastala proposes a 'compact' plant of 150 tonnes per day capacity, with a rotary suspension preheater kiln, using the dry process of manufacture. The kiln would be fired by pulverised coal. Proposed process details, economies, and manpower requirements for Indian conditions are given.

2.5 Cement production in the People's Republic of China

According to Sigurdson[11], more than half of China's cement is produced in small-scale plants. The standard design for such a plant has an annual production of 32,000 tonnes, approximately 100 tonnes/day. The technology is described as follows:

1. the feed is uniform nodules obtained from a simple disc noduliser
2. the kiln is fed more or less continuously by a team of men working on the top of the kiln

3. clinker formation is confined to the upper portion of the kiln
4. draught is usually induced and heat exchange takes place in the lower portion of the kiln
5. clinker discharge is usually discontinuous
6. fuel economy is good because
    a. fuel is being interground into the nodules
    b. there is efficient heat exchange within the kiln
    c. and porous clinkers are produced, which need less energy for grinding

Chinese cement production will be discussed further in 2.7.

2.6 Economic considerations: Comparison of small and large-scale plants

Operating economics based on long-term production experience are not available for small plants in developing countries. Much of the economic data available is therefore tentative. Because of the production experience at the PRAI plant at Lucknow the projected economic data for the ATDA 25 tonne/day kiln[12] is the most reliable available. Overall economic data for this plant has been compared with the economic data given for a 1200 tonnes per day plant of the type which the Cement Corporation of India are currently installing. Costs for the 25 tonne/day plant at 1977 prices, those for the 1200 tonne/day plant are at 1975 prices.

		25 tpd *vertical shaft*	1,200 tpd *rotary*
1.	Annual production (tons)	8,000	340,000
2.	Capital investment	Rs. 2.5 million	Rs. 240 million
3.	Capital investment per worker	Rs. 48,000	Rs. 381,000
4.	Capital per unit of output	Rs. 312	Rs. 706
5.	Jobs per Rs. million invested	21	2.6
6.	Ratio of 5 above	8.08:1	
7.	Jobs per thousand tons produced annually	6.5	1.84
8.	Ratio of 7 above	3.51:1	
9.	Population supplied by one plant	250,000	11 million
10.	Raw material reserve required by one plant (40 years output) tons	496,000	24 million

Table 3. Economic comparison of small and large scale cement plants in India.

Source: ITDG

Production costs are such that, with an equivalent selling price (including packing and transport) the return on capital for the 2 plants would be approximately the same. In practice however it is envisaged that cement from the 25 tonne a day plant would be bought unbagged straight from the silo with customers providing their own transport, and consequently the selling price will be lower by some 25% than bagged cement from the large plant. Other economic comparisons are shown in Table 3.

The economic advantages of the small plant as compared with a large rotary kiln plant, for India conditions have been summarised by Garg[12] as follows:

a. Lower capital investment per ton annual cement production (40–50% of that required in large rotary kiln plants). This is a very important factor as capital costs account for about 50% of the cost of production in a large rotary plant.
b. Lower fuel cost per ton of cement produced, due to utilisation of cheaper quality coal or coke and slightly lower fuel consumption than average rotary kiln.
c. Electric power consumption no greater than in large rotary plants.
d. Lower consumption of grinding media and kiln refractories than in large-scale rotary plants.
e. Lower transport and distributive costs due to proximity of consumer market and possibility of selling unpacked cement to local consumers (for very small plants). This is important, as packing, transport and distribution account for about 25% of the cost to the consumer of cement produced by large rotary plants (in India).
f. Simpler machinery of small plants allows quicker development of machinery manufacturing capacity due to possibility of using less sophisticated, less capital intensive workshops.
g. Simpler machinery allows quicker spread of know-how among less skilled personnel — very important in developing countries.
h. Lower spares and maintenance costs than in large-scale rotary plants, due to simpler machinery and smaller inventory of spare parts.
i. Greater flexibility in rate of production to meet fluctuating demand due to lower costs of shutting down and starting up, possibility of operating several kilns in parallel.
j. Capability of producing from the same kiln a variety of different cementitious products to suit local needs.
k. Quicker installation and running-in of new plants (one year as against five years for a rotary plant in India) which improves cash

flow and makes quick build up of production possible (as in China).

l. Small plants can utilise small reserves of calcareous materials that are widely scattered throughout many countries but cannot be utilised by large plants.

m. Small plants allow dispersal of production in rural areas, creating a better balance of regional development.

n. Small plants, being less capital-intensive create more employment per unit of investment — an important consideration in developing countries.

There appear, however, to be institutional factors which have so far inhibited the commercial development of small-scale cement production in India, in spite of the advantages claimed for it, and in spite of the intensive experimentation of the last ten years. This will be discussed in the next section.

2.7 Comparison of Indian and Chinese experience

According to official statistics, during the years 1965–75 cement production in China more than tripled from 15 million to about 48 million tons. Jon Sigurdson (11) states that more than half of this total, 28.3 m tonnes in 1975 is produced in small shaft kilns, dispersed in the rural areas, the number of which has increased from 200 in 1965 to 2,800 in 1975. Such plants whose average capacity is approximately 10,000 tonnes/year have now been set up in over 80% of all counties. An example is shown in Fig.2.

Over the same period, cement production in India increased far more slowly, from 11 million to 16 million tonnes. Although during this period there were a number of experiments with small-scale production using shaft kilns the whole of India's production continues to be from rotary kiln plants, ranging in size from the rather small 20,000 tons/year capacity plant at Srinagar to ACC's very large 1,080,000 tonnes/year Jamul plant. It is interesting to consider the reasons for the difference between the two countries in their choice of technology.

First, it is probable that small-scale plants have been used by China primarily for reasons of development policy rather than of production economics. Chinese policy is to decentralise production and to create rural self-sufficiency wherever possible. Such a policy favours small cement plants in rural agricultural areas, built with capital raised at county or commune level, with equipment built in local workshops and with a locally trained workforce. For the larger demand of the cities, large plants are still used.

PORTLAND CEMENT : TWO SCALES OF PRODUCTION

Fig 1. Cement plant at Ndola, Zambia
Capacity 600 tonnes/day
(Photo by permission of the Chilanga Cement Co)

Fig 2. Small scale cement plant, China
Capacity 100 tonnes/day

Secondly, China has a much less well-developed transportation network than India, which encourages its policy of decentralised production. In China, in order to reach district centres, cement from large centralised points would frequently need to be transported by road, and transport would add greatly to the price of cement. In India, on the other hand, the extensive railway system enables cement to be transported cheaply all over the country.

Thirdly, India's national policy on cement production has, over the last 20 years, been greatly influenced by the large-scale cement manufacturers. These large manufacturers would not welcome the competition in cement production which would result from the availability of small plants cheap enough to be owned and run by small entrepreneurs. This must be an important contributory reason why there are as yet hardly any small-scale cement plants in India.

Fourthly, India's freight equalisation system reduces the economic benefit from the establishment of small plants. One of the strongest arguments in favour of small plants is that they enable raw materials near to markets to be exploited, thus reducing transportation costs. A national freight equalisation system eliminates this potential advantage.

A fifth difference between India and China is in the standards adopted for cement quality. In China, there are six classes of cement,[58] with compressive strength ranging from 200 to 600 kg/cm^2 (20 to 60 N/mm^2). For different types of construction, different cements may be used. Most small plants are said to produce cement class 400 (400 kg/cm^2) which could be used for most rural construction, though Sigurdson (11) suggests that these claims may be overstated. But the range of standards available ensures that whatever cement is produced can find some use. For projects requiring higher quality cement than the local plant would produce, the cement would have to be transported from plants elsewhere.

In India, by contrast, there is only a single standard for Portland cement, and if a plant does not produce cement fully satisfying the standard, the cement cannot be sold for general use. A major reason for the abandonment of the PRAI's Lucknow plant (section 2.2) although it produced a cement very acceptable for most purposes, was that it failed, on occasions, to satisfy the expansion ratio test specified in the standard. Thus the national control of distribution and the rigid insistence on a single standard (following the practice of the industrialised nations) has greatly inhibited the development of the small cement plant in India. The precise conditions of India and China are not found in other countries, whose experience will be very different. But this brief review has some obvious policy implications if small-scale cement plants are to be successfully established. These will be stated in section 5.

