OCCASION

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

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

D03094

ID

Distribution LIMITED

ID/WG.20/4
19 July 1968

ORIGINAL: ENGLISH

United Nations Industrial Development Organization

The Workshop on Organizational and Technical Measures for the Development of Building Materials
Moscow, 25 September - 19 October 1968

SMALL-SCALE MANUFACTURE OF PORTLAND CEMENT[1]

by

Jaime Nadal Aixalá

1/ The views and opinions expressed in this paper are those of the author and do not necessarily reflect the views of the secretariat of UNIDO.

id.68-2244

Symbols and abbreviations used in this report

^{o}C = degree Celsius

CL = cost (in US$) per litre of liquid fuel and lubricant (gas oil)

CP = cost (in US$) per ton of coal (6500 kcal/kg)

FO = cost (in US$) per kilogram of fuel oil

GC = grinding of cement

GR = grinding of raws

j = daily wage (in US$) of one man. (Obtained by dividing by 365 the total cost of the services of an unskilled worker for one year.)

kcal = kilocalorie

kg = kilogram

kW = kilowatt

kWh = kilowatt hour

NE = number of employees

t = ton of productive capacity

w = cost (in US$) of 1 kWh

Note: The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country or territory or of its authorities, or concerning the delimitation of its frontiers.

Contents

		Page
CHAPTER ONE	GENERAL REMARKS	5-18
	Cements	5
	The production and consumption of cements	12
CHAPTER TWO	TECHNICAL AND ECONOMIC ASPECTS	19-31
	Initial capital investment in the cement industry	19
	Exploitation costs	27
CHAPTER THREE	PORTLAND CEMENT MANUFACTURE	32-52
	Manufacturing processes	32
	Descriptions of production processes	36
	Choice of manufacturing system	47
CHAPTER FOUR	RAW MATERIALS AND THEIR EXPLOITATION	53-64
CHAPTER FIVE	PRODUCTION EQUIPMENT	65-91
	Equipment for the preparation of the raw materials	65
	Drying and grinding of raw materials	71
	Homogenisation	78
	Calcining	80
	Packing and shipment	86
	Preparation of fuels and additives	88
CHAPTER SIX	INSTALLING CEMENT PLANTS IN DEVELOPING COUNTRIES	92-109
	General	92
	Plant with a cement output of 20 tons/day	93
	Plant with a cement output of 50 tons/day	97
	Plant with a cement output of 100 tons/day	100
CHAPTER SEVEN	SUMMARY AND CONCLUSIONS	110-111
ANNEX	Comparative Cost Data on Portland Cement Manufacture in Plants of 20, 50 and 100 Tons/Day Output	

Figures

		Page
I.	Cement production capacity in Spain in 1950	17
II.	Cement production capacity in Spain in 1966	17
III.	Schematic diagram of the processes used for the grinding and homogenization of raw materials for Portland cement at the pilot plant of the Instituto Eduardo Torroja in Madrid	38
IV.	Kiln and feed arrangements of a rotary-kiln pilot plant	41
V.	Schematic diagram of a cement plant using a belt kiln	43
VI.	Schematic diagram of a tunnel kiln	45
VII.	Schematic diagram of a vertical-kiln cement plant of 20 tons/day capacity	49
VIII.	Schematic diagram of a vertical-kiln cement plant of 50 tons/day capacity	50

CHAPTER ONE

GENERAL REMARKS

Cements

1. In the construction and ceramic industries the term "cement"[a/] is applied to materials which, when mixed with water, constitute pastes that solidify and harden into a stonelike substance. They are either aerial or hydraulic, as defined below.

2. Cements are used in the four following ways: (a) alone, as pure pastes that serve to mould parts, to join ceramic parts or other construction elements, or as media to bind granulated materials to produce conglomerates; (b) mixed with sand, to produce mortars; (c) mixed with sand, gravel and perhaps other materials to make concrete and (d) as additives to soils to stabilize them.

3. Pastes made by mixing aerial cements with water harden in contact with air, but do not harden under water. The most important aerial cements are gypsum and lime.

4. Pastes obtained from hydraulic cements set and harden under water as well as in contact with the air. The most important hydraulic cements are hydraulic limes or natural cements, portland cements and cements derived from Portland cement.

Gypsum

5. Gypsum is a powdered material of white or whitish colour that is obtained by treating the so-called gypsum stone (essentially dehydrated calcium sulphate) The treatment consists in heating the raw material at a low temperature (about 110-120°C) to obtain the hemihydrate. The material is then ground into a powder suitable for use. Where gypsum stone is abundant the manufacture of this material is simple and inexpensive and can be done by artisan methods, almost without initial capital outlay. Firewood is an appropriate fuel.

6. Gypsum paste normally hardens within a few minutes, but the hardened material is stronger when drying is slow. Gypsum cement is sensitive to humidity, especially if the humidity is maintained over long periods. Gypsum cement loses part of its strength when wetted but regains it on drying again.

---

a/ Cement is used in the present report in the sense of the Spanish term <u>conglomerante</u>.

7. In dry climates, such as that of south-eastern Spain, gypsum has been used from time immemorial to build external walls of dwellings and even as a flooring material. In very dry climates, such as those of the Sahara and the sub-Saharan zones, this material could well serve even as a roofing material.

8. In many countries, notably in Spain, gypsum is still the ideal material for indoor partitions. It is also very useful for the interior facing of rooms (floors and ceilings as well as walls), to the extent that gypsum is known as "the material of comfort" in such places. Furthermore, gypsum has important fire-retarding properties.

9. Ceramic units bonded with gypsum mortar may be used not only to build indoor partitions but also form the basis of a technique for the construction of vaults and arches and by which roofs, flooring structures and staircases can be built. This method is very rapid and inexpensive, even when the labour cost is relatively high. Industries can be developed for the manufacture from gypsum of prefabricated elements for housing construction. Some of these industries are considerably developed.

<u>Lime</u>

10. The earliest use of lime in building has been lost in prehistory. It was used in many of the most outstanding architectural and engineering works up to last century, and it is very widely used even today.

11. Hydrated lime is commonly obtained by the treatment of limestone (essentially calcium carbonate). The treatment consists in calcining the stone at a moderate heat (over 900°C) to obtain calcium oxide, which is later slaked with water, producing calcium hydroxide, the form in which it is used.

12. Where there is limestone, manufacture of this material is easy and inexpensive and can be done by artisan methods, with very low initial capital investment. Firewood can be used as the fuel.

13. The hardening of a lime and water paste is due primarily to a carbonation process resulting from the action of the carbon dioxide in the air. This process is normally very slow, but it can be speeded considerably. Once it has hardened, lime is practically unaffected by humidity.

14. Lime can be used to produce load-bearing mortars and concretes. If material such as pozzolana is added to lime a hydraulic cement is obtained: that is, one that can harden under water.

15. With lime, industries can be developed to produce building blocks that are of high strength (silico-calcarous), of low specific weight and high insulating capacity (porous materials). In some places such industries have attained high development, and their influence in building is very considerable.

16. Limestone is rarely pure calcium carbonate; it usually also contains other compounds such as alumina and ferric oxide. The nature of such impurities has much influence on the properties of the calcined material. Consequently the treatment of the raw limestone and the clacination temperature should be adapted to its chemical composition so that products with the required properties will be obtained.

17. Impurities present in the raw stone may result in limes that harden relatively quickly and that have considerable strength. When the composition of the limestone is suitable and it is calcined at the proper temperature, a lime is obtained that cannot be slaked. This material can be ground to produce true cements with great usefulness in building. These are called "natural cements" and are of three kinds: quick-hardening cements, slow-hardening cements, and cements resistant to sea-water.

18. Natural cements are obtained by powdering calcined marls, with or without later additions, depending on the circumstances. In general, calcining is done at temperatures higher than are required for lime but considerably lower than those needed to produce Portland cement. This makes it possible to utilize relatively simple kilns and poor-quality fuels for their production.

19. The calcined material is relatively soft, and the fineness (mesh) required for a good natural cement is less than that for Portland cement. This means that grinding mills can be inexpensive and grinding costs may be kept low. Indeed, natural cements can be produced at competitive prices in installations whose initial cost is very low, provided that labour is plentiful and cheap.

20. A natural cement plant can be economically feasible even if its production is under twenty tons daily. Cements of this kind have long been widely used in Spain, and much is known there about their production.

21. Natural cements that are resistant to sea-water and are therefore suitable for maritime work and other uses where the water is salty, are obtained by calcining certain marls without any additives. Quick-setting natural cements are usually ground with certain additives that amount to not more than 5 per cent

of the total mix. These cements begin to set a few minutes after the mix water is added; the setting is complete 30 minutes later.

22. The compressive strength of mortars made with these cements[a/] is of the order of 13 kg/cm^2 after 7 days and about 20 kg/cm^2 after 28 days. These mortars are only used in bricklaying.

23. Slow-setting natural cements are manufactured in much the same way as quick-setting cements. They begin to set within 30 to 35 minutes after being mixed with water, and setting is complete after 12 hours. Their tensile strength is about 15 kg/cm^2 and reaches 23 kg/cm^2 after 28 days, at which time their compressive strength is about 80 kg/cm^2.[a/] These cements are excellent for use in bricklaying.

24. Although it is difficult to say when Portland cement made its appearance in construction work, its discovery is often attributed to Joseph Aspdin of Leeds, who was granted his first patent in England in 1824.

25. By calcining a finely ground and carefully blended mixture of limestone and clay materials at about 1450°C, a hard material technically referred to as "clinker" is obtained. A hydraulic cement known as Portland cement is produced by grinding this clinker.

26. With this cement mortars and concretes are obtained that, a few days after mixing with water, attain strengths much higher than those obtained with lime. In consequence, Portland cement rapidly attained widespread use. The increasing demand for the new cement stimulated the development of its industrialized production and its commercial use, so that it soon became easier and often less expensive to buy cement than lime, which was thereby progressively displaced from many of its traditional uses.

27. At present, the use of Portland cement has become highly developed in specific uses in which it has no substitute, such as in reinforced and prestressed concrete. It is also widely used where its properties are not fully exploited and has displaced lime, gypsum and natural cements for commercial rather than for technical reasons.

---

a/ RILEM (Cembureau) test method (The European Cement Association, 2, rue St-Charles, Paris 15e, France).

28. Present-day Portland cement is a hydraulic cement obtained from powdered clinker with no additive other than a setting-time regulator. Until recently this regulator was natural gypsum stone, which was added in proportions related to the composition of the clinker, but which generally compose around 4 per cent of the mix.

29. Depending on the composition of the raw materials, on the manufacturing process and on the degree of fineness, cements are obtained whose strength is of the order of 250 kg/cm^2 or higher.[a] High-strength cements, that is, those with strengths greater than 350 kg/cm^2, are excellent for particular uses, such as pre-stressed concrete and some reinforced concrete work.

30. However, to make the best use of the properties of these high-quality cements it is necessary to adopt certain precautions as to storage, date of use and conditions under which setting and hardening (curing) take place and of the products that are made with it. Also, concrete made with high-strength cements must be carefully proportioned, adequately mixed and placed at the site, with due care to its proper compaction etc. being taken.

31. These cements are not very suitable for certain uses in bricklaying, since mortars made only of clean sand and cement are not very plastic and have low capacity to retain water. Both mortars and concrete that are very rich in high-quality cement often undergo dimensional changes. To reduce these it is necessary to adopt a technique that is not always practicable at small- and medium-sized working sites.

32. To correct these effects and sometimes to improve certain properties of pure cement, it is possible to obtain, from clinker, other kinds of Portland cement known generically as "addition Portland". We refer in particular to the three following: (a) commercial Portland, (b) blast-furnace Portland and (c) pozzolanic Portland.

33. In some cases the term "commercial Portland cements" can be applied to those that contain, in addition to the primary ingredients of Portland cement (clinker and gypsum stone), certain additives, in a proportion no higher than 10 per cent, that improve some of the qualities of the cements, mortars or concretes made with them. Functionally, these cements, whose strength is always higher than 250 kg/cm^2,[a]

---

a/ After 28 days, compression tested by the RILEM (Cembureau) method.

are suitable for most reinforced-concrete work. From the manufacturing standpoint, these additional Portlands permit an increase in plant output and a reduction in production cost.

34. Blast-furnace Portland cements are prepared with very thoroughly mixed ingredients, consisting essentially of basic granulated slag obtained from blast-furnace processes, clinker and calcium sulphate. The proportion of slag used varies greatly, according to the composition of the clinker and the desired characteristics of the cement that is sought. For example, it can be stated that 30 per cent slag is an ordinary proportion, and that in certain cases it can be doubled, so that the resulting cement will still have a strength of not less than 350 kg/cm^2.[a]

35. Blast-furnace Portland cements are useful for large-scale concrete work including large-volume jobs: reinforced concrete work, especially if low hydration heat is needed; maritime works; pre-cast units; paving and soil stabilization for it. The use of these cements is not advisable when the ambient temperature is below 5°C and when the external aspect of the work is important, since they may stain and change colour.

36. Pozzolanic Portland cements are hydraulic cements obtained from grinding a thorough mixture of pozzolana and Portland cement clinker, with the possible addition of a setting regulator. These cements, whose strength is also of the order of 300 kg/cm^2,[a] are useful for certain facing and jointing mortars, work in which low heat-development is needed, and cases where there is a risk that the aggregate may react with the cement alkalis. They are particularly suitable for maritime work.

37. Diverging further from strictly Portland cement, but still using Portland clinker as the raw material, it is possible to make other types of cement that are of great use in specific work. Notable among these are supersulphated cements and mixed cements.