3. Lime-based cementing materials

3.1 Background

Before the development of today's cements, lime would have been used in many of the situations where cement is now used. For several centuries before the present one, the great majority of permanent buildings in the countries of the northern hemisphere were of masonry construction, and the masonry units, whether brick or stone, were usually laid up in lime mortar. Plastering, both internally and externally, was also done with lime plaster (usually with some fibrous binding material such as horsehair to hold the plaster together and prevent the formation of cracks). And such concrete as was used, for example in foundations, was also made with lime[13].

The quality of the mortar or plaster depended on both the material used and on the control of the lime-burning process. Some limestones gave a lime which was hydraulic (i.e. when hardened it would be resistant to water), others only hardened extremely slowly by the process of carbonation (absorption of carbon dioxide from the atmosphere). But the best limes produced a mortar which had admirable properties of plasticity, water-retentivity, low shrinkage and resistance to water penetration.

The replacement of lime by cement resulted in much quicker setting mortars and plasters, and the uniform quality of the material gave the builder more confidence. At the same time, the messy lime-slaking operations which used to be needed to produce the best lime mortars were eliminated. Consequently, wherever Portland cement has been available at a reasonably low price, it has tended at first to replace lime altogether.

But mortars made with Portland cement and sand alone, without lime, tend to be harsh and difficult to work with, and when they have reached their full strength, tend to be much stronger than the bricks that they bond. This is extremely undesirable as it can be the cause of cracking in the masonry. A much better mortar is one which is based on lime, to give the workability required, but has just enough cement added to provide adequate strength, and a fast enough set, to allow the work to proceed. This is the standard mortar used in the industrialised countries today. The availability of bagged hydrated or slaked lime enables such mortars to be made on site just as readily as cement mortars.

An alternative way of achieving the strength necessary for lime mortars and plasters is by the addition of certain materials known as pozzolanas. Pozzolanas are materials which are not cementitious in themselves, but which when mixed with lime will cause the mixture to set and harden in the presence of water, like cement. These materials are of ancient origin, and were used by the Romans to make the concrete for many large and durable structures. The massive 42m. span dome of the Pantheon in Rome, for example, which has survived nearly 2,000 years, is made from lime-pozzolana concrete. The name pozzolana is derived from the village of Pozzuoli in Italy where the Romans quarried the volcanic ash which was their first pozzolana. Many other materials, both natural and artificial, have this same pozzolanic property, and pozzolanas have been extensively used by builders from Roman times to the present day, either in conjunction with lime, or more recently with Portland cement.

The significance of lime and lime-pozzolana mixtures as alternatives to Portland cement in developing countries is that both can be manufactured by very simple processes suitable for village-scale technology.

Lime is made by age-old technologically unsophisticated processes in most countries where limestone is available, in lime kilns of an enormous variety of shapes and sizes. But most of these processes are highly inefficient, being based on intermittent or batch production of lime. Because of the inefficiency of the process, the price of lime is often high (as high as or even higher, per unit weight, than the price of cement), and it is cheaper and more reliable to use cement alone in mortars and plasters. A 1:6 cement sand mortar is common in many developing countries. Locally produced lime is frequently used only for lime washes. But with improved manufacturing techniques, which will be described in 3.2, it is possible to produce lime to a consistent and satisfactory quality, and at a price which will usually be competitive with Portland cement.

Pozzolanas are also used in many places in the developing countries. In volcanic Indonesia, the huge deposits of volcanic ash or tuff provide one source of pozzolana which is used for mortars and for block-making; another pozzolana commonly used in mortars both in India and Indonesia is pulverised fired clay, sometimes made by grinding up reject bricks and tiles from the brick and tile kilns; another is the ash from agricultural wastes such as rice husk. But a lack of scientific understanding of pozzolanas, and a lack of quality control in the manufacture has often meant that these potentially very valuable cheap locally produced building materials are rejected in favour of the modern factory produced materials. The new knowledge which recent research had made available, and recently developed manufacturing techniques make it possible for local pozzolanas to be used much more widely than at present, and in major building and civil engineering work. This will be discussed in 3.3.

The use of lime and pozzolanas is not restricted to mortars and plasters. As indicated above lime can be used for lime-wash, and for blockmaking. It also has uses in road construction as a stabiliser for soils. Pozzolanas, as well as being used in conjunction with lime in mortars and plasters and block-making can also be used in conjunction with Portland cement, in order to reduce, by up to 25%, or even more, the quantity of Portland cement needed for high quality work such as reinforced concrete. These uses will be further discussed below.

There is thus considerable scope for the replacement or supplementation of Portland cement by lime and pozzolanas in a wide variety of alternative uses. It has been estimated that in India 45% of the cement used in building construction is used in mortars and plasters, all of which could be replaced by lime and pozzolanas if materials of suitable quality were available. The scope for replacing cement with lime is much greater in countries in which concrete blocks are a widely used building material. The same type of block could also be made using lime-pozzolana mixtures. And the replacement of Portland cement by 25% pozzolana, as is already done in India, provides further scope for replacement of cement.

As will be shown, the capital cost of providing the equipment to manufacture these alternative materials is very much less than that needed to set up the equivalent cement-making capacity, even using small scale cement plants, and all of it could be built locally or manufactured in small or medium sized workshops. The manufacturing process could create considerable employment. And the existing source of supplies of Portland cement could be reserved for the essential constructions such as dams, highway bridges and other reinforced concrete work for which no alternative material is available.

Much of the Portland cement made today in developing countries is used in reinforced concrete construction for multi-storey or even single-storey buildings. A further way of reducing the need for Portland cement and replacing it with other cheaper or more appropriate materials would be to design buildings in such a way that reinforced concrete is reduced. There are a great many techniques of this sort available, but discussion of these is beyond the scope of this paper.[14]

3.2 Lime: raw materials

Lime is made from calcium or magnesium carbonate. These are naturally abundant minerals. The most common source is in limestone rocks which are generally formed by the deposition in seas or lake beds of the shells or skeletons of marine organisms. Subsequent heat and pressure convert these deposits into rocks — limestones, dolomites or chalks — often in beds of several metres thickness. The thick-bedded limestones are very suitable for lime production. Thin-bedded limestones are also used, but are more likely to contain impurities.

In some parts of the world where sea shells are found in great abundance, these are used for lime burning. Coral is another very pure form of calcium carbonate which can be used.

Where neither rock limestone nor other forms of high-grade calcium carbonate are found, a form of limestone is sometimes found in nodules which have formed in the soil by solution and subsequent deposition of small quantities of carbonates in the soil. Such secondary limestones are often very impure, but the impurities can enable hydraulic lime to be made from them, and consequently increase their suitability for use in building. They are quite commonly burned for lime production, for instance in the northern plains of India where this material is known as kankar. Calcium carbonate is also a by-product of sugar manufacture, and lime is a by-product of acetylene manufacture.

There are few countries or substantial areas of the world where some form of calcium or magnesium carbonate suitable for lime production is not available. Limestone occurrences of any size are usually noted and mapped by geological surveys because of the mineral's importance as a raw material in cement production and other industries. But localised outcrops or occurrences of very little economic significance, and too small to be marked on available geological maps, may nevertheless yield sufficient quantity of material to supply a village-scale industry for many years. There are undoubtedly many such occurrences still to be discovered.

3.3 Lime: production process

Lime is produced by a two stage process. First limestone is burnt (or calcined) in a kiln, at a temperature in excess of 900°C, driving off carbon dioxide gas, and producing quicklime (calcium oxide).

The second stage is called slaking, or hydration. Quick-lime reacts rapidly with water, evolving heat, and expanding so that the lumps of quicklime break down to a fine powder. This powder is slaked or hydrated lime (calcium hydroxide).

The production process thus involves quarrying and sizing material, calcining or burning in a kiln, and hydration[15] followed by bagging and distribution, or by some further process using lime as the raw material. The process can be carried out at very different scales and levels of capital-intensity. The largest-scale operations are used in industrialised countries and are described in Boynton[16]. Medium-scale lime production is described by Bessey[17]. This paper only deals with the smallest-scale operations, of 10 tonnes/day or less.

At this scale quarrying operations can be entirely manual, possibly assisted with explosives if the limestone is massive, but frequently it will be soft or fragmented and explosives will not be needed.

The type of kiln used depends greatly on the fuel available. In many ways the ideal fuel for lime-burning is firewood, because the length and low temperature of the flame make for much more even burning of the stone than with other fuels. In parts of the world where firewood is cheap and abundant (e.g. some tropical areas) this may still be the best fuel, but in most areas firewood is an increasingly scarce resource and alternative fuels must be found. For the small shell-burning kilns of Kerala in South India, charcoal is still used as a fuel, but a manually-operated bellows is needed to create the necessary draft. Charcoal is not generally a good fuel. Where they are available coke or coal can be used: and they can be used in continuous mixed-feed kilns leading to improved fuel economy. Large kilns are usually fired by oil or gas. These fuels can also be used for small continuous or batch-operated kilns, and very low-grade oil can be used. But the cheaper, more primitive, oil burners create a very hot concentrated flame which makes even burning difficult and a poor quality lime can result. George Bessey has proposed the use of a gas producer, making producer gas from oil or any other combustible materials such as sawdust or agricultural waste, which could be used to fire a small lime kiln, thus making a much wider range of fuels suitable for lime-burning. But no kiln of this type is known to exist.

Small lime kilns are of two types; batch kilns, which are filled, fired and then emptied before the next firing; and continuous kilns in which the firing is continuous, with limestone and (for mixed feed kilns) fuel being continuously fed from the top of the kiln and quicklime removed from the bottom.

Batch kilns are by far the most common types of small kiln in use in developing countries today. They are cheaper to build and easier to control: and they fit well with the pattern of intermittent production and demand which is commonly associated with rural industries. The design and size of batch kilns varies greatly in different parts of the world. Some traditional types have been described by Bessey[17], Ellis[18] and Spence[19]. VITA have developed a new type of small batch kiln for use in Honduras[20]. But fuel efficiency is low by comparison with continuous kilns, and because of the length of the cycle of operations (20 days in the case of 'country type' lime kilns in India,, average production is low even from a large kiln.

Continuous kilns can be used where coke, coal or oil are available, and even firewood can be used to fuel a continuous kiln. The kiln typically consists of a cylindrical shaft made of some local material (e.g. stone or brick). At its simplest, the kiln is open at the top for the feeding of raw materials, and has one or more openings at the base for removal of the burnt limestone. If coal or coke are used as fuel these are fed with the sized pieces of stone at the top of the kiln: the stone and fuel falls gradually into the firing zone of the kiln, which is in the middle, insulated by a zone of unburnt stone above and a layer of burnt stone below. An efficient heat exchange process between stone and gases takes place. The shaft may also be insulated. Consequently fuel efficiency is much higher than that of batch kilns, and if the kiln is well controlled, greater evenness of burning results. If oil is to be used as a fuel one or more oil burners are located at an appropriate position round the shaft. A semi-continuous kiln of traditional design used in North India is shown in Fig.3.

The India Khadi Village Industries Commission has studied the performance of small continuous shaft kilns, and a design for a 1½ tonne/day coal or coke-fired kiln is available from the Commission with details of its expected performance characteristics[21]. A kiln of this type is shown in Fig.4. A fuel consumption of 0.15 tonne of coke per tonne of lime is claimed, equivalent to 60–70% efficiency, very high for a small kiln. These kilns need to be fed and discharged continuously at a carefully controlled rate, and require considerable operating skill and experience to run them at their optimum performance. Consequently a lower figure is to be expected initially. Indian Standards for the design and operation of small kilns are also available. The same type of kiln can also be operated using firewood, either continuously or intermittently. For intermittent operation, fuel efficiency will be lower, and average output will also be lower.

At the Indonesian Directorate of Building Research in Bandung a new type of small oil fired kiln has been developed though its sophisticated burner design makes it too expensive for widespread rural use.[22]

The simplest technique for hydration is known as platform slaking. The pieces of quicklime are spread out in a layer not more that 300 mm. deep and water sprinkled on it just sufficient to break down the lumps into powder; and until no more water can be absorbed. The layer is turned once or more during the process. The lime is then sieved through a fine screen to remove coarse material which is either unburned or unhydrated. Inevitably some finer pieces of unburned material will pass the screen, and lime made this way is not the best material for mortars and plasters unless it is subsequently ground in a mortar mill. But it is

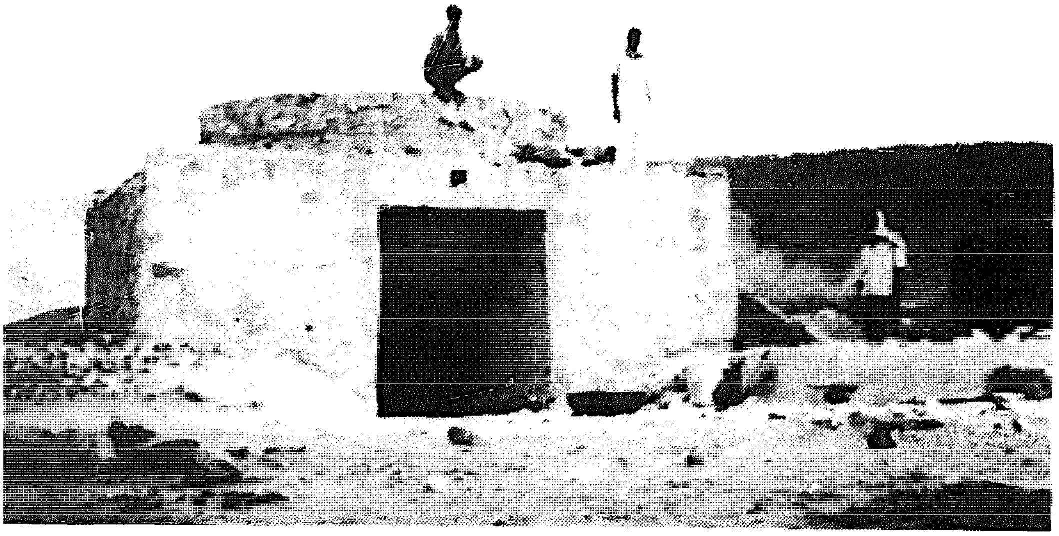


Fig 3. Traditional semi-continuous kiln
Jaipur, Rajasthan, India

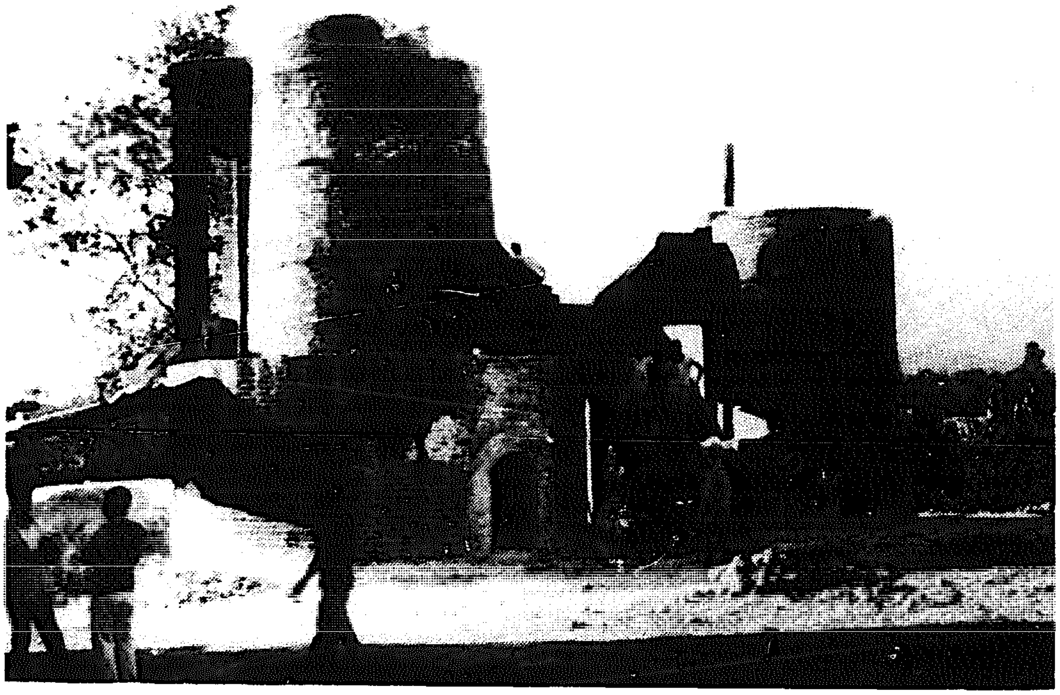


Fig 4. Improved continuous kiln, KVIC design
Dehra Dun, India

perfectly adequate for many of the uses of lime — block-making, soil stabilisation, and agricultural use. Slaking can also be done in a tank or pit in an excess of water to form lime putty. These simple techniques have been described by Zvare[23].