38. Supersulphated cements are hydraulic cements obtained from the close mixture of granulated slag and calcium sulphate in such a ratio that the product contains 5 - 12 per cent sulphur trioxide, with additions of lime, Portland clinker or Portland cement in amounts of no more than 5 per cent. These cements have low

---

a/ After 28 days, compression tested by RILEM (Cembureau) method.

compressive strengths but never below 250 kg/cm^2.[a] They are useful for mass concrete work and certain reinforced concrete structures that must withstand high pressures and aggressive agents for hydraulic work, and for underground and maritime work. They are unsuitable for dry environments or when slow setting may be undesirable or in climates with temperatures below 5°C.

39. Most of the cements thus far mentioned are really mixed cements, and many of them are especially useful for brickwork. However, the term "mixed cements" can be reserved for those designed and manufactured especially for use in bricklaying. In all such cements, Portland clinker is mixed with other ingredients to produce plasticity, adhesiveness, water-retention and other desired characteristics. This involves a loss of mechanical strength and, in some cases, of quickness in setting.

40. The plastifiers normally added to the clinker are over-calcined natural cements, clay and lime. The compressive strength[a] of such mixed cements varies considerably; there are standardized types with strengths of about 35 kg/cm^2, others of 60 kg/cm^2. It was noted above that, with natural cements, a compressive strength of 80 kg/cm^2 can be attained easily.

41. It is often possible to produce good brickwork mortar of more than 150 kg/cm^2 compressive strength by grinding together Portland clinker and inert materials, with or without over-calcined natural cements. Lime may be used instead of slow-setting natural cement. The inert materials can be either any matter that is insoluble in concentrated hydrochloric acid and treated subsequently with sodium carbonate (5 per cent solution) or calcareous magnesian or dolomitic marls. It is not advisable to include the following materials in cements for brickwork mortars: high-alumina, natural quick-setting, blast-furnace or supersulphated cements, or any material that may affect unfavourably the setting process, hardening, volume stability or durability of the cement or of the mortars that are made from it.

42. The purpose of these introductory remarks is not to review exhaustively all cements that are used in construction but merely to provide some information on the more common cements that have some relationship to Portland cement. High-alumina cements, whose manufacture is very similar to that of Portland cement, but whose uses are very specific have been omitted, as well has any consideration of special facing cements, whose main features are their bonding and deformation capacity, since their compositions are very specific and varied.

---

a/ RILEM (Cembureau) test method.

The production and consumption of cements

43. Cements are used to stabilize soils, as bases of road paving, to make such paving, to build bridges, dams, canals, power stations and the like. They are used to make harbours usable, to canalize rivers and to build healthy, durable and comfortable dwellings. However, cement is only one of many usable materials. Many centuries before the first cement factory was built, structures were erected whose beauty and solidity still amaze us.

44. Certain materials and techniques which appeared and were developed at various historical epochs and which fully met the requirements of those times have been abandoned; unfortunately so in some instances. Present conditions in some developing countries are very similar to those of societies which, in earlier times, used these materials to create such techniques. It would thus seem appropriate to use these materials and methods, especially if they have been improved, in places where the social and economic conditions, including the labour supply, are suitable. Such conditions are quite different from those needed for the development of large-scale modern industry. It is thus clear that gypsum, lime and the natural cements can be very useful in solving simply and economically some of the problems of certain developing nations. This is especially true since the production and use of these materials can benefit considerably from the advances that science, technology and industry have placed at the service of manufacturers and builders.

45. An example is Spain, where the annual consumption of cement per person is more than 430 kg, and where 647,000 tons of natural cement as well as 78,000 tons of hydraulic lime and 2,000,000 tons of gypsum are produced each year. In many cases, these materials make it possible to solve construction problems of such importance as rural housing, facing of water conduits, construction of small dams, diversion of irrigation water and soil stabilization in road-building.

46. The production and utilization of these materials have the advantage of absorbing much manual labour at the times of the year when agriculture does not need it. The necessary installations are small and can be adapted to limited market needs and declines in demand.

47. In more developed countries, Portland cement tends to displace other binding materials. This phenomenon should, however, be analysed in terms of the conditions in these countries; conditions that are not always present in developing countries.

On the contrary, for example, in some developing regions nomadic peoples may still be found who must be settled and for whom means of livelihood must be found. Distances are large, the means of transport are limited, and the consumer nuclei, both actual and potential, are still very small. Also, in many of these countries, although manual labour is relatively abundant, there is little capital.

48. In many situations, therefore, parallel with the development of Portland cement production, the possibility of producing other cements and of developing techniques for their use should be considered. In such cases, these useful and inexpensive materials can contribute to the solution of existing problems. They can help in the development of a specialized labour force and an indigenous technology that could be the expression of the creative genius of a people.

49. To return to the consideration of Portland cement and its derivatives, we find that there are extensive areas of the world where their consumption is very limited and where this lack is not compensated for by the use of other types of cement. Thus, annual cement consumption per person is 37 kg in Asia, 43 kg in Africa and 90 kg in South America, as compared with 375 kg in Europe.

50. In all developing countries it is found, fortunately, that the use of cement is increasing,[a] but this rise would certainly have been sharper had there not been an unmet demand. An indication of this demand is the volume of imported cement. However, this indicator is not very accurate since, because of the high cost of imported cement and the shortage of foreign exchange, as well as the inaccessibility of some of these markets, the import of cement is severely restricted in many developing countries. Analysis of cement imports shows that inland countries, and particularly those of Central Africa, import far less cement than coastal countries. In interior zones the use of cement is therefore limited almost wholly to the minimum basic requirements.

51. If mean individual income and cement consumption for various countries are compared and both of these values are marked on a system of logarithmic co-ordinate axes, a scattering of points is obtained that may be fitted by a curve whose slope measures the elasticity ratio[b] of demand for cement according to income level. Most developing countries are situated below the curve, which indicates consumptions that are lower than would actually correspond to their income level. This difference

---

a/ In Africa, during the period 1950-1963 it was 5 per cent.

b/ Elasticity is defined as the ratio of the relative change in total demand to relative change in income.

is another barometer that permits estimation of degree of unmet demand in a given country. This estimated unmet demand can serve to determine the necessary volume of imports, but it is an unsatisfactory guide for the calculation of needed production capacity of a future cement industry, since the establishment of such an industry must take a certain time, during which demand would continue to increase.

52. It is possible to estimate potential production in each developing country by examining the close relation that exists between mean individual income and per person consumption of cement. Thus, for instance, on the basis of the study of African populations done by the United Nations,[a] we could obtain some idea of the order of magnitude of the future demand for cement in that region.

53. To this end, and only as examples, let us consider three hypotheses on the increment rate of individual income; namely 2 per cent, 3 per cent and 4 per cent. These rates of increase roughly correspond, respectively, to increases in the total national income of 4.5 per cent, 5.5 per cent and 6.5 per cent if estimated probable increases in population are taken into account. It will be observed that for a mean income increment of 3 per cent in all regions of Africa there would be a total demand for cement in that continent of 18.7 million tons in 1970; this would increase to 26 million tons in 1975.

54. However, different regions will develop at different rates. Experience attained over the last few years and plans for future economic development indicate that a rate of increase of 2 per cent can be forecast for Western and Central Africa, one of 3 per cent for East Africa and Southern Africa and one of 4 per cent can be expected for North Africa. This would mean total demands for cement of 18.5 million tons in 1970 and of 26.4 million tons for 1975, which is a very similar demand to that resulting from an expected mean productivity increment of 3 per cent for Africa as a whole. On the basis of the cement output in 1963, there would be deficits of 9 million tons in 1970 and of about 16 million tons in 1975 in Africa alone. In other continents there are regions that are also in the process of development and where increasing deficits in cement output may be anticipated in the next few years.

55. To meet the demand there are but two alternatives: either to increase cement imports or to develop local cement industries. Because of the growing need for

---

a/ Demographic Yearbook 1964 (United Nations publication, Sales No.65, XIII, 1).

cement in developing countries, the first alternative would cause a large drain on currency reserves. Thus, for instance, the 3 million tons of cement imported in 1963 by African countries, at the CIF price of US 25 per ton, meant a currency outlay of about US 75 million. By 1975 this outlay might have to be increased fivefold.

56. The principal contribution of the cement industry to the economies of the developing nations would be to aid development with a capital input lower than the cost of imported cement, thus permitting a saving in foreign currency.

57. From the social standpoint the establishment of domestic cement industries would help to settle any nomadic populations and to provide employment for the population, in addition to stimulating the building industry. From the educational standpoint, a local cement industry would favour the training of skilled labour and technicians. Also, the resulting concentration of families would facilitate the education of their children.

58. However, there are factors that may impede the establishment of a domestic cement industry. Some important ones are the following: (a) wide separation of the zones where there is a significant demand (b) limited consumption capacity of each of these zones (c) considerable distances between the consumption zones and sometimes from the districts where raw materials, fuel and electricity are available for production (d) limited transport facilities (road, railways etc.) (e) limited raw materials deposits and (f) limited availability or complete lack of capital.

59. The dispersal of the consumption zones and the distances which often separate them makes it difficult to supply several of them from the same plant; this therefore implies, provisionally at least, a dispersal of plants. The limited consumption of each zone makes it essential to consider plants of relatively low capacity but which are so planned as to facilitate increases in their capacities by successive steps when demand justifies it.

60. When great distances separate various consumption zones it is advisable to plan cement plants primarily for local consumption, with a marginal production to supply relatively distant zones when these zones are without their own local supplies. The distance between the cement plant and existing sources of electrical energy may make it necessary to establish a local power plant.

61. Inadequacy of the transportation network may require the distribution of cement plants in such a way that the cement produced by a given plant will not be much more costly in the more remote parts of the region supplied by it.

62. Raw materials deposits, because of their quality and location, may require the adoption of manufacturing methods that might not be the most economical and profitable, for the estimated output.

63. When capital is lacking, the extent to which cement plants should be mechanized should be considered very carefully. It will usually be found advantageous to set them up with minimum mechanization, making maximum use of manual labour. Of course, the closeness with which such a course can be followed will depend not only on economic considerations but on the political requirements of the country in question. The experience of Spain in this connexion is illustrative.

64. In 1950 (figure I) cement production in Spain was barely 2,932,000 tons, of which a very appreciable proportion came from small plants, almost entirely without mechanization. More than 45 per cent of these plants produced no more than 200,000 tons, and even these had productivities of the order of only 250 tons per man per year. At that time the annual output of hydraulic lime was about 400,000 tons, which is a relatively high proportion of the total cement production.

65. The increasing industrial development of Spain has influenced its cement industry, and well defined tendencies have resulted:

(a) Low-output plants with well defined local markets continue to operate at their earlier capacity, and they continue to be useful in the development of their local marketing zones.

(b) Low-output plants without very local and specific markets have had either to close down or to extend and modernize their installations.

(c) Medium-output plants (which in 1950 were regarded as having large outputs) have been enlarged and mechanized.

(d) Newly established plants have greater outputs than the older ones. Their levels of mechanization vary widely but in general are fairly high. Automation is still to come in Spain.

66. When this report was in preparation (1966) the number of cement plants in Spain had almost doubled (figure II). Plants with yearly outputs of no more than 60,000 tons were only 17.9 per cent of the total and tended definitely to decline still further. On the other hand, plants with yearly outputs of 200,000 tons or more constituted 55.8 per cent of the number of plants. In large plants productivity was of the order of 2,000 tons per man per year. In spite of the influence

Figure I

Cement production capacity in Spain in 1950

Annual production in plants with capacities of:	1000 tons	Per cent
Less than 50,000 tons	385	13.5
50,000 to 100,000 tons	821.4	27
100,000 to 200,000 tons	1,306.4	45
More than 200,000 tons	419.25	14.5