The best quality dry hydrated lime can only be achieved by using a mechanised hydration plant with an air separator, so that all coarse material is removed. Mechanised hydration is described by Bessey[17]. Hydration plants are commercially available with nominal outputs ranging from 40 to 400 tonnes per day, the smallest being considerably larger than the smallest kilns. The Central Building Research Institute in Roorkee India has developed a much smaller hydration plant, which could be fabricated in a local workshop.

Special care needs to be taken in the hydration of a lime containing a substantial proportion of magnesium oxide; for these limes platform slaking cannot be used.

3.4 Lime production: capital costs, labour intensity and production costs

The simplest processes of lime manufacture using batch kilns built from local materials and entirely manual quarrying, loading and unloading and slaking methods would involve very little capital cost, probably less that £1.00 per annual tonne[17]. In Honduras, labour for making quicklime including quarrying was found to be about 25 to 40 manhours per tonne.

Shell lime in South India made in small batch kilns, requires about 15-20 manhours/tonne including slaking, but excluding the collection of shells. The capital cost of establishing the small lime kiln designed by the Khadi and Village Industries Commission, including storage was at the time of publication of the commission's descriptive booklet (approx 1970) about Rs. 25,000 (£1,650). If 300 days a year production was achieved, this would work out at Rs. 60/annual tonne (£4). Labour for kiln operations and slaking only, is about 35 manhours per tonne.

The same kiln recently established in Northern Tanzania as a wood-fired kiln, cost approx, 30,000/- (£2,100) including storage shed. The maximum annual production is about 200 tonnes giving a capital cost of 150/- (£10) per annual tonne. Labour requirement including for quarrying and preparation of stone and firewood is around 130 man-hours per tonne.

Capital costs and labour requirements for another type of small kiln have been given by Ellis[18]. By comparison, a modern mechanised plant is capital-intensive. A minimum sized oil-fired plant, with a production capacity of 60 tonnes/day (20,000 tonnes/yr) exported from the UK would cost £600,000 to £1,000,000 or £30 to £50 per annual tonne production. Labour requirement would be very small.

Production costs depend primarily on costs of fuel, on labour, and on interest and depreciation on the capital cost of the kiln. The fuel requirements can be approximately deduced from the efficiency of the kiln. A method for making this calculation is given by Bessey.[17]

3.5 Pozzolanas: raw materials

Pozzolanas are materials containing silica or alumina in a state which is available for reaction with lime. Not themselves cementitious, they react with lime to form a material which sets and hardens like a cement. A wide variety of silicious or aluminous materials may be pozzolanic. In this paper only those of widespread occurrence or availability will be discussed. These are volcanic ash, a natural pozzolana; pulverised burnt clay, ash from agricultural wastes, and p.f.a. (pulverised fuel ash from coal fired power stations) which are classed as artificial pozzolanas.

The first pozzolana used was volcanic ash from Mt. Vesuvius. Deposits of volcanic ash or tuffs are likely to found wherever there are active or recently active volcanos, for example in the Mediterranean, the Pacific region, central Africa and elsewhere. The natural state of these tuffs varies greatly. Some of them are fine-grained, others contain large particles; some are loose, others strongly cemented so that they would need to be ground before they could be used. The quality of these tuffs as pozzolanas also varies greatly: some are very good pozzolanas, while others have hardly any pozzolanic activity at all. Also, the quality of a material may vary widely within a single deposit or a single geologically consistent stratum: variations in quality with depth are common with in some instances the more recently deposited upper layers tending to be more active, while in other cases the reverse is true. The variation has undoubtedly hindered the commercial exploitation of volcanic pozzolanas, but they are used today in Italy, in Northern Europe (Rhenish trass), in Japan and in Indonesia and elsewhere; deposits in Rwanda and Tanzania are beginning to be exploited. There are certainly potentially valuable deposits elsewhere waiting to be used.

Burned clay pozzolana also has a long history, since the Romans used crushed pots and bricks in their mortars in Northern Europe where volcanic pozzolana was not available. The use of clay pozzolana has survived until the present century in India (surkhi), Egypt (homra) and Indonesia (semen merah). Although sandy clays are commonly used for surkhi (often using reject bricks or tiles as the raw material), the sand is not reactive, and the pozzolanic activity resides in the clay mineral fraction. All the common clay minerals can be used to make active pozzolanas when burned to the appropriate temperature (usually 600–800°C) and finely ground. But a wide range of activity is found, the precise reasons for which are not fully understood. The question of identifying suitable clays for making pozzolana has been discussed by Bain[24]. Almost certainly, wherever plastic clays are found (those suitable for pottery for example) a pozzolana can be made. Thus raw materials for clay pozzolana are even more widespread than those for lime manufacture.

The use of ashes to improve the quality of a mortar has a considerable history[25]. But their specific pozzolanic nature appears to be a recent discovery. Rice husk ash is particularly high in silica, and has been found to be an excellent pozzolana.[26, 54] Throughout South and East Asia rice husk ash is a waste product of no commercial value, which rice millers have difficulty in disposing of. In India it has been estimated that 10 million tonnes of rice husk are produced each year, of which about 20% is ash. The raw material is thus very widely distributed, and rice husk ash pozzolana could be a valuable by-product of rice milling in rural areas. The ash from other agricultural wastes such as rice straw, bagasse (from sugar cane) are presumably pozzolanic, but no studies are available.

Pulverised fuel ash (p.f.a) from coal-fired power stations is another waste material which has pozzolanic properties. Its activity varies considerably from one power station to another, and at any one power station it can also vary from day to day. Although the best p.f.a. is unlikely to be as good as properly processed burnt clay pozzolana or rice husk ash, it has been shown that displacement of 25% Portland cement in concrete by a slightly larger quantity of a selected p.f.a. can lead to a general overall improvement in properties.[27]

A large number of other naturally occurring materials can have pozzolanic properties. Diatomite is a silicious material consisting of the shells of unicellular plants. If pure it is reactive with lime even without calcining; if impure calcination at about 600°C is needed. According to Robertson,[28] diatomite occurs in many countries.

Bauxite, another widely occurring mineral can also be a pozzolana if calcined; calcination temperature may be much lower than for clays, 250–350°C. There is also a slight pozzolanic cementing reaction between lime and many of the lateritic soils commonly found in Africa and elsewhere in the tropics.[29] This reaction is enhanced by increasing the temperature and pressure, and is the basis for the Latorex block-making process.[30]

3.6 Pozzolanas: processing and uses

The processing and use of pozzolanas depends to a great extent on the type of pozzolana. In this section, some examples will be given.

3.6.1 Volcanic pozzolana in Indonesia

Much of Indonesia is volcanic, and huge deposits of volcanic tuff are found. In some places, for example at Lembang near Bandung, this material is used for blockmaking, Fig.5. The Lembang trass is a coarse-grained material (which would require grinding if it were to be used in mortars). It is loosely cemented and easily quarried. For blockmaking it is mixed with 20% dry hydrated lime — produced in small-scale traditional kilns about 50km distant — and sufficient water is added to facilitate compaction. Moulding and compaction is traditionally carried out manually; but for larger-scale production of better quality blocks the Directorate of Building Research has introduced a vibrating compaction machine.[31] The blocks are cured at ambient temperature for 28 days before being sold. The blocks are extensively used in the city of Bandung where they are cheaper to use than burnt clay bricks. However, shrinkage cracking in walls built with them is common, possibly because they are sold before the full curing period has elapsed.