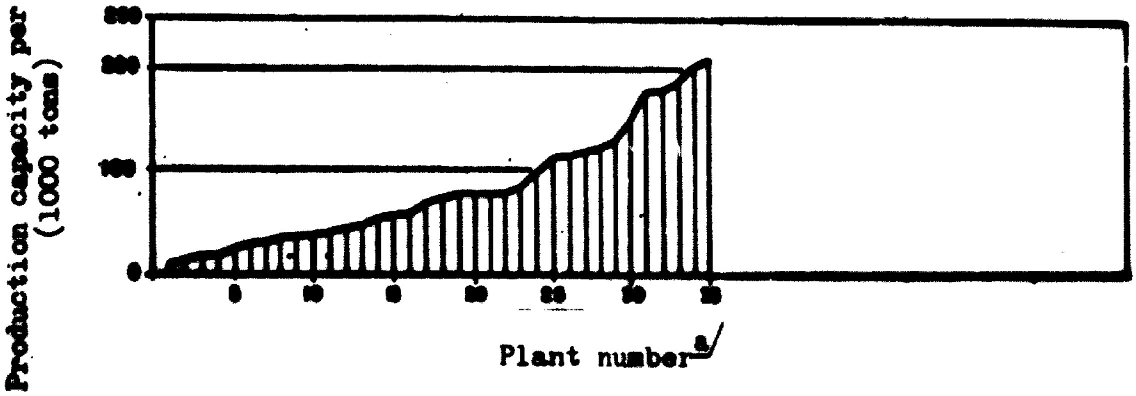
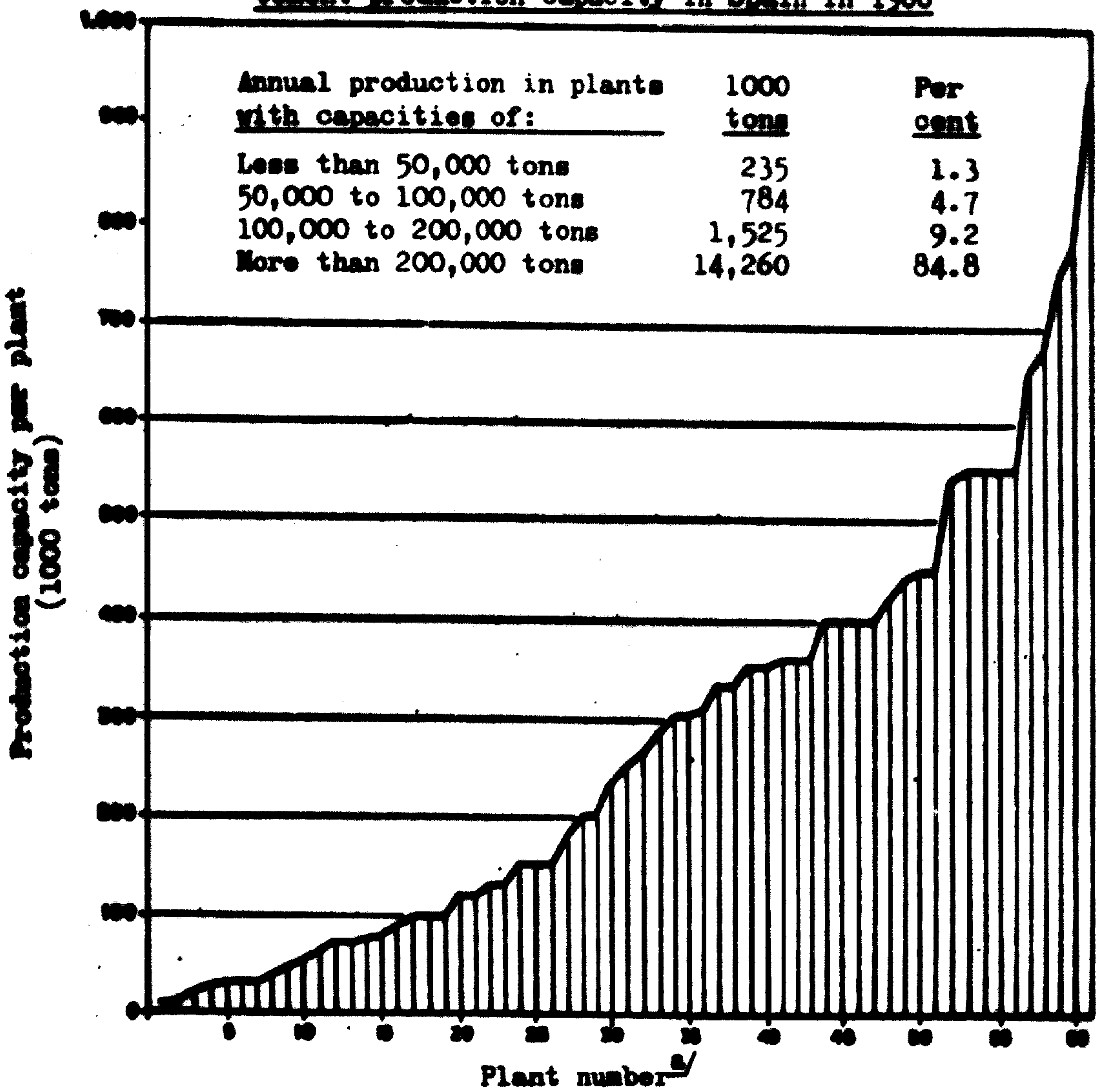


Figure II

Cement production capacity in Spain in 1966



Annual production in plants with capacities of:	1000 tons	Per cent
Less than 50,000 tons	235	1.3
50,000 to 100,000 tons	784	4.7
100,000 to 200,000 tons	1,525	9.2
More than 200,000 tons	14,260	84.8

a/ Each vertical line represents a specific plant still exerted by small plants, the mean productivity in the cement industry of Spain as a whole is about 1,000 tons per man per year.

67. The course of development of the Spanish cement industry is thus a very real and eloquent example that can serve as an indication of what might happen in other regions where conditions are to some extent similar. It thus seems that in countries whose development is now beginning to accelerate, the first step would be to establish a number of plants of small output, connected to specific development zones ("first-generation" plants). The following guiding factors should be considered in the development of these early plants:

(a) Production capacity should be adequate to meet the present markets and demand that may arise in the near future.

(b) Plants should be designed so as to facilitate increase in output and in degree of mechanization.

(c) The greatest use of manual labour should be made that is compatible with competitive conditions in the marketing zone.

(d) Set up these plants with the minimum initial capital investment that implied currency outlay, even if this involves higher civil engineering costs. These can be met primarily with local manual labour and materials.

(e) Make the installed power supply as small as possible.

(f) Make the greatest possible use of local raw materials and fuels.

(g) Avoid the use of delicate mechanisms that require careful handling and involve high maintenance costs.

(h) Use the plants as technical training centres.

68. A second step would be the enlargement and modernisation of these first-generation plants, so that production can be supplemented with "second-generation" plants with wider marketing areas. These plants would have a regional rather than a local character. Where there are already concentrated zones with sufficient demand for cement to justify production at a relatively high yearly output, it might be justifiable to establish some second-generation plants initially, but these should be planned so that they can be readily transformed into even more highly mechanised installations.

CHAPTER TWO

TECHNICAL AND ECONOMIC ASPECTS

Initial capital investment in the cement industry

69. The experience of industrialized countries shows a certain constant magnitude in the elasticity factor between the capacity of a plant and the total invested capital. In medium-capacity plants this factor may be said to be 0.7; that is, to establish a plant with double the capacity of another, the necessary investment is about 70 per cent larger.

70. In developing countries, and specifically in the case of small plants, the above ratio becomes very different for several reasons, among them:

(a) The costs of bringing water, preparing the ground, building approach and service roads, the laying of electrical and other lines and so-forth are practically constant.

(b) The costs of initial research, technical aid, analysis and prior tests for a small plant are practically the same as for a medium-sized one.

(c) The difference in cost between small machinery and medium-sized equipment is, in general, very slight in small-scale production.

(d) The costs of assembly of a small-output plant are not much smaller than those for one of medium-output.

71. In some parts of Africa and in other regions with under-developed communications networks, transportation costs may critically affect the cost of the plant. This can be illustrated by two examples taken from the same part of Africa. In Nigeria, a cement plant of 200,000 ton/year capacity was built in 1960[a], with a unit (ton of output per year) capital investment of the order of US $49. In Niger, another plant of 45,000 ton/year capacity, is being erected, whose unit cost is about US $116. This immense difference is attributable to the high transportation costs at the latter project.

72. It would therefore seem that to estimate provisionally the cost of the initial establishment of a small- or medium-sized plant in a developing country, the following formula could be proposed:

$$C_1 = \alpha (A + B P_a)$$

where:

C_1 = Cost of initial establishment in thousands of US dollars. This includes:

---

a/ The year building was begun.

(a) cost of machinery, (b) transportation of machinery to the plant site, including insurance cost, (c) civil-engineering works at the cement plant and at the quarry, and (d) erection and installation costs and technical assistance.

73. Not included are: (a) customs duties, taxes and other fiscal charges on the machinery, (b) road approaches to the plant and quarry, if either or both are more than two kilometres from the main road or other road that is usable throughout the year, (c) water, electrical power supply and the like if these are not at a reasonable distance from the plant site, (d) interest charges on capital during the construction period and on the initial capital needed to start production, mining or taxes and dues of a local character, or (e) social amenities of any kind, such as housing for workers.

74. α = Possibility factor, which depends upon the conditions under which machinery that has been sent by ship can be unloaded and transported to the plant site. When a port exists that is reasonably well fitted for unloading, and when the plant is not more than 500 km from it and is accessible by road or rail, then $\alpha = 1$. When distances are longer and tracks or adapted roads must be used, the value of α may approach 2.

75. A = Summation factor, which depends on the state of development of the country. If the country is sufficiently industrialized to supply an appreciable part of the plant and technicians experienced in the cement industry, then A = 700. Most usually, in countries that are beginning their industrial development, A = 1500.

76. B = Factor depending on the type of manufacturing process:

for long rotary kilns	B = 32
for short rotary kilns	B = 30
for vertical kilns	B = 23

77. P_a = Annual clinker output in thousands of tons. This figure is obtained by multiplying the daily capacity by 330 working days per year.

78. From the above statements, in those countries whose development is still in the initial phase, the applicable formulae would be:

for long rotary kilns	$C_1 = \alpha (1500 + 32 P_a)$
for short rotary kilns	$C_1 = \alpha (1500 + 30 P_a)$
for vertical kilns	$C_1 = \alpha (1500 + 23 P_a)$

79. In plants that are not far from the sea-coast or are connected to it by road, such as those in Ethiopia, which are within the zone served by the railway from Djibouti to Addis Ababa, or which are on roads linking the capital to the seaports,

a = 1. In the case of Niger and other inland countries, a could take values very close to 2. Consequently, referring only to easily accessible places, the appropriate formulae would be:

for long rotary kiln	$C_1 = 1500 + 32\ P_a$
for short rotary kiln	$C_1 = 1500 + 30\ P_a$
for vertical kiln	$C_1 = 1500 + 23\ P_a$

80. For plants of other production capacities it would be possible to obtain a first approximation of the cost of initial establishment if the above formulae applied, as shown below. These approximations are given in thousands of US dollars.

(a) Plant with yearly output of 65,000 tons, dry process, short kiln, recuperator and cooling grill. High degree of mechanization.

$C_1 = 1500 + 30 \times 65 = 3450$

(b) Plant with yearly output of 100,000 tons, dry process, short kiln, recuperator and cooling grill. High degree of mechanization.

$C_1 = 1500 + 30 \times 100 = 4500$

(c) Plant with 150,000 tons yearly output, similar to the above.

$C_1 = 1500 + 30 \times 150 = 6000$

(d) Plant with yearly output of 40,000 tons, wet process and reasonable degree of mechanization.

$C_1 = 1500 + 32 \times 40 = 2780$

(e) Plant with yearly output of 100,000 tons, wet process, similar to the previous one.

$C_1 = 1500 + 32 \times 100 = 4700$

(f) Plant with yearly output of 25,000 tons, vertical kiln.

$C_1 = 1500 + 23 \times 25 = 2075$

(g) Plant with yearly output of 45,000 tons, with vertical kiln, similar to the previous one.

$C_1 = 1500 + 23 \times 45 = 2535$

(h) Plant with yearly output of 60,000 tons, vertical kiln, similar to the previous one.

$C_1 = 1500 + 23 \times 60 = 2880$

81. As regards the influence due to the principal items that must be taken into account to estimate the investment C_1, the following guidance is offered:

(a) In plants with short rotary kiln with heat-recovery unit: the machinery will constitute about 45 per cent of the total cost; transportation expenses may be somewhat more than 30 per cent of the total cost; and erection costs, start-up

costs and related items can be estimated at 15 - 20 per cent of the total cost.
(b) In long rotary-kiln plants: machinery will represent about 42 per cent of the total cost; transportation expenses are somewhat higher by 11 per cent than in the previous case, for a total of 41 per cent; civil-engineering work should be calculated at more than 35 per cent of total cost, and erection costs, start-up costs and similar items are of the same approximate relative cost as in the previous case.
(c) In vertical-kiln plants, the approximate relative costs of various items are as follows: machinery involves 30 per cent of the total cost; transportation is 10 per cent of total cost; civil-engineering work is 40 per cent of total cost; and erection costs, start-up costs and various other items are 20 per cent of total cost.

82. Outlay of foreign currency is usually a very serious problem in countries without their own heavy industry and no specialized capability in the cement branch. When all machinery and transportation equipment must be imported, the foreign currency investment is of the order of 75 - 80 per cent. However, if the country has an industry capable of providing light machinery and part of the general equipment, such as electrical motors, means of transportation, metal structures, boiler-shop facilities, and electrical installations, the foreign investment can be reduced to about 55 per cent of the total initial establishment cost.

83. Fixed expenses are almost independent of the production output. Before setting up the industrial activity in either large or small plants, it is necessary to carry out a number of prior investigations, among the most important of which are: market research and study of the raw materials. In general, prior market research must be more exhaustive for small plants than for larger ones, but in any case the following aspects must be considered: (a) current and projected consumption capacity, (b) presently unmet demand, (c) present and possible future substitution of imported cement for domestically produced material, (d) location of the consumption zones and (e) distribution of cement and, where applicable, of the semifinished product (clinker).

84. Even zones that are almost entirely devoid of supplies, with primitive economies and very limited consumption nuclei, subject to strictly defined development programmes, require the presence of the site of specialists who should devote

not less than one month to feasibility studies. However, should these experts decide that a plant with very limited output should be established, the cost of such preliminary study will represent a heavy charge on the initial establishment costs.

85. Studies relating to raw materials should be equally complete, whether they apply to a small plant or to a large one and should cover the following aspects:

(a) Location of possible raw materials;

(b) Investigation of the raw materials that are known to exist, with the principal aim of determining whether they have any properties that make them unsuitable for use;

(c) Estimation of approximate volumes of deposits that are considered available for immediate use; and

(d) Provisional technical analyses of each probable deposit, so that the best possible system of cement production can be chosen.

86. The cost of these undertakings will depend upon the accessibility of the regions under study and on whether, sooner or later, suitable mineral deposits are found. In certain regions of developing countries, the cost of hiring helicopters for such exploration can represent a sizeable element of the total cost of the initial investigation phase;[a] similarly, the cost of exploratory borings has great influence in the total cost of these operations.

87. Once the quarries have been investigated and found to be adequate, the work must be completed with a careful analysis of the availability of other requisites such as electrical power, fuels, and other energy sources, manual labour, communications and water. The total cost of this phase may vary considerably. If it does not require any special work, it can be included in the previous studies. On the other hand, it may involve a substantial outlay, if communications are difficult, if electrical power lines are remote and if water must be brought to the surface and conducted to the site from a considerable distance.

88. The plant design requires tests on the granulation, calcining and sometimes grinding of raw materials, on the basis of which the process of manufacture is decided upon and the machinery is designed and its size determined. Generally, the design of the plant is priced as a decreasing percentage of its total cost.

---

a/ From studies performed in the Iberian Peninsula, in the Canary Islands and in some African countries, it appears that the cost of such investigations can be estimated at more than US $50,000.

This may vary from 3 to 4 per cent for large plants to double this figure for small ones. In any case, there is a minimum cost of design, including the tests, which is independent of the plant size.[a]

89. From the above it is clear that independently or almost independently of the manufacturing process and the plant capacity, allowance must be made for prior expenses, whose minimum amount will rarely be less than US $70,000 and it is often greater. In medium-sized plants these expenses are relatively unimportant to the total cost of initial establishment, but this is not the case for small plants such as those considered in this report. To reduce the burden of prior expenses in the total costs of separate small plants, it is suggested that such studies be done for relatively large regions, so that their cost can be distributed among several plants.

90. The civil-engineering work applicable to a cement plant can vary considerably, depending on factors such as the site topography, type of foundations, length of approach roads and the manufacturing process selected. As a first approximation, it can be said that in general the following prior works will be required:

	Approximate cost in thousands of US dollars, per plant of		
	20t[b]	50t	100t
Ground conditioning	10	12	17
Road to quarry	-	-	50
Approach road to plant	20	20	50
Urban planning of plant	8	8	16
Total	38	40	133

a/ This minimum cost of technical assistance is unlikely to be less than about US $12,000.

b/ Tons of daily capacity.

91. The following installations for the receiving, storage and transport of raw material must be provided:

	Approximate cost in thousands of US dollars per plant of		
	20t	50t	100t
Crushing	5	15	50
Clay reception	2	4	8
Raw-materials storage	10	15	30
Gypsum warehouse installations	6	8	16
In-plant transport of materials	2	10	17
Total	25	52	121

92. The preparation of raw materials by the dry process requires a number of buildings to house the machinery. These include:

	Approximate cost in thousands of US dollars per plant of		
	20t	50t	100t
Grinding mill building	20	30	50
Homogenisation building	30	50	85
Homogenisation installations	6	6	8
Total	56	86	143

93. The calcining process calls for suitable installations to house the kilns, granulators, recuperators, and other equipment. In the case of vertical kilns, the civil-engineering work will be approximately as follows:

	Approximate cost in thousands of US dollars per plant of		
	20t	50t	100t
Kiln building	8	10	12
Sieving devices	-	25	25
Clinker storage facilties	8	20	35
Transport of materials	5	10	16
Total	21	65	88

94. The grinding and storage of cement will involve the following works:

	Approximate cost in thousands of US dollars per plant of		
	20t	50t	100t
Grinding-mill building	a/	30	50
Storage silos	30	50	100
Packing and delivery	5	15	32
Total	35	95	182

95. The fuel and water installations will require civil-engineering work that will vary considerably, depending on circumstances, but in general the following requirement can be assumed:

	Approximate cost in thousands of US dollars per plant of		
	20t	50t	100t
Storage and conditioning of fuel	10	15	20
Water softeners and decanters	8	15	25
Galleries and conduits	7	8	10
Total	25	38	55

96. Electrical installations, including high-tension lines entry, transformers and low-tension distribution grid, involve work whose cost may be estimated as follows:

Approximate cost in thousands of US dollars per plant of		
20t	50t	100t
5	15	20

97. In addition, at each plant it will be necessary to set up general stores, stores for spare parts, a workshop, a laboratory, a first-aid room and a building to house dressing-rooms, the workers' mess, offices and similar services. The cost of this auxiliary construction can be estimated as follows:

Approximate cost in thousands of US dollars per plant of		
20t	50t	100t
15	30	70

a/ The 20 ton per day plant will normally have but one grinding mill.

98. Thus the total civil-engineering costs can be estimated at:

	Approximate cost in thousands of US dollars per plant of		
	20t	50t	100t
Initial works	38	40	133
Raw materials	25	52	121
Preparation of raw materials	56	86	143
Calcination	21	65	88
Grinding and delivery of cement	35	95	182
Fuel and water	25	38	55
Electrical installations	5	15	20
Auxiliary construction	15	30	70
Total	220	421	712

Assuming that the whole of the civil-engineering work is amortised in 15 years for plants 20 tons and 50 tons/day output and that it will be amortised in 20 years for plants of 100 tons/day output, the influence of this item on the production cost will be:

20t	50t	100t
US $2.10	US $1.40	US $1.08

99. In plants with vertical kilns, the cost of first establishment can be appreciably reduced, not only due to the lower cost of the machinery, but also because special arrangements can be made. For example, in very small plants the same grinding mill can be used alternatively for the clinker and the raw material. This arrangement, which is presented in detail elsewhere in this report, can make possible important savings. In medium-sized plants, when the raw material makes it feasible, it is possible to use vertical grinding mills to prepare the raw materials. This can also be a source of savings.

Exploitation costs

100. The present trends in all industries, and specifically in the cement industry, are threefold; that is, to rationalize production methods, to mechanize the installations, and to automate the processes.

101. Rationalization of production methods implies programming and systemization of the operations. This can result in an effective reduction of unit cost only if it is applied to specific minimum volumes of production. With smaller volumes, the cost of organization, inspection and management might not only fail to reduce unit cost but could increase it by increasing the overhead expenses. In cement manufacturing, these minimum production volumes are relatively low; they are applicable, at least to a degree, to plants with annual outputs as low as 20,000 tons.

102. Mechanization has two aspects, depending on whether its purpose is to achieve a specific final quality or economize on manual labour. In small plants, these objectives can be met by mechanizing the grinding and homogenizing of the raw materials and the cement. The calcining process must also be included in this aspect to a certain extent. The remaining processes need not be mechanized. Mechanization to reduce the use of manual labour, which is desirable in some of the more developed countries, is a problem of balance between existing labour costs and the initial outlay that is necessary to reduce them.[a] In countries in earlier stages of development, there are social and political factors that have more weight than the strictly economic ones; hence it is not uncommon and may be convenient for a country or an industry to remain slightly behind those more advanced in mechanization.

103. Automation, it may be said, is to the intellectual worker what mechanisation is to the manual worker. If automation is to be meaningful, a high degree of mechanization must precede it. Consequently, in countries in the earlier phases of economic development, this subject should be considered very carefully.

104. The progressive scarcity of manual labour and concurrent increase in its cost cause manufacturers to increase the degree of mechanization in their plants. However, for technical reasons which are considered later in this report, mechanization cannot be successfully applied to installations below a certain size. New plants therefore tend to have increased productive capacities. This tendency is accelerated by the following four factors:

(a) Increasing demand for cement in the marketing zone of the plant;

(b) Improvement in transportation, which makes it possible to extend the market area of the plant;

---

a/ In Spain this amount was of the order of US $20,000 in 1966.

(c) The greater efficiency of large machinery as compared with that of small machinery; and

(d) The fact that the cost of machinery increases less steeply than does its output capacity. For instance, to install a vertical kiln with a 100 ton/day output costs only approximately 1.6 times as much as for a kiln with an output of only 50 tons/day.

105. However, each manufacturing system seems to have a specific size above which the relative saving, as regards initial establishment cost and technical production cost, is less marked. Indeed, certain manufacturing systems are specifically suited to production levels that do not exceed certain limits; beyond these limits there is no economy in increasing the size of installations. In such instances it is preferable to abandon the existing production system and adopt another that is better suited to the new magnitude of output.

106. The technical cost of production will decline as the size of the plant increases, if this increase in production capacity is accompanied by a suitable mechanisation. The following figures are cited only for guidance and refer to a plant fitted with vertical kilns.

	Yearly production capacity (tons)				
	18,000	36,000	65,000	100,000	400,000
Technical production cost as percentage of the corresponding production cost in a plant with 400,000 ton capacity.	210	150	126	116	100

It is evident that the competitiveness of a plant with very low capacity is correspondingly poor.

107. The production factors that affect technical production costs can be demonstrated in the form of percentages that vary with the size of the plant. In general, the influence of manual labour decreases, while the costs of spare parts and maintenance are kept constant, and other factors increase in influence. The following figures are given merely as an indication:

Dry-process plants with short kiln, fed with granulated material

Influence given in percentages, on the technical production cost, for plants, whose daily production in tons (t) is:

	100t	200t	1000t
Raw materials	10.10	13.94	21.75
Manual labour	45.19	31.19	10.60
Fuel	23.02	30.11	36.86
Energy	11.54	14.61	20.72
Spare parts, maintenance and miscellaneous	10.15	10.15	10.07
	100.0	100.0	100.0

Dry-process plants with vertical kiln, fed with granulated material

Influence, given in percentages, on the technical production cost for plants whose daily production in tons (t) is:

	50t	100t	180t	280t	1120t
Raw materials	10.4	14.5	17.0	19.5	22.0
Manual labour	51.0	36.0	26.6	21.6	11.2
Fuel	18.6	26.2	31.4	33.6	39.5
Energy	9.6	13.1	14.9	15.2	17.3
Spare parts, and miscellaneous	10.4	10.2	10.1	10.1	10.1
	100.0	100.0	100.0	100.0	100.0

108. All that has been presented above, and most especially the illustrative numerical data, has practical significance for these countries here wages, electrical energy and fuel have relative values of the same approximate order as in Spain. To facilitate comparisons with conditions in other countries and to make it possible for the reader to have some general idea of the magnitudes of a technical and economic nature that we are discussing, some complementary data are presented.

109. The consumption of various items per ton of cement manufactured, depending on the production capacity of the cement plant, are approximately as given below:

	Daily production of clinker in tons (t)				
	50t	100t	200t	300t	1200t
Tons of raw materials	1.5	1.5	1.5	1.5	1.5
Man-hours	9.28	4.64	2.91	2.17	0.97
Electricity consumption (kWh)[a]	92.0	90.0	85.0	81.0	80.0
Coal consumption (kg)[b]	130.0	130.0	130.0	130.0	130.0

[illegible]. The personnel directly engaged in manufacturing is approximately as follows:

	Daily production of clinker in tons (t)				
	50t	100t	200t	300t	1200t
Engineers	3	3	4	5	6
Auxiliary technicians	3	3	4	4	6
Laboratory staff	5	5	5	5	11
Office staff	2	2	2	3	7
Production operatives	35	35	38	44	77
Workshop operatives	8	8	8	9	24
Service staff	6	6	8	9	12
Quarrymen	4	4	5	6	7
	66	66	74	85	150

Provision also must be made for drivers, transport personnel, security staff and cleaning staff.

---

a/ The consumption of electrical energy will depend upon the degree of mechanization, on the manufacturing process used and on the ease with which the raw material may be ground. In a plant with a daily capacity of 200 tons, using a short rotary kiln, a normal consumption rate of 120 kWh per ton of cement can be attained.

b/ This can vary widely, depending upon the caloric value of the coal. Coal consumption at a rate of 200 kg per ton of cement is not unusual.

CHAPTER THREE

PORTLAND CEMENT MANUFACTURE

Manufacturing processes

111. Rock is the raw material from which Portland cement is made.[a] This material consists basically of calcium oxide, silica, alumina and ferric oxide in proportions that can vary within certain limits. Nature rarely offers deposits whose composition meet the requirements for cement manufacture exactly but it is not infrequent to find rocks with a mineral make-up fairly close to that which has been found to be adequate for this purpose. In such cases, it is possible to burn the stone as it comes from the quarry. Thus a calcined material is obtained which, when suitably ground, is known as cement. When the composition of the rock is inadequate for the manufacture of Portland cement, it is necessary to add other minerals to give the mixture the required composition.

112. In the course of the burning, the raw materials react chemically and form Portland cement components. It is necessary for the calcium oxide, silica, alumina and ferric minerals to be in close contact. In order to attain this close blending the rocks are reduced to very fine powder. This powder, of suitable composition and fineness, is generally referred to as "cement raw materials" or merely as "raws".

113. Cement manufacturing requires the preparation of large quantities of uniform raw materials. However, their composition changes continually according to the local variations in the quarry and in the proportioning methods adopted. Consequently, it is necessary to intermingle the various lots of material prepared in the course of the day, or days, to obtain a uniform mix. This operation is called homogenisation.

114. A simple and economical means of obtaining a good homogenisation is to mix the cement raw materials with water. The wet mixture thus obtained is more manageable than the dry dust; it can be pumped, transferred from one vessel to another and shaken. When homogenisation is done in this manner, manufacture is said to be done by the "wet process".

---

a/ The term "rock" is used here to mean a mixture of various minerals, whether in the form of solid stone, of loose sand, of clusters of shells or of dried mud.

115. Recently, techniques have been developed that make it possible to mix dry powdered materials thoroughly. This is achieved by agitating them with air currents and by transferring the powder from one vessel to another, using suitable pneumatic or mechanical means. When homogenizing is done in this way, manufacture is said to be done by "dry process".

116. The raw material, either as the wet mixture or as the dry powder, is subjected to a thermal treatment whereby it is transformed into clinker. The transformation occurs through the destruction of some of the original rock components and the formation of new ones, which are essentially calcium silicates. The burning process begins by totally desiccating the raw material. In the wet process, considerable amounts of heat energy are consumed in this way.

117. Desiccation is followed by a pre-heating phase during which the raw material attains a temperature of the order of 600°- 700°C. It is during this phase that the destruction of some of the mineralogical structures of the raw material takes place.