3.6.2 Volcanic pozzolana in Eash Africa

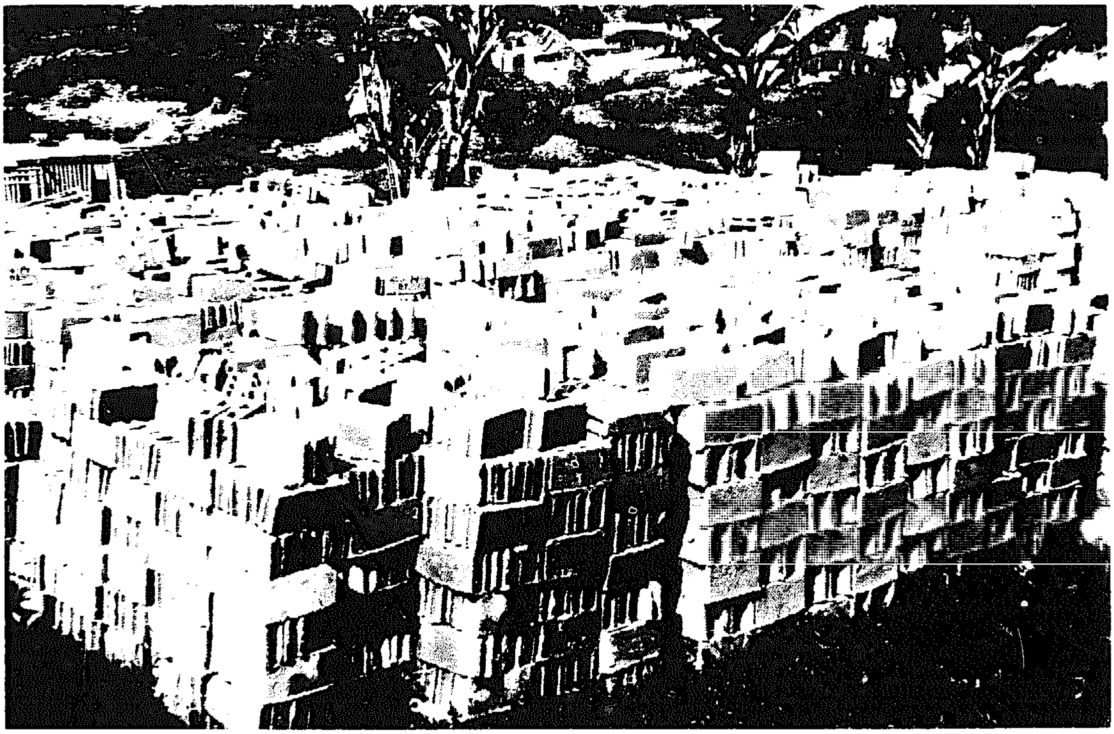
The Arusha-Moshi region of Northern Tanzania is volcanic and huge deposits of yellow fine-grained tuff are available. Tests on some samples of this material have shown it to be reactive. Moreoever, it is sufficiently loosely-cemented and fine-grained in its natural state to be able to be used both for blockmaking and for mortars and plasters without grinding. High calcium limestone is also found in many places in the region. A small industry has recently been established by the Tanzanian Small Industry Development Organisation to make lime and lime-pozzolana mixture. The lime pozzolana mixture (1 part lime to 1 part pozzolana) is used in two ways: either with sand for mortars and plasters, or with pumice aggregate to make blocks.[32] A demonstration building using pozzolime for foundations, blocks, mortar and plaster has been completed.

A project to utilise the volcanic tuff of Rwanda as pozzolana has also been started. In this case the material is coarse-grained, and needs to be ground before it could be used in mortars. A ball mill is to be used for this.[33]

3.6.3 Burnt clay pozzolana in India and Indonesia

Traditional surkhi in India is made by grinding reject bricks or tiles in a

a. Trass (volcanic ash) quarry



b. Block making technique

Fig 5 Lime-trass blocks at Lembang, Bandung, Indonesia ball mill or hammer mill. It is somewhat coarse and not very reactive, but sufficiently reactive to enable masonry mortars to set and harden. In Jaipur, Rajasthan, a form of surkhi is made from a soil which contains too little clay, and too much sand to be of any use for brickmaking. The process is shown in Fig.6. The soil is cut and removed in blocks, forming circular pits. The blocks of soil are then replaced in the pit with alternative layers of firewood and the whole mass is fired through. The resulting burnt soil is very friable and needs no pulverising. Mortar is made by adding it to lime putty and mixing with a hoe. Neither sand nor cement is used. The mortar has been used by the Rajasthan Housing Board for all masonry work throughout a large housing scheme.[34]

In Kerala plastic clays suitable for tile manufacture are found, and the Mangalore tile industry, though now declining, has been in existence for more than a century. Because the Mangalore pattern tile is very liable to crack during drying, a high proportion (up to 15%) of rejects are produced. When pulverised in a hammer mill these tile rejects give a surkhi which is being used in conjunction with lime for masonry mortars, and in the warm humid climate of Kerala sets and hardens rapidly.

A similar coarse pozzolana is made in the Indonesian island of Java. A clayey soil is mixed with water, moulded into blocks and dried in the sun. The blocks are built into a clamp, fired with firewood, then disintegrated using wooden flails. The coarser particles are then screened out. The resulting red powder "semen merah" is used in conjunction with lime, sand, and sometimes cement in masonry mortars.

3.6.4 Improved burnt clay pozzolana in India

During the 1960's the Central Road Research Institute in Delhi carried out extensive investigations on burnt clay pozzolana[35]. They located suitable clay deposits throughout India, established procedures for firing and grinding to obtain maximum reactivity, and set up pilot small-scale manufacturing plants using down-draught and rotary kilns.

These plants were able to produce a pozzolana of very much higher quality and uniformity than the traditional surkhi, which could be used either in lime-pozzolana mixtures for mortars and plasters or for the production of Portland-pozzolana cement by intergrinding cement with the burnt clay.

To improve the fuel efficiency of burnt clay pozzolana production, the Sri-Ram Institute, in conjunction with National Buildings Organisation, has developed a fluidised bed calciner with a capacity of 20 tonnes/day.[36]

a. *Digging clay*

b. *The kiln before loading*

d. *Mixing with lime*

c. *The kiln during firing*

Fig 6. Burnt clay pozzolana (Surkhi) in India

The Khadi and Village Industries Commission of Bombay has developed an alternative lime-pozzolana material, known as Lympo. The pozzolana is obtained from underfired bricks from rural brick clamps. These are pre-crushed and then interground with lime using a hammer mill; a small proportion of mineral gypsum is also added to control the setting and initial rate of hardening. Detail of the process are given in the Commission's publication.[37] India has developed standards both for burnt clay pozzolana and lime pozzolana mixture.[38, 39] Three grades of lime-pozzolana mixture are specified for different uses.

3.6.5 Rice husk ash

ASHMOH is a rice husk ash cement developed at the Indian Institute of Technology, Kanpur. Rice husk ash from rice mills and hydrated lime are ground together in a small ball mill. ASHMOH is a fine powder of light to grey colour with a bulk density about half that of Portland cement. After 28 days strengths of 15 to 20 N/mm^2 are achieved. ASHMOH is recommended for use in mortars, plasters, sand-cement blocks, well rings and canal linings.[40] A small pilot plant has recently been set up at Aau in the Banda district of U.P.[41], and a further plant at Jitra, Malaysia.

In January, 1979, a workshop on *Production of Cement-like materials from Agro-wastes* was held at Peshawar, Pakistan and a number of action programmes for developing and disseminating RHA technologies were agreed, including the establishment of pilot plants in a number of South and South East Asian countries.[57]

An alternative way of using rice husk to make a pozzolana has been developed at the NAVE Technical Institute, Shahjahhanpur.[42] Equal quantities of clay and rice husk are mixed with water and shaped into cakes. These are then dried in the sun and fired in an open clamp. No fuel is needed except for the initiation of the fire. The fired product is ground to a fine powder in a ball mill and then passed through a 200 mesh (75 micron) sieve. If the clay content of the soil is greater than 20% it is claimed that a highly reactive pozzolana is produced.

Another process for making a cement from rice husk ash is the Schifferle process developed at the University of California (Berkeley). This will be discussed in section 4.3.

3.7 Economics of pozzolana and lime-pozzolana production

Little economic information based on commercial operating experience is available. Economics of production are also dependent on time, place, availability of raw material, fuels and other inputs. The economic data given below gives only an indication of likely performance. The Khadi and Village Industries Commission,[37] give capital costs for the production of Lympo at 3 different scales of production, Table 5.

Scheme		A	B	C
Capacity tonnes/day		2	5	10
Investment*	Rs	20,000	45,000	80,000
	£	1,300	3,000	5,200
Working capital	Rs	10,000	15,000	30,000
	£	720	980	1,960
Power required	H.P.	5	10	15
	Kw	3.8	7.6	11.2
Employment total no.		5	10	15

Table 5. KVIC 'Lympo' lime-pozzolana. Expected economics at 3 different scales of production (1975 prices).