118. The third phase involves calcination, which occurs at temperatures between 700° and 1200°C. In a natural cement this would be the last phase. Both in those and in Portland cement, decarbonation of the calcium compounds occurs, as well as a partial combination of these compounds with the acid components of the raw material.

119. Clinkerization is the next and characteristic phase of the making of Portland cement. This takes place between 1200° and 1500°C, and at this stage, part of the calcined mixture fuses into liquid. The chemical reactions are completed in the course of this liquid phase. To aid in the development of this liquid phase, it is very often necessary to add to the raw materials small proportions of roasted pyrites or other ferriferous compounds that act as fusion agents. From this point, the final phase of movement of the material along the kiln involves only a process of cooling.

120. In some burning processes, a sudden cooling phase is added in order to freeze the clinker, keeping its components in a state of maximum usefulness and avoiding regressive chemical steps that would produce other and less desirable components.

121. Industrial burning procedures are normally performed in tube kilns, vertical kilns, or long or short rotary kilns. Some non-conventional methods are also used.

122. Tube kilns are essentially vertical tubes which are generally excavated into the ground or made with bricks. The raw material is calcined in them by burning together alternate layers of raw material and fuel. The process is intermittent. The fuel can be firewood. charcoal or high-grade mineral coal. This type of kiln can be used to produce hydraulic or natural cements.

123. The vertical kiln is derived from the tube kiln and, like it, consists of a vertical tube, made of metal plate and lined with insulating and refractory materials. These kilns are fed automatically: along the top opening briquettes, cylinders, granules or ovoids composed of a mixture of raw materials and fuel are fed in. Nowadays the granules are used most often. The manufacturing process is continuous. The material descends by gravity to the bottom of the kiln, where the clinker is extracted through special gates. Kilns of this kind can produce up to about 250 tons daily. Hard, low-flame coals or coke must be used. Modern kilns have a forced air draft induced by injection, usually at the top part of the kiln. All clinker-formation processes from desiccation to cooling take place, and their thermal efficiency is excellent. While the product obtained is ordinarily of fair quality, it is not easy to produce material of excellent quality with kilns of this type.

124. The use of rotary kilns is characteristic of the wet process, although they are sometimes used in the dry process. These kilns are essentially cylindrical metal shells lined with insulating and refractory materials. The shells are inclined slightly from the horizontal and rotate slowly. The raw material is fed into the higher end and runs down the slope, aided by the rotary motion of the kilns, counter to the current of the combustion gases, which come from a burner at the lower end of the kiln. These kilns are fed automatically, usually in one of the three following ways: (a) with paste, when the wet process is used; (b) with granules, when the semi-dry process is followed, or (c) with powdered raw material in the dry process. In any case, the production process is continuous, and within the kiln all the clinker formation phases take place except the last cooling stage which occurs either within an apparatus situated next to the kiln or within device fitted to the kiln.

125. Rotary kilns can be fired with any of the following: (a) high-flame coal, (b) low-flame coals mixed with liquid or gas fuels, (c) liquid fuels or (d) gas fuels. The thermal efficiency is low in the wet process but is considerably higher in the dry process.

126. In the dry process, short rotary kilns can also be used. A heat-recuperator can be added to dry, pre-heat and partly calcine the raw material before it is fed into the kiln. These devices, through which the raw material passes counter-current to the combustion gases, have a high thermal efficiency and can be fed with raw material in the form of powder, granules or paste. Those for powdered raw material generally consist of a series of cyclone burners; those for granules are mobile grills through which the hot gases pass the layer of raw material moving toward the kiln once or more times. Heat-recuperators for raw materials of the paste type generally use grilled drums that contain mobile metal parts which simultaneously mix and heat the paste. The use of heat-recuperators improves the thermal efficiency of the plants.

127. Non-conventional systems have not yet been greatly developed; most of them are still in the experimental stages. Information available about installations of this type is presently scant and imprecise, but there is nothing to suggest that they have serious limitations as regards their methods of feeding or their thermal efficiency.

128. The ground clinker constitutes the active part of the binding material of the cement. As soon as it is mixed with water, the ground clinker begins to set, and within a few seconds it acquires a monolithic stiffness. To avoid this, a setting regulator is added. The clinker and the regulator, ground together, constitute Portland cement. The regulator that is used almost exclusively is gypsum, which is added to the clinker in a proportion of 4 - 5 per cent.

129. Cement grinding is generally done in ball mills. These are cylindrical units divided longitudinally into two or three chambers and charged with grinding elements such as steel balls or hard, smooth pebbles and rotating about their axes, which are in the horizontal plane. As the unit revolves, the grinding elements are carried to the highest point, whence they fall upon the material beneath. Grinding is affected by friction and collision of the grinding elements and the materials being ground, which are carried by an air current from chamber to chamber, attaining a greater fineness in each successive one.

130. Grinding can be done in either an open or a closed circuit. In the first case, the material passes through the mill only once and is collected at the outlet, together with the "fines" from the dust separators. In the second case, the ground material is screened and over-sized particles are returned to the mill for re-grinding. While the present tendency is to adopt the open-circuit principle,

in plants of small output, such as those discussed here, it may sometimes be advantageous to provide for both systems. It should be possible to feed the mills with three or four proportioners: perhaps one each for clinker and gypsum and one or two for additives when manufacturing cements derived from Portland cement.

131. When the cement leaves the mill it is hot and must be allowed to cool. In the vertical kiln systems the initial storage of the cement, as it comes from the mill, should be in small silos where it is simultaneously homogenized and cooled. With rotary kilns, homogenization is not always necessary, but cooling is still essential. However, when cement is ground in ventilated circuits, the exit temperature of the powder is not high.

132. Once it has been homogenized and cooled, the cement is stored in suitable silos for packing and shipment. Cement is usually delivered in paper bags of about 50 kg weight. In small plants the packing operation is very simple and rarely requires auxiliary equipment. When it is anticipated that the cement must remain packed for a long time or when it is to be shipped to places with humid and hot climates, waterproof bags should be used. Normal bags can be waterproofed by treatment with wax or with synthetic materials. Cement can be shipped unbagged, but this is seldom done from small-capacity plants.

Descriptions of production processes

Preparation of the raw materials

133. The manner in which the raw materials will be prepared depends upon their properties and the way in which they are quarried:

(a) In the case of very hard limestone from a quarry that yields large-sized blocks, a primary crushing is needed to reduce the stone to pieces of about 50 mm diameter. A secondary crushing will follow at the plant.

(b) For hard limestones or marls, excavated in such a way that medium-sized stones are obtained, it will also be necessary to perform a preliminary crushing to reduce them to 20-30 mm size. Secondary crushing is not needed.

(c) Where limestones are excavated from fossilized seashores, an initial sieving should be done to remove sands that are not as rich in carbonates. The sieved material can then go directly to the plant, where secondary crushing will be done.

(d) In general, clays need no prior treatment. Where necessary, they are crushed at the cement plant.

(e) Gypsum is crushed at the plant before being taken to the grinding mill proportioning installation.

134. Depending on the nature of the raw materials, it may or may not be necessary to subject them to a second prior treatment at the plant before they are stored. For limestone, this secondary treatment would be crushing until the stones are below 20 - 30 mm in size. For clays, in cases where the wet process is used, the clay material will be mixed with water and stored as a paste.

Grinding of raw materials and homogenization

135. To facilitate the reactions leading to the formation of clinker during the calcining process, it is necessary to grind the raw materials to a given fineness beforehand. Usually it should yield a residue, by weight, of 10 per cent when passed through an 88 micron sieve (4900 holes/cm^2).

136. When the dry process is used, it may be necessary to dry some or all the materials that make up the raws. The raw material is usually dried at the time of grinding, except when the mean humidity of the whole mass is more than 8 per cent. In such instances the ground materials are dried separately. In either case the heat needed to evaporate the water content may be provided either by gases recovered from the kiln or from an independent oven.

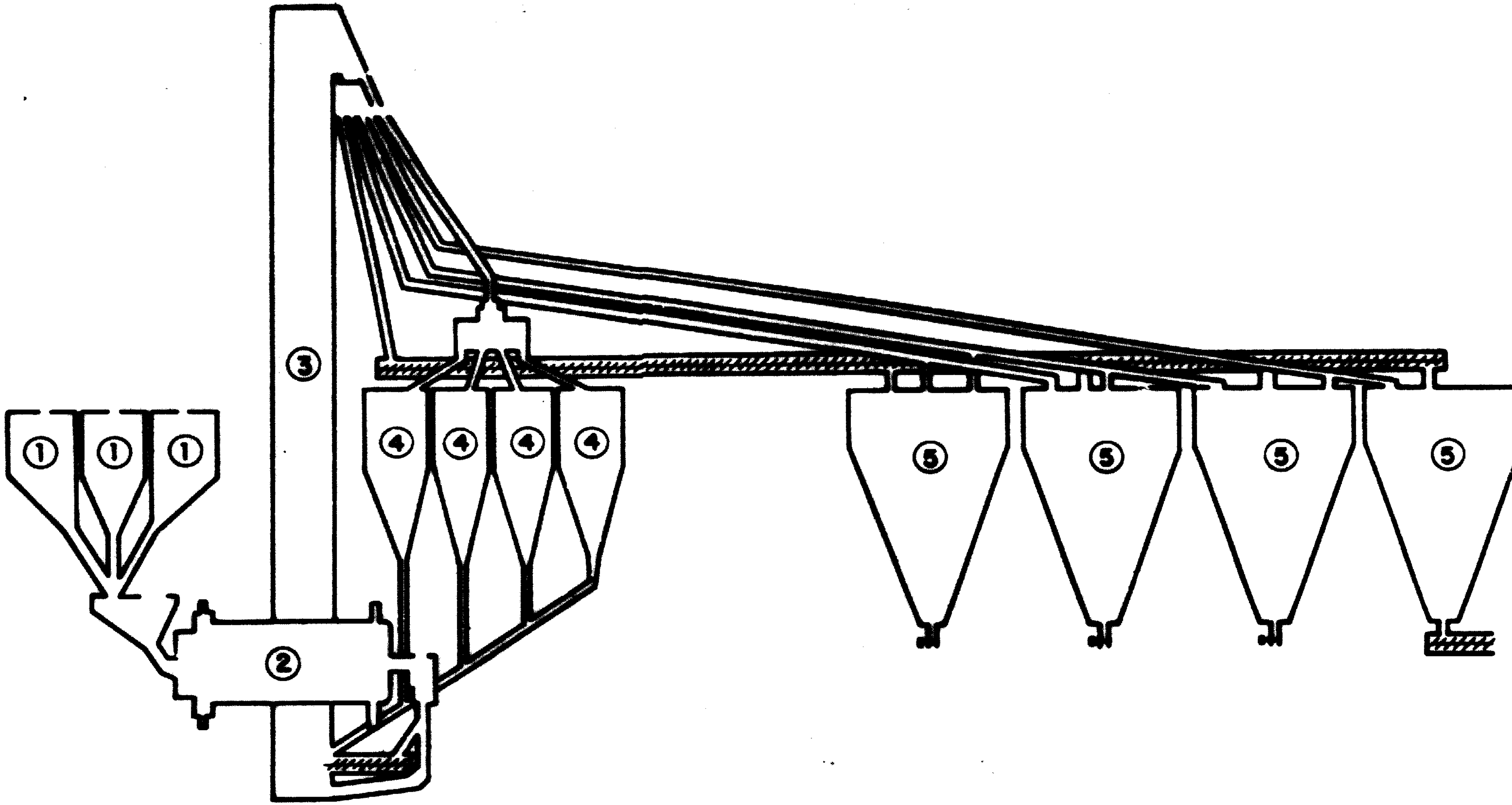
137. When the wet process is used no prior drying is needed. In this case it is usual for water to be added to the raws during grinding. Clays can be added in paste form. Whether the wet or dry process is used in grinding, it is essential that all ingredients - the limestone products, the clays and materials that are added as correctors - be properly proportioned at the entry into the mill.

138. The ground raws are stored in silos on coming out of the mill. In the dry process, the raw material is homogenized by agitation, which may be done with the aid of an air current or by jigging and recirculation in a closed circuit. The homogenized raw material is stored in other silos, from which it is transferred to the kiln feeder. In the wet process, the ground raws, in paste form, are homogenized by air agitation. The homogenized paste is stored in other silos, from which it is fed into the kiln. Figure III shows schematically the grinding and homogenization of raws at the pilot plant installations of the Instituto Eduardo Torroja in Madrid. This installation can operate with either the dry or the wet process.

139. In certain systems of cement production in a vertical kiln, the grinding and homogenizing process is similar to that for the dry process, but coal is ground together with the raw material, to which it remains closely bound in what is termed "black raw material".

Figure III

Schematic diagram of the processes used for the grinding and homogenisation of raw materials for Portland cement at the pilot plant of the Instituto Eduardo Torroja in Madrid[a]



[a] Feeding silos, 1; grinding mill, 2; bucket elevator, 3; homogenisation silos, 4; raw material silos, 5.

Kiln feeding

140. The feeding of kilns varies according to the process and equipment used; for example, wet process, dry process with powder feed, dry process with granule feed, vertical kiln, or tunnel-type kiln. In the wet process the kiln is fed by means of a pump. In the dry process, when the kiln is powder fed, any of several methods of transporting the powdered material may be adopted. The actual feeding is done by a mass proportioner. The blended raw materials are granulated, wetted and then fed into the kiln.

141. In the vertical kiln a prior proportioning of the raw material and the coal takes place to produce black raw material. Both materials then pass to the mixer, where water is added. The material is then passed to a granulator or modulator where more water is added. The resulting granules or nodules fall into the kiln by gravity. However, if the coal and raw material arrive from the grinding mill already mixed correctly, the proportioning referred to here will not be needed. In kilns of the tunnel type, loading is discontinuous and, depending on the individual case, it may follow a procedure similar to that in rotary or vertical kilns, or it can even be done by hand.

Calcining

142. The principal feature of clinker manufacture is the burning or calcining of the raw materials, which is done in the kiln and ancillary installations. The kilns normally used in the cement industry are usually of the vertical type or of the rotary type. Kilns with sinterization grills and other non-conventional methods are also used (fluidified bed etc.). The industrial use of such non-conventional methods is still experimental and is not discussed in this report. For small-scale production, the tunnel kiln is considered, however, although it does not appear to have been used in the cement industry.

143. Vertical kilns are really tube/kilns that are only used with the dry process and for daily clinker outputs of up to 250 tons[a] of clinker. At present these kilns can only burn solid fuels that produce a low flame. In these kilns the drying, calcining and clinkerization all take place in the relatively narrow zones at the top, and the rest of the kiln serves as a cooler of the clinker and pre-heater of the combustion air.

---

a/ In some very exceptional cases this output can be surpassed.

144. The vertical kiln is more economical than the rotary kiln for several reasons: its setting-up cost is far lower;[a] the space required by a vertical kiln is usually only one third of that taken up by a rotary one of the same capacity, and similarly, the ground area occupied by the vertical kiln is only one eighth to one tenth as much as is needed for a rotary kiln; and the technical manufacturing cost is slightly less with the former kiln than with the latter.[b]

145. Furthermore, the vertical kiln has, among others, these advantages:

(a) Its functioning is very adaptable to varying circumstances.

(b) It is possible to stop the operation of the kiln for rather long periods without having to extinguish the fire.

(c) It can use fairly coarsely powdered coal as fuel.

(d) Its consumption of energy of refractory materials is low.

146. There is ample experience with the successful use of these kilns for cement outputs of 50 - 100 tons/day. However, experience with significantly larger outputs, in the range of 200 - 250 tons/day, is still limited, so that their use for plants with such large outputs is inadvisable except in certain very specific cases.

147. There is little industrial experience with the use of vertical kilns in plants with outputs of about 20 tons/day. Nevertheless, an experimental kiln of this capacity could be put into operation within a relatively brief period.[c]

Rotary kilns

148. Rotary kilns can be used with both the wet and dry processes, and they can utilize solid, liquid or gaseous fuels. A schematic diagram of the rotary kiln pilot plant at the Instituto Eduardo Torroja is shown in figure IV. This installation can operate with either process and can use any of the three types of fuel.

149. Long rotary kilns can be adapted to both the wet and dry processes. All phases of calcination take place within them: drying (in the wet process, preheating, decarbonation, clinkerization and partial cooling). The cooling of the clinker is completed in another installation (tube, grill or the like) fitted to the outlet of the kiln.

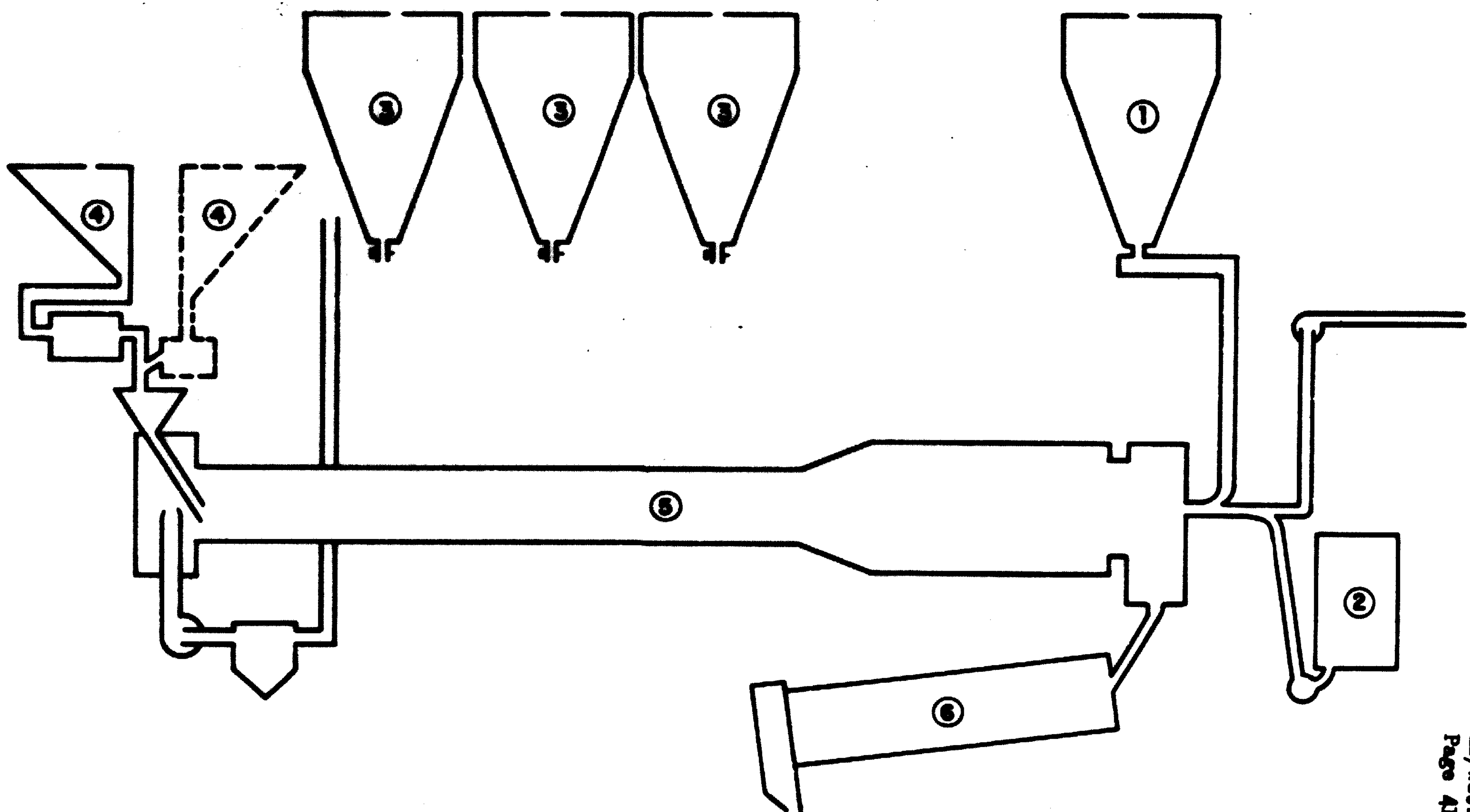
a/ From 60 - 70 per cent of the cost of a rotary kiln

b/ Manual labour, fuel, electricity, refractory materials and spare parts

c/ Except for the kiln, the Instituto Eduardo Torroja has all that would be needed including engineers and auxiliary equipment such as mills, granulators and control equipment.

Figure IV

Kiln and feed arrangements of a rotary-kiln pilot plant [a]



a/ Key: 1, coal storage silo; 2, fuel-oil storage tank; 3, raw materials silos; 4, kiln-feeding silo; 5, kiln; 6, cooler.

150. The short rotary kiln is used only with the dry process and is normally with a recuperator. The phases of operation are the same as those described above for long kilns, and the cooling of the clinker can be completed in a similar manner.

151. Kilns with heat-recuperators can operate in three different ways, according to whether they are fed with powder, granules, or paste. Those that are powder fed are fitted with a system of heat-recuperators at the inlet where the powder to be fed in circulates against the combustion air current, thus heating the raw material. The tube is longer than in the kilns without a recuperator, and calcining and clinkerization take place within it. The process is similar to that just described. When fed with granules, the kilns are fitted with a system of heat-recuperators at the inlet, and they operate in a manner similar to that described for powder feeding, although the design of the heat exchanger is essentially different. When the material is a paste, the use of the heat-recuperators is based on the general principle of making use of the available heat in the gases leaving the kiln. Operation thus consists in exchanging heat between the gases and the raw materials with the aid of moving metal parts such as chains.

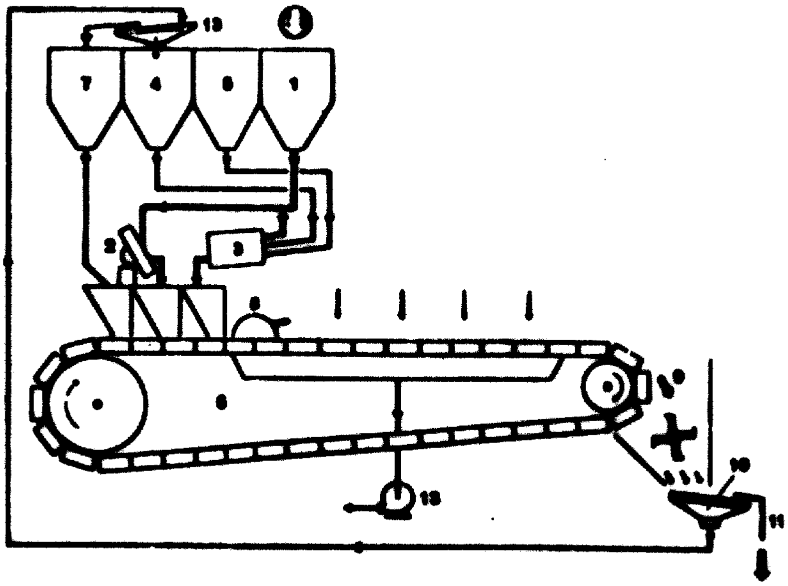
152. At present, the output of rotary kilns, whether long or short, ranges between 200 and 1600 tons/day. However, they can be used for smaller outputs. Indeed, at the beginning of this century, the first rotary kilns that were used industrially had outputs of about 20 tons/day, and very small kilns have been used industrially, with good results. Nevertheless, the high unit cost of calcining in thes small kilns increases the cost of the cement, so their use for outputs below 200 tons/day has almost ceased.

153. The idea of using a mechanical grill for making cement appears to have been originated by Timm (1911). Belt kilns with production capacities of 300 to 500 tons/day have been used that have a thermal consumption of 1050 kcal/kg of clinker The exhaust gases are used for the drying and grinding of the raw materials. Such a plant is diagrammed in figure V. Such kilns with granules composed of raw material to which set proportions of coke and clinker have been added. The additional fuel that is required can be either liquid or gaseous. A layer of clinker protects the grill.

154. The installation for a belt kiln, as compared with those for a rotary kiln seems to be of the same order as regards machinery and about half as great in civil-engineering costs. Despite the need to replace the kiln slabs, maintenance

Figure V

Schematic diagram of a cement plant using a belt kiln (Krupp-Lurgi Sinterband)[a]



[a] Key: 1, raw mix silo; 2, granulating disc for lower layer (raw mix); 3, mixing drum for lower layer mixture (raw mix, return material and fuel; 4, silo for fine return material; 5, fuel silo; 6, belt sintering grate with protective layer of finished clinker; 7, silo for coarse return material; 8, ignition furnace; 9, discharge end, with spiked roll crusher; 10, vibrating screening trough for return material; 13, exhaust pump to draw sinter gases from suction boxes through dust separators and out into the stack.

costs are less than is normal for a rotary kiln. However, information obtained from the manufacturers of this type of kiln is thus far insufficient to permit recommendation of their use.

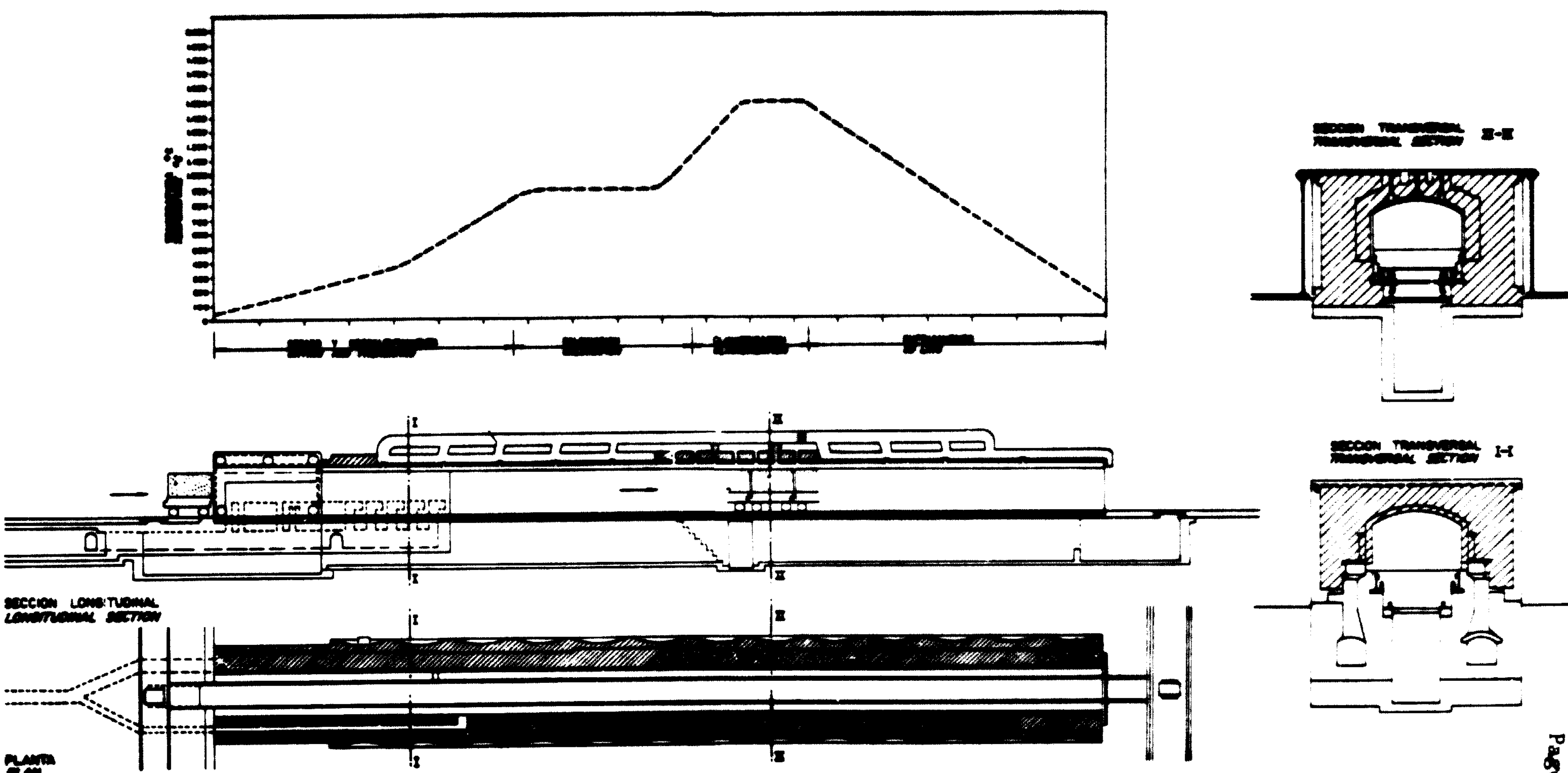
155. The tunnel kiln is a type of installation that has been used successfully in the ceramic industry. The working temperatures can rise to 1600°C, and their thermal efficiency is very high. The capacities of tunnel kilns vary considerably, depending upon their sizes, which cover a wide range, according to the needs of the particular type of industry in which they are used. Some of these kilns are as long as 120 metres.