Assuming 200 days (8 hrs. per manday) operation per year working at full capacity, the largest of these schemes has capital cost (excluding working capital) of Rs.40 (£2.60) per annual tonne production. Labour is approximately 12 mandays per tonne. Cost of production is not given but according to KVIC publications, the material is 40% cheaper than cement in construction, allowing for the fact that an increased quantity of Lympo has to be used. In Tanzania a unit producing 60 tonnes of lime-pozzolana mixture per month using natural volcanic ash would have a capital cost of 35,000/- (£2,400) and would employ approximately 10 people. Thus the capital cost is approximately 50/- (£3.50) per annual tonne production, and labour is about 35 manhours per tonne (for kiln operation and mixing only).

The cost of the ASHMOH plant at Aau is said to be £1,500. This does not include the lime kiln. For an annual production of 250 tonnes this works out at £6 per annual tonne.

3.8 Comparative economics of lime-pozzolana production and Portland cement production

Direct comparison between Portland cement and lime-pozzolana cannot be made because the two materials are not of comparable properties. In India the standard cement; sand mortar is 1:6 by volume. This can be replaced by a 1:2:9 lime: pozzolana: sand mortar if the lime-pozzolana mixture has a 28-day strength of 20 kg/cm^2 or above. In this

---

*Investment includes for kiln and all machinery: excluding land and buildings.

case approximately 1.7 tonnes of lime-pozzolana mixture replace 1.0 tonnes of Portland cement. Comparative economics of the two materials for use in mortars can be worked out on this basis.

This was done for the KVIC Lympo technology by a Kerala Government working party in 1974. The total investment in one small 10 tonne/day plant would be Rs. 290,000 (£19,000) including Rs. 138,000 (£9,000) working capital. Annual production would be 3,000 tonnes and the selling price Rs. 250 (£16.30) per tonne. This would replace 0.6 tonnes of cement at approximately Rs. 450 (£29.50) per tonne and there would therefore be some saving in cost to the consumer. In addition, each plant would provide direct employment for 15 people and indirect local employment for a further 40 (in shell collection, charcoal burning etc.) and release 1,800 tonnes of cement annually for alternative uses. The capital cost of Rs. 100 (£6.50) per annual tonne can be compared with Rs. 350 (£23) (at that time) for an annual production of 0.6 tonnes of Portland cement.

In the Tanzanian project described above it is estimated that the selling price of bagged pozzolana in 1980 will be approximately 720/- (£40) per tonne. At a 1.7:1 replacement rate, this could replace 0.6 tonnes of Portland cement at up to 1400/- (£78) per tonne with some cost saving to the consumer. In each such plant employment will be provided for at least 12 people, and 500 tonnes of cement can either be released for alternative uses, or need not be imported and transported 450 km from the coast.

4. Other cementing materials

4.1 Hydraulic lime and natural cement

A limestone containing a proportion of clay will, if calcined at the appropriate temperature, produce a lime which will set and harden without addition of any pozzolana. Such a lime is called hydraulic lime. The Vicat classification distinguishes feebly hydraulic limes (–12% active clay), moderately hydraulic (12–18% active clay) and eminently hydraulic (18–25% active clay) limes.

Many of the limes produced before the advent of Portland cement were hydraulic, their rate of strength development making them superior to high calcium limes for mortars in large buildings or underwater structures. The processes for calcining and slaking a hydraulic lime are different from those for a high calcium lime. Slaking can be expected to take much longer, and firing temperatures to be somewhat higher. No detailed account of the process of manufacture of hydraulic limes appears to exist. Hydraulic lime has not been produced in the UK since 1948. Nevertheless excellent low cost mortar and plaster material can be produced by simple technology from the right material, and hydraulic limes should not be overlooked.

In the construction of the Lloyd Barrage at Sukkur, Pakistan, the engineers produced an artificial hydraulic lime. The process has been described in the 1948 PWD (Bombay) Handbook[43].

High calcium lime was calcined and slaked in the normal way, then ground wet for 20 minutes with 25% of its volume clay. The resulting slurry was then dried, cut into lumps and fired a second time in an intermittent kiln. The hydraulic lime on removal from the kiln consisted of lumps and powder; in about 7 days it had slaked to powder. The double calcining involved in this process is likely to make it uneconomic today except in very special circumstances.

Natural or Roman cement is a material made by calcining certain very impure carbonate rocks. It was the fore-runner of Portland cement, widely used between 1776 and 1825 in the UK. The best known raw material used was septaria, "cement-stones" which were found washed out of the London clay at coastal outcrops. Their composition was approximately 60–70% carbonate, 30–40% clay. Calcining at a temperature just below that required to cause fusion (approx. 1100–1200°C) and subsequent grinding produced a powdery material of cementitious properties. A recent laboratory study[44] has indicated that the strength achieved after 28 days would be no more than around one third to one half that of Portland cement. Natural cements are not made commercially today, but the process could be used in areas of cement scarcity where raw materials were suitable.

4.2 Gypsum

Some of the earliest plasters used in ancient Egypt were made from gypsum. Gypsum, calcium sulphate, is an abundant mineral. It occurs naturally as rock gypsum often found in beds of substantial thickness. Calcination at about 165°C drives off about 75% of the water, leaving a white powder, hemi-hydrate or Plaster of Paris. If water is added to Plaster of Paris it hydrates back to the original mineral, setting hard in a very short time.

This quick-setting property of Plaster of Paris makes it very useful for a variety of building purposes, but it is soluble in water, which makes it unsuitable for external use except in arid climates and where well protected. For this reason its use in most industrialised countries today is limited to internal plasters and plasterboard, though in some countries it is used for blockmaking.

Because of the low temperature required in calcination, the processing techniques for producing hemi-hydrate are very simple. Calcination takes place in some form of pan, kettle or kiln. Also, the process has an energy requirement less than one fifth that for producing Portland cement. Details of manufacturing techniques are available from UNIDO[45]. A survey of the global resources of gypsum and anhydrite and its uses has been published by the Institute of Geological Sciences.[46]

A Gypsum block manufacturing project in the Cape Verde Islands has recently been described.[59]

4.3 Other cements and cement-making processes in development

In the Schifferle process,[47] a cement is made by the intergrinding of lime with siliceous materials to a considerably greater fineness than that achieved in Portland cement production (over 9,000 cm^2/gm as against 2,500 cm^2/gm). A variety of materials may be suitable, among them volcanic ash, rice husk ash, kaolinitic and montmorillonitic clay. Strengths at 28-days comparable with that achieved by Portland cement are claimed.

One advantage of the process, is that no heat is used other than that used in manufacture of the lime. On the other hand considerable grinding energy is needed. The process is said to be suitable for use on a very small scale.

Magnesium oxychloride or 'sorel' cement is made from magnesium carbonate. It is a hard-wearing cement which was once used for floors in hospitals and other public buildings. However, there is only one known occurrence of magnesium carbonate, at Salem, Tamil Nadu in India. Recently work at the CBRI, India has shown that magnesium oxide can be produced from half-burnt dolomite, and this could be used for making sorel cement. The present state of development of this process is not known.

In the recently developed Tetrosem process,[49] the raw materials are reacted together in falling through a plasma generated by a rotating electrical arc. The process offers opportunities for small scale plants in which a wide range of different raw materials could be processed. At the present time the process is under development and precise costs and operating economics are not known.

5. Non technical problems in implementing appropriate technologies

5.1 Small scale cement production

In section 2.7 some of the factors inhibiting the development of small-scale cement plants in India have been discussed. From this experience, the following general conclusions may be drawn:

1. Even when technical problems have been overcome, the establishment of an alternative technology will be difficult if certain types of support continue to be given to manufacturers of the conventional technology.
2. In particular, a national controlled price which does not allow the industry sufficient margin to finance its own expansion makes it difficult for alternative technologies (which must find their own capital) to compete.
3. National control of distribution and a freight equilisation charge also reduce the economic advantage of setting up small-scale plants near their markets, at a distance from the large-scale plants.
4. A single national standard which prevents an adequate but slightly below standard material from being sold and used makes the establishment of any different technology a very high risk.
5. The large-scale manufacturers will want to retain their monopoly on production and will do what they can to resist the proliferation of small-scale units.

None of these factors, it will be noticed, applies only to cement, but to any other widely produced or essential commodity, such as fertiliser, steel or sugar.

Other problems are encountered when it is proposed to replace a product now produced in large-scale modern industry with a village-produced alternative, of rather different properties, for example if cement is replaced by lime-pozzolana mixture. Unfamiliarity of the product will initially make users suspicious of it, and unwilling to take the risk of using it in preference to the well-known and reliable existing product. Confidence will be further reduced by the fact that it is made in the village with less quality control than can be expected in a factory, and not subject to any recognised standard or specification; and because the techniques for using it will be different from those for using cement, any incorrect use leading to failure will have a damaging effect on the reputation of the material.

There will also be considerable production difficulties, at least in the early stages. Each new raw material presents its own production problems which must first be solved. Subsequently an adequate quality will depend on accurate, responsible and methodical work by people who are likely to be unfamiliar with the industrial method of production. Any sub-standard material which finds its way on to the market particularly in the early stages of production when users are unfamiliar with the product, will increase the potential users lack of confidence in the material. Thus in the initial stages, demand is likely to be low. But production economics will suffer if labour productivity is low, and if the expected output from the capital investment is not achieved, and it will initially be difficult to achieve the expected economic performance.

5.2 Problems of rural industrialisation

Further difficulties in the establishment of small rural industries applicable both to small-scale cement production and other cementing materials are:

1. The difficulty of getting sufficiently well-qualified people, who can understand and control the technology used, to work in the rural areas, particularly when there are opportunities for employment in the cities.
2. Lack of detailed surveys of raw materials. National geological surveys have tended to concentrate their activities on locating raw materials for large-scale industry, and to have ignored, or failed to observe, the smaller deposits which would be suitable for establishment of small industries. Thus a special localised survey must be conducted for the establishment of each new small production unit, and this can be expensive and time consuming. In the absence of such survey data, planning at a district or regional level for the establishment of new industries is impossible.
3. Because of all the risks and difficulties mentioned above, it is difficult to find the capital for the establishment of new small industries. Though the capital cost per unit of production is much lower the risk of failure, or of a much lower return on capital than expected, is greater than with an already well-known technology making a product for which there is an established demand.
4. The production costs of alternative materials do not accurately reflect their economic advantages. Capital in developing countries is often cheaper than its economic cost, and labour is often more expensive. The fact that an alternative technology saves capital and uses more labour, though of benefit to the overall economy, is not reflected in the cost of production, and consequently alternative

> technologies are competing with conventional technologies on unequal terms. The structure of market economies is strongly distorted in favour of conventional capital-intensive, labour-saving technologies. A study by Kannan and Spence[50] of alternative technologies for producing mortar materials in Kerala, South India, shows that although the technically comparable lime-pozzolana mortar is greatly to be preferred on economic grounds, the conventional sand-cement mortar will in fact always be chosen because of the high price of labour, and the underpricing of cement.

To counteract these market distortions, as well as to overcome the other obstacles to the establishment of small-scale production of cementitious materials, strong policy instruments, backed where necessary by legislation, are needed.

5.3 Proposed policy measures

The following policy measures are suggested to support the establishment of small-scale cement plants.

1. Capital for those intending to establish plants should be made available on at least as generous terms as that provided for larger-scale manufacturers.
2. In order to create incentive for the establishment of small plants distant from existing factories, there should be no freight equalisation charge or other distortion of the real transportation cost of cement throughout the country.
3. To assist in the introduction of small scale technology and its gradual improvement, a range of standards for cement should be instituted, as in China, rather than the one single standard produced by the ISO, and used almost everywhere else. The standard should permit different grades of cement to be used for different purposes. A national system of quality control to ensure that all cement produced was correctly classified would also be needed. Further studies of how Chinese systems work in practice would be valuable background for such a policy.
4. Since the interests of large-scale cement manufacture conflict with the national interest over this issue, the development of small-scale Portland cement plants should be the responsibility of an institution entirely independent of the large-scale cement manufacturers. Such an institution should have many of the characteristics of the U.P. Planning Research and Action Institute, described by Garg[51]. It will be responsible for the technical work leading to the design of satisfactory plants, and also for the promotional work needed to

establish these plants as commercially successful alternatives to the existing technology. Its responsibilities will therefore include:

Supply of drawings and designs, and financial data.
Technical guidance and supervision during installation of new plants.
Running training programmes for skilled workers.
Preparation of simplified technical literature.
Standardisation of manufacture of plant and machinery and supervision of manufacture of plant.

Organisation of technical seminars and meetings.
Such an institution will be referred to as a "Small Industry Development Organisation" (SIDO). Such organisations already exist in many countries.

The development and promotion of lime-pozzolana or other alternative village-scale technologies for producing cementing materials should also be the responsibility of the SIDO.

5.4 SIDO responsibilities

The responsibilities of the SIDO will be the same as in the case of small-scale cement plants, but because of the unfamiliarity of the new product, there will be additional responsibilities concerned with promoting it to potential users. These will include:

1. Preparation of descriptive leaflets showing correct uses of the material and warning against incorrect uses.
2. Running training courses for potential users.
3. Showing the proper use of the material through demonstration buildings.
4. Preparing national quality control standards (and establishing test facilities to check that these standards are met).
5. The lack of information on raw materials resources for small-scale industry should be rectified by conducting a new survey of potential raw materials resources, initially from existing geological maps and records, and subsequently by field surveys in promising areas. The work of the Tanzanian National Building Research Unit is a good example of how this work can be started.[52]
6. Means must be found to rectify the shortage of technically qualified or trained people, to work in industries in rural areas. No specific recommendation on how to achieve this can be given, but the example of some countries (e.g. Zambia, Tanzania) in requiring two

years of directed compulsory government service after graduation from University or Technical College is worth considering.

7. In order to overcome the prejudice on the part of technically qualified builders and engineers against village-produced cementing materials, the properties and use of these materials should be taught as an essential part of all courses in building and civil engineering. To facilitate this, suitable course material needs to be prepared. The economic benefit to the national economy of using these materials in place of conventional factory-produced ones should be clearly pointed out.

6. Summary and Conclusions

Small scale Portland cement plants

There would be great economic advantage, in certain circumstances, from the production of Portland cement in much smaller plants than are currently used. (Sect. 1.2) Such plants could

1. be located wherever local demand for cement were large enough, and suitable raw materials existed
2. be locally manufactured and assembled, avoiding the need for imports and reducing dependence on foreign firms
3. be erected and brought into production quickly
4. make only a small localised additional burden on the existing infrastructure (power, transportation, etc.)

At present the smallest available plants made by European cement machinery manufacturers are vertical shaft kilns with outputs of 180–200 tonnes/day (Sect. 2.3) Plants of this size could be manufactured partly in local workshops. Much smaller mini-plants of 20–30 tonnes/day capacity are under development in India. (Sect. 2.2) Plants of this size could be manufactured completely independently of European companies, and would reduce capital costs per unit of output. But technical and institutional problems have so far prevented the designs of these plants becoming available for commercial production.

In China more than half of the cement is produced in small-scale plants, typically with a production of about 100 tonnes/day. (Sect. 2.5) Detailed information on the technology used is not available.

Lime-based cementing materials

Much of the production of Portland cement could be replaced by lime and lime-pozzolana mixtures. (Sect. 3.1) Technology for producing these materials is relatively simple, and can be carried out at a very small scale. (Sects 3.4, 3.6) Capital costs for the the equivalent output are very much lower than for Portland cement production and employment potential is considerable. Construction of plants could be entirely local. (Sect. 3.8) A considerable range of raw materials is suitable, many of which are of widespread occurrence. (Sects 3.2, 3.5).

Other cementing materials

Other raw materials, gypsum, impure limestones, and dolomites can be used to make different forms of cements. These processes could, in appropriate circumstances, be cheaper to establish and produce cheaper materials than Portland cement. (Sects 4.1, 4.2, 4.3). Some other processes for small-scale production of cements are under development (Sect. 4.3).

Policy recommendations

A number of recommendations are made concerning the institutional support needed to promote the development of appropriate technologies for the manufacture of cementitious materials (Sect. 5).