156. Tunnel kilns can be operated with solid, liquid and gas fuels. The products to be burnt can, if desired, be brought into contact with the combustion gases. The product to be burnt is placed on railway trucks or flat-cars, which move into the kiln at a set speed. The motion of the trucks can vary considerably within the kiln, thus permitting precise and either slow or rapid burnings. The advance of the trucks within the kiln can be continuous or intermittent, as required. Tunnel kilns do not appear to have been utilized to produce Portland cement. However, given existing knowledge and experience in their use to produce ceramics, kilns of this type should be taken into consideration for making cement, especially when small outputs are planned.

157. If a tunnel kiln were to be used, it would have to incorporate drying, preheating, calcination (decarbonation) and clinkerization zones, and finally a cooling section with good thermal recuperation. Such an arrangement might permit cement manufacture within the production magnitudes considered here. Figure VI shows the general arrangement of a tunnel kiln adjusted to burning process corresponding to that of a kiln of the Lepol type. The raws can be fed in the form of granules with or without fuel. If fuel is incorporated, it should probably be less than the total needed. The rest of the fuel (solid, liquid or gas) should be supplied by burners placed on the vault of the oven, in the clinkerization zone. In this way the time required for the carbonation of the raw materials would be less than that taken by the coal in the granules to burn. The coal added to the raws should be of a type similar to that used in vertical kilns (size 0 to 5 mm). The cooling gases may be used partly to burn the fuel and partly to dry and pre-heat the raw material. This could be done by injecting the gases at suitable points in the kiln.

Figure VI

Schematic diagram of a tunnel kiln



158. The cost of a tunnel kiln for small cement output should be low, although lack of experience in their use for cement-making makes it impossible to provide actual figures. A pilot plant investigation would lead to applied research, from which certain details of the performance, such as optimum dimensions, support for the material to be burnt and means of adding the fuel could be established.

Storage of raw materials and clinker

159. A widespread recent tendency is to set up a single general depot for both the raw materials and the semifinished products. This single-depot system consists in establishing a very long warehouse, within which, in logical order, the limestone, clay, gypsum, siliceous sand (when it is necessary), fusion materials, coal and clinker are placed. Materials transport is usually done by means of a travelling bridge crane or the like.

160. In small- and medium-sized plants, however, this system of a single warehouse is not always suitable. It is often better to establish two or more separate storage facilities. These depots are usually for the following materials: (a) materials rich in carbonates, (b) clays, (c) additives (gypsum, fusion additives and the like), (d) fuel, and (e) clinker.

161. (a) Materials rich in calcium carbonate constitute the major portion of the raws used for making cement; that is, about 1.4 tons per ton of clinker. The storage facility should be of large capacity, for it is often advisable to store these materials for two months operation of the plant. These materials should be removed from storage in a continuous manner, at least during two working shifts. It should be designed for cheap and rational operation for the purpose intended without forcing it to meet conditions normal for the storage of other materials.

(b) Clays make up about 0.25 ton per ton of clinker. The storage facility for this material can be small and cheap, and there will be little problem in removing the clay, but the installation should be so designed that easy and efficient prehomogenization can be carried out.

(c) The additives should be placed very close to the site where they are to be used, that is, close to the feeding system of the grinding mill. This will avoid transportation problems. The volume of these additives is usually very small; of the order of 5 per cent of all the materials.

(d) Solid fuel can be stored in the open to a large extent, if need be, especially in dry climates.

(e) Usually there is need to store only fifteen days production of clinker. Any additional amount might be stored in the open. If the stock still increases, however, the shutting down of one or more kilns should be considered, since the existence of excess clinker implies unutilized capital investment.

162. Cement grinding has been discussed earlier in this chapter. Further details are as follows: The grinding involves two phases: (a) initial crushing and (b) grinding with additives. The first of these is not always necessary, depending upon the size of the clinker coming from the kiln. Grinding with additives is normally done in tube mills operated in either open or closed circuits. After grinding, the clinker goes to storage silos, where it should remain for some time before shipment. With vertical-kiln clinker, cement homogenization silos should be set up to treat the cement before storage.

Choice of manufacturing system

163. The minimum "first-generation" cement plant is one with a clinker output of 20 tons/day; that is, about 7,000 tons of Portland cement per year, or about 8,300 tons of mortar for bricklaying. It is unlikely that high-quality cements can be produced in such small plants unless they are specially designed for this purpose. This would be justified if special cements, for very specific purposes, were needed, but this case would be unusual.

164. The most suitable means of producing cement on this small scale is the vertical kiln. This equipment requires solid fuels that produce a low flame and raw materials that granulate easily. When suitable fuels are not available, the vertical kiln cannot be used. Difficulties in granulation can, however, be overcome in various ways, although the resulting granules will be undersized.

165. Such undersized granules should be subjected to high temperature, perhaps by making use of the gases produced by the kiln or from an auxiliary oven. Experiments performed at the Instituto Eduardo Torroja seem to demonstrate that certain raw materials, when subjected to temperatures from 100° - 300°C will acquire stability and strength. The material thus treated can be handled easily and can also be stored for later use. Another way is to add ground clinker to the raw material, and thus obtain a conglomerate. Experimental work in this area indicates that the proportion of ground clinker to be added is usually high (of the order of 10 per cent). Also, conglomerates may be obtained by the use of a press such as is used to produce ovoids. The material may be compressed either alone or with the addition

of a small quantity of ground clinker or cement. Compressed pellets may be thus obtained which harden either at once or after a few hours and can be stored and handled easily. This operation is not always possible, however, and above all it may increase the price of the final product.

166. A vertical kiln with an output of 20 tons/day can be designed with a single mill that can be used both to prepare the raw material and to grind the clinker (figure VII). The enlargement of a plant from an output of 20 to 50 tons/day can be foreseen by installing a mill for the raw material (if possible vertical) and setting up a second mill (figure VIII). Plans for such successive enlargements should take into account the abandoning of several of the installations of the initial small plant.

167. When clinker manufacture with a vertical kiln is not possible because of a lack of suitable solid fuels or difficulties in granulating the raw materials, the possibility should be considered of setting up a tunnel kiln without muffles and with moving trucks. The kiln and trucks should be designed for an output of 50 tons/day, since the cost is approximately the same as for a smaller kiln. The enlargement of the plant capacity from 20 to 50 tons/day could be done by merely changing the rate of heating and the velocity of movement of the trucks through the kiln. A 20 ton/day plant, using a tunnel kiln, can be set up with a single mill, similarly as for a plant with a vertical kiln.

168. The best size for a first-generation plant is one with an output of 50 to 60 tons/day of clinker; in other words, having an output of about 20,000 tons of Portland cement per year, or about 25,000 tons/year of mixed cement suitable for bricklaying purposes. The most suitable method of manufacture, when the quarries provide raw material of good and uniform quality and the fuel is of the right quality, is the vertical kiln.

169. If the use of a vertical kiln is not feasible and the dry process is mandatory, the tunnel kiln should be considered, designed on a scale that would permit subsequent increase in capacity. However, if the tunnel kiln cannot be used either, the next choice would be the long rotary kiln, preferably using the wet process, since it produces better homogenization and is, on the whole, simpler than the dry process. Cements of excellent quality can be obtained with this system, but a high consumption of heating energy must be allowed for; one higher than 1800 kcal would not be unusual.

Figure VII

Schematic diagram of a vertical-kiln cement plant of 20 tons/day capacity

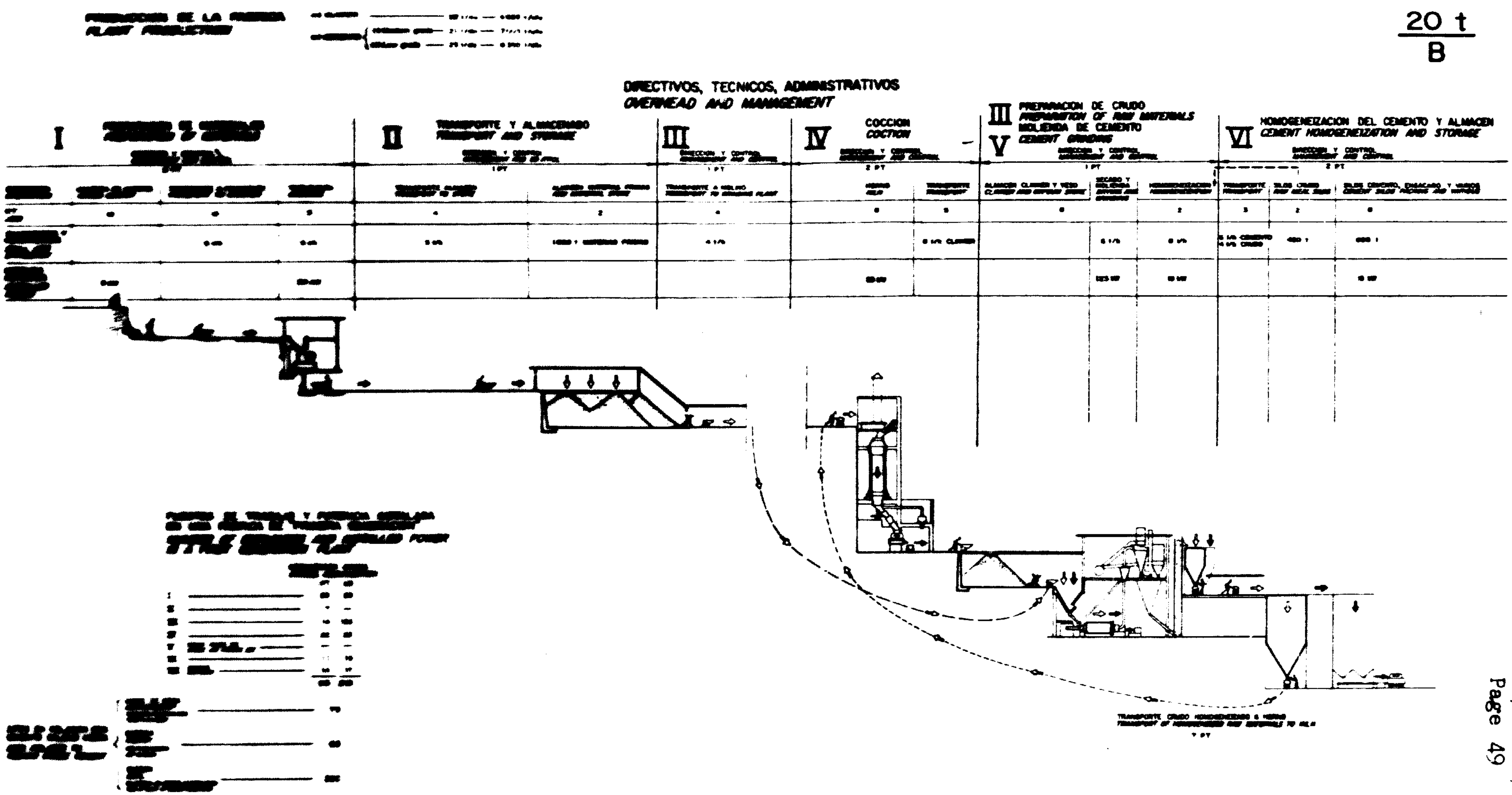
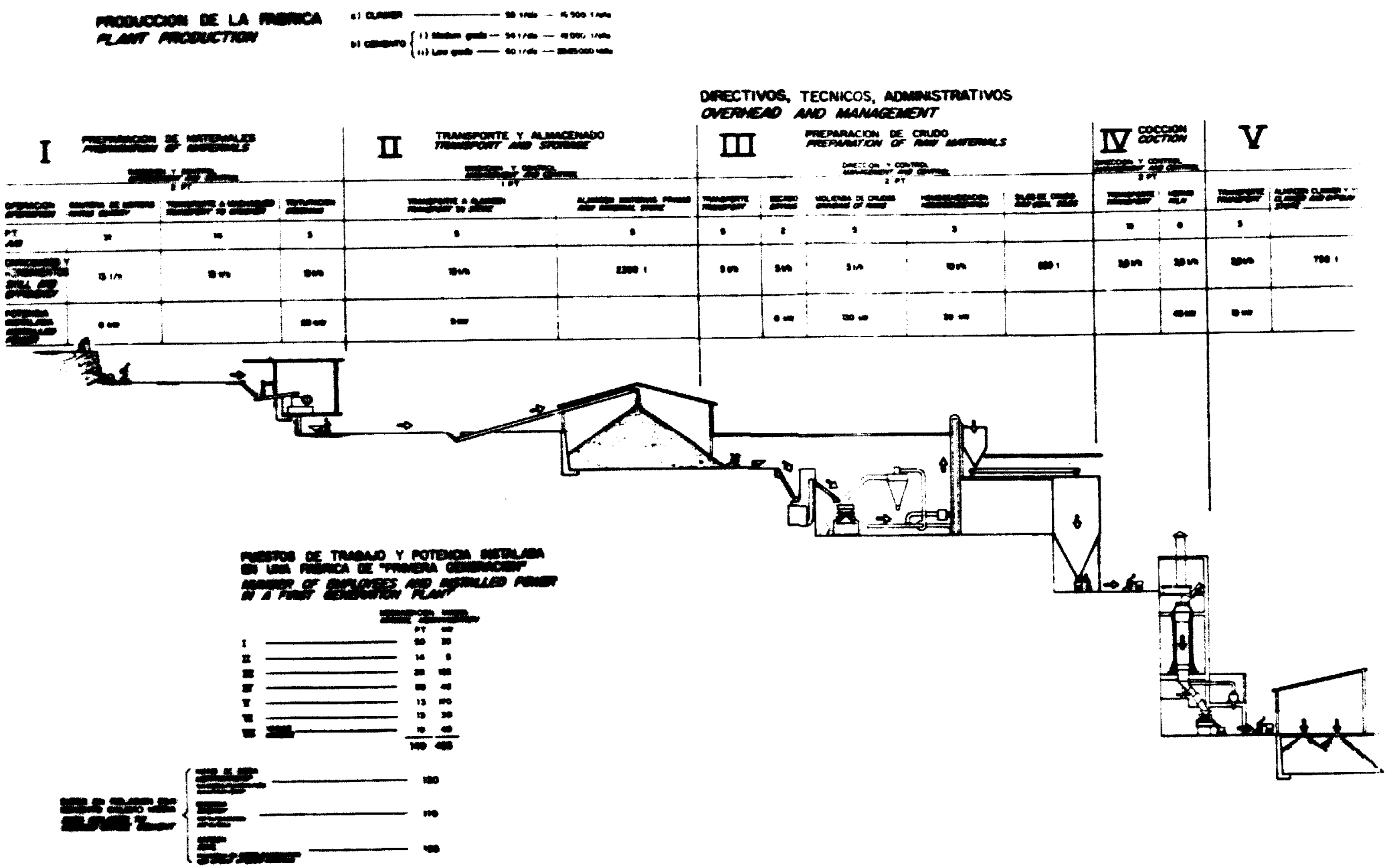