Notes and references

1. Information based on two reports on the cement industry in India in *Cement Technology*. "The cement industry in India" Sept/Oct 1974, pp. 428–434, and I.J.S. Bassi, "The Indian cement industry", Nov/Dec 1975, pp. 236–238.
2. H.C. Visvesvaraya "The problems", *Science Today*, January, 1975, pp. 33–35. This entire issue is devoted to the problem of cement production in India.
3. A recent report from a large West German cement manufacturer (unpublished) states that neither fuel nor capital costs have substantially been reduced by the installation of larger units; greater expenditure on servicing personnel and reduced competition among machinery manufacturers are additional factors which in practice weigh against the larger plants.
4. A.L. Pastala, "The compact cement plant", *Cement Technology*, May/June 1978.
5. *Proposal for the Development of small-scale cement production in India*, July 1977, Intermediate Technology Development Group, London and Appropriate Technology Development Association, Lucknow.
6. NATO/CCMS-46, *The Cement Industry*, Technical Information Centre, Energy Research and Development Administration, 1976.
7. M.S. Iyengar, "On an alternative approach", *Science Today*, Jan 1975, pp. 36–39.
8. Cement Research Institute of India. Various reports on the work of CRII on mini-cement plants can be obtained from Dr. J.C. Misra at the Institute, M-10 NDSE 11, New Delhi 110049.
9. UNIDO, *Development of Appropriate Technology for small-scale production of Portland cement in least developed countries and regions*, based on the work of Harold C. Boeck, UNIDO/10D48, September, 1976.
10. A.L. Pastala, ref. 4.
11. Jon Sigurdson, *Small scale cement plants*, IT Publication, 9 King Street, London WC2 8HN, 1977.
12. *Proposal for the Development of small-scale cement production in India, ref. 5.*
13. Kenneth Hudson, *Building Materials*, Longman, London, 1972.
14. See, for example M.S. Iyengar, Ref. 7 and R.J.S. Spence, "Laurie Baker and the Technology of low-cost building", *Appropriate Technology*, Vol. 1 no. 3 Autumn, 1974.
15. In certain circumstances, the lime leaves the kiln as quicklime to be

slaked at site or used for some other purpose. This can save weight in transportation. But quicklime exposed to the air gradually becomes "air-slaked", which makes it useless.

16. Robert S. Boynton, *Chemistry and technology of lime and limestone*, John Wiley, New York, 1966.
17. G.E. Bessey, *Production and use of lime in the developing countries*, Overseas Building Notes, no. 161, Building Research Station, Garston, Watford, WD2 7JR, April 1975.
18. C.I. Ellis, "Small scale lime manufacture in Ghana", in *Lime and alternative cements*, ed. Spence, IT Publications, 1975. See especially the illustration on pp. 127–136.
19. R.J.S. Spence, "Lime and surkhi manufacture in India", *Appropriate Technology*, Vol 1, no. 4, 1974.
20. VITA, "Lime production in Honduras", a case study presented at the *Conference on effective use of appropriate technologies*, April, 1977. Available from VITA, College Campus, Schenectady, New York, 12308, U.S.A.
21. Khadi and Village Industries Commission, *Lime kiln designs*, available from KVIC, Irla Road, Vile Parle West, Bombay 56, India.
22. UNIDO, *The Indonesian prototype lime kiln at Mranggen, Central Java*, Technical Report No. 18. Available with other reports on this small lime kiln project from UNIDO Project Manager, Directorate of Building Research, 84 Jalan Tamansari, Bandung, Indonesia.
23. T.I. Zvare, *Lime*, National Building Research Unit, Box 1964, Dar es Salaam (Mimeograph).
24. J.A. Bain, "Mineralogical assessment of raw materials for burnt clay pozzolanas", in *Lime and Alternative cements* Ref. 18.
25. See Norman Davey, *History of Building Materials*, Phoenix House, 1961.
26. See, for example, P.D. Cady and P.R. Groney, Hydraulic cement from rice husks, *Cement Technology,* November/December, 1976, p.215.
27. For further information write to the Technical Director, Pozzolanic Ltd., Nicholas St. Mews, Chester CH1 2NS, U.K.
28. R.H.S. Robertson, "Alternative cements and their raw materials requirements", in *Lime and alternative cements*, ref. 18.
29. Lyon Associates, Inc. and Building and Road Research Institute, *Laterite and Lateritic Soils of Africa*, BRRI, Kumasi, Ghana, 1971.
30. Details of the LATOREX process can be obtained from F.L.

Smidth, 77 Vigerslev Alle, DK 2500, Valby, Copenhagen, Denmark.

31. Information on blockmaking plant for lime-pozzolana blocks is available from the Director, Directorate of Building Research, 84 Jalan Tamansari, Bandung, Indonesia.
32. Further information on the project can be obtained from the Director General, Small Industry Development Organisation, P.O. Box 2476, Dar es Salaam, Tanzania.
33. Further information on this project may be obtained from: ARCB, B.P. 451 Kigali, Rwanda.
34. The process has been described in more detail in ref. 19.
35. Central Road Research Institute, *Pozzolanic clays of India*, Special Report No.1, CRRI Okhla, New Delhi, Aug 1964. A comprehensive account of a ten-year research programme, including a survey of pozzolanic clays of India, a description of manufacturing process for pozzolana, and methods of using them in buildings.
36. Further information on their fluidised bed kiln for manufacturing clay pozzolana may be obtained from the National Buildings Organisation, Nirman Bhawan, New Delhi — 11.
37. From descriptive pamphlets on LYMPO issued by Khadi and Village Industries Commission, address as ref. 21.
38. Indian Standards Institution, *Burnt clay pozzolana*, ISI344-1968.
39. Indian Standards Institution, *Lime-pozzolana mixture*, IS4098 -1967.
40. Further details on ASHMOH may be obtained from Dr. P.C. Kapur, Department of Metallurgical Engineering, Indian Institute of Technology, Kanpur, U.P. 208016, India.
41. *New Scientist*, 22 July, 1976, p. 178.
42. From APPRO Newsletter, July 1978 published by Action for Food Production, New Delhi. For further details write to Nave Technical Institute, Shahjahanpur.
43. *Public Works Department Handbook*, P.W.D. Bombay (1948 edition).
44. M. Spencer, "An investigation of natural cements", in *Lime and Alternative Cements*, ref. 18.
45. Information on small-scale processing of gypsum is available from UNIDO, Vienna.
46. W.A. Groves, *Gypsum and Anhydrite*, Institute of Geological Sciences, HMSO, P.O. Box 569, London, SE1 9HN 1958.
47. P.K. Mehta, Cement production without heat, *Rock products*, May 1971. Gives results of laboratory tests on processed materials.

The process is described more fully in US Patent 3,066,031. Details from Prof. P.K. Mehta at the University of California, Berkeley.

48. K.P. Kacker, et. al., Evaluation of dolomites for magnesium oxychloride, *Journal of Applied Chemistry*, 1970, Vol. 20, 189–193.
49. Further details of the Tetrosem process, write to Tectronics Ltd., Farringdon, Oxfordshire, U.K.
50. K.P. Kannan and R.J.S. Spence. A social cost approach to choice of technology in building construction, *Economic and Political Weekly*, (Bombay) Vol. 10 No. 48, November 29, 1975.
51. M.K. Garg, "The scaling down of modern technology: crystal sugar manufacturing in India", in *Appropriate Technology, Problems and promises*, ed. N. Jequier, Development Centre of the OECD, 2, rue Andre-Pascal 75775 Paris Cedex 16, France.
52. National Housing and Building Research Unit, *Compilation of raw material occurrences*. A region by region survey of raw materials for building material manufacture including limestones and volcanic tuffs. Further details from NHBRU, P.O. Box 1964, Dar es Salaam, Tanzania.
53. G. Thomas, "Mini-cement plants — a review", *World Cement Technology*, Jan-Feb, 1979.
54. D.J. Cook, et. al., "Rice husk ash-lime-cement mixes for use in masonry units", *Building and Environment*, Vol. 12, p. 281, 1977.
55. Indian Standard Institution, *Code of Practice for manufacturing lime in vertical mixed-feed type kilns*, IS 1861–1961.
56. Indian Standards Institution, *Code of Practice for design and installation of lime kilns*, IS 1849–1967.
57. The report of this workshop, and a regular newsletter giving information on the progress of follow-up programmes, is available from The Regional Centre for Technology Transfer, 49 Palace Road, Bangalore 560 052, India.
58. Beijing Architecture and Engineering Institute, Building Materials Laboratory, *Selection of new standards for materials*, 1980 (In Chinese).
59. Projects de Gesso, Cape Verde Islands, *Gypsan production in Maio Island*, 1979.