Figure VIII

Schematic diagram of a vertical-kiln cement plant of 50 tons/day capaci



170. The output of a plant of 50 to 60 tons/day capacity can, in some cases, be doubled by fitting the operating rotary kiln with a heat-recuperator. This simple device increases the over-all thermal efficiency. It is therefore good policy to design the other parts of the plant with a suitable margin for increase in capacity. Particular attention should be given to the capacity of the grinding unit.

171. The most typical first-generation plant, and the one best able to meet a relatively rapid expansion in cement production is one that produces 100 tons/day of clinker; that is, 35,000 tons/year of Portland cement or of nearly 40,000 tons of mixed cement for bricklaying purposes. The crushers, transporting machinery, filters, cyclones and the rest of the equipment of such a 100 tons/day plant would be similar to those of existing plants in Europe. Some of these items would be industrially manufactured, which would facilitate their purchase and the obtaining of spare parts.

172. As noted at the beginning of this chapter, if the available raw material and fuel are suitable, the vertical kiln should be used, since there is much experience with its use in this production range. Otherwise, either the long or the short rotary kiln should be selected, since both of these are also well suited to operation on this scale. With any of these three systems homogenization should be preferably done by the wet process, since it is less expensive and less complicated than the dry process. However, if the quarry produces a uniform raw material, the latter process can be adopted from the beginning, and homogenization can be accomplished by air injection.

173. It cannot yet be said whether the tunnel kiln would be adequate for production on this scale except in exceptional instances, since its possible advantages might well be cancelled by the lack of experience with its use in cement manufacture. Nevertheless, it is recommended that this method should be developed to practical working efficiency. This could be done quite rapidly.

174. The rest of the equipment of plants with outputs of 20, 50 and 100 tons/day should be studied separately for each particular case. However, the following general guidelines should be followed:

(a) The indoor transportation should be standardized in the form of transportation belts and buckets, the former for low inclination sections, the latter for vertical displacements.

(b) Pneumatic transportation methods, which are excellent in large plants, might prove to be too complex in first-generation plants.

(c) Dry-process grinding should be installed with an auxiliary oven (when this is necessary), and, if possible, with vertical grinding mills.

(d) Grinding of cement should be planned with the possibility of working with either open or closed circuits.

175. The fitting of heat-recuperators in first-generation plants should be considered with great care. It is usually preferable to install them later, during an enlargement phase of the plant, since the fitting of these devices complicates the manufacture of cement to some degree and may lead to difficulties, the overcoming of which would require a certain degree of experience and skill on the part of the personnel.

CHAPTER FOUR

RAW MATERIALS AND THEIR EXPLOITATION

176. The basic materials for the manufacture of Portland cement include limestone rock (loose carbonaceous materials, marls and compact limestones), clays, addition materials, fuels and water. Each of these is considered below.

Limestone

177. Loose materials rich in calcium carbonate are usually found in the five following forms: concentrations of rounded river pebbles; deposits of sharp-edged gravel at the bottom of mountain slopes; aeolian deposits in the form of dunes, as in the Canary Islands; marine coral deposits, as in East Africa, the Bahamas and Hawaii; and as fossilized beaches containing a high proportion of shells, as in East Africa, El Salvador and the Gulf of Mexico.

178. Marls rich in calcium carbonate are not usually very hard and thus may be easily exploited. They may yield a natural cement, so that in such cases manufacture is reduced almost to the mere excavation of the raw material from a single deposit. When the mineral composition of the deposit does not permit this, it usually suffices to add small quantities of a corrector, usually one rich in calcium carbonate. Corrections with clay are infrequent.

179. Compact limestones are quarried, with or without the use of explosives, according to the hardness, stratification and topographical situation of the deposits. Deposits in which the layers break off easily can be exploited very economically, since the use of special machinery is not required.

Clays

180. Clays are of two general kinds. Those obtained from fluvial or lacustrine deposits have a very low carbonate content, if any at all. These can be exploited either by hand or by mechanical means. Some schists and slates are of a mineral composition suitable for cement-making, but it is often necessary to subject them to prior crushing. Furthermore, materials made from schists and slates are usually unsuitable for granulation.

Additives

181. The addition materials include some volcanic materials such as pozzolana, which can be used after crushing and grinding, as well as certain mining and industrial by-products. Since the use of these materials is very specific, no

further reference to them is made in this report. Gypsum stone is used in the final phase of cement production, as described earlier. The proportion of this material in the finished product is usually about 5 per cent. Fusion materials, which are generally iron ores (pyrites) are used frequently in widely varying proportions, but normally not more than 5 per cent by weight. Experience in Africa indicates that bauxite and other materials rich in alumina can be very useful, and that end-products of good quality can be made with them. It is sometimes necessary to add small quantities of sand to increase the silica modulus, and still other materials are used as correctors for special purposes.

Fuels and electrical energy

182. Solid, liquid and gaseous fuels are all used in cement manufacture. Solid fuels include charcoal, natural mineral coal and treated coals such as metallurgical and petroleum cokes. The caloric value of the coals normally used is of the order of 5500 - 7500 kcal/kg. Any coal or coal mixture can be used, although each process has its own special requirements. In any case, the coal must be crushed or ground to the degree of fineness appropriate for the type of kiln in which it is to be used. For example, vertical kilns require fuels such as anthracite or metallurgical or petroleum coke that contain little volatile material and produce a low flame. Bituminous coal can be used in the "black raw material" system. Solid fuels have the disadvantages of requiring preparation before use and of requiring considerable storage space.

183. Heavy fuel oil is the liquid fuel normally used in the cement industry. Its caloric value is about 10,000 kcal/kg. Installations for its use are far simpler than those for the use of solid fuels. Gaseous fuels are hardly used except when natural gas is available in large amounts. Its caloric value is about 9000 kcal/kg. Installations for its use are even simpler than those for oil, although the laying of pipe-lines is costly and time consuming.

184. A plentiful supply of electrical energy must be assured, since a small plant, even when it is not mechanized, requires about 100 kWh/ton of cement produced. If the available supply of electrical power is insufficient, a generating plant must be incorporated into the design of the plant.

Water

185. Water consumption in cement production is of the order of 10-12 per cent of the total weight of the raw materials when they must be granulated, as for use in vertical, rotary or Lepol-type kilns. It is a 1 m^3/ton of clinker when the wet process is used, but it may be treble that amount, and it is in the range of 50-100 liters per ton of cement in dry-process manufacture in long or short powder-fed rotary kilns, with or without heat recuperators. The needed water may be obtained from wells, but it is usually more economical to use fresh or salty surface water. Salty water is not recommended for granulation and should be studied carefully before it is used in the wet process. Sea-water, which contains chlorides, alkaline substances and magnesium salts, presents many problems and should not be used in the wet process, although it can be in the dry process. Water that contains appreciable amounts of organic matter may cause difficulties when used in the wet process, but it can be used for granulation.

Selection of a cement-manufacturing process

186. Some factors that must be considered in planning a cement-manufacturing process are the following. While loose carbonate-rich materials usually contain no harmful impurities, silicon sands are often present. These can usually be removed by sieving. Another separation process may be needed if sieving does not suffice; this represents an additional cost, although usually not a large one.

187. Raw materials derived from shell deposits may be difficult to granulate; consequently, if suitable clay material is not available, it will be difficult to use these materials in vertical or Lepol-type kilns. Such raw materials are generally used in small production plants, preferably using the wet process. Dry-process, powder-fed kilns can also use them, but homogenization is more difficult and less economical than the wet process. The key factor here is the relative importance of the greater fuel consumption required by the wet process.

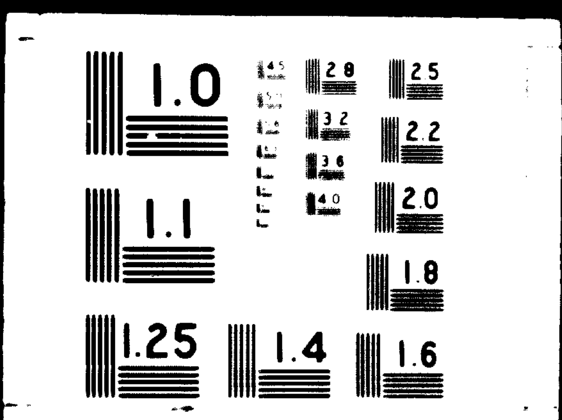
188. The ideal materials for the manufacture of cement are marls rich in calcium carbonate. However, the presence of certain impurities may be critical. Thus, if there is a high (more than 8 per cent) proportion of free, non-reactive silica, the plant must be designed to cope with this; indeed, such raw material may be unusable. Magnesium oxide, even in minor proportions (about 5 per cent)

18. 5. 73

2 OF 2

DO

3094



may be very dangerous and may also render the raw material unusable. The presence of iron compounds may increase the smelting modulus and thus may have a decisive influence on the selection of the manufacturing process to be used. The presence of alkaline compounds may complicate the manufacturing process and should be considered in the designing of the kiln, especially as regards selection of a heat-recuperator.

189. What has been said about marls is largely applicable to compact limestones as well. In addition, however, their hardness, consistency and stratification must be considered in their quarrying and secondary crushing. Indeed, some palaeozoic limestones with acceptable chemical and mineralogical characteristics are unusable because of the high cost of their quarrying and treatment. Furthermore, the granulation of crystalline limestones may be quite difficult.

190. Fluvial or lacustrine sedimented clays seldom have properties that render them wholly unsuitable, but it is very advisable that the silica modulus be kept within certain limits. Schists, slates and other minerals that supplement clays or may be substituted for them should be studied within the context of the raw material as a whole, and all that has been noted above should be taken into account.

191. Gypsum stone should consist of more than 70 per cent dehydrated calcium sulphate. This ingredient normally contains no harmful impurities. The use of anhydrate gypsum is not recommended.

192. The moisture content of the raw materials must be taken into account in selecting the manufacturing process. When the moisture content is below 20 per cent, desiccation may be economically acceptable and the dry process may be adopted; when humidity is about 25 per cent the wet process should be considered. In intermediate cases the choice between the dry and wet process can depend upon many other factors.

Exploitation of raw materials

193. The manufacture of cement begins with the exploitation of deposits of the raw materials. This includes extraction, prior treatment and transportation to the plant. The methods used and their costs will, of course, depend upon the nature of these materials. Loose carbonaceous materials, marls, compact limestones, clays, and schists, slates and addition materials are considered separately below.

Loose carbonaceous materials

194. Alluvial gravels and fosslized seashore materials can be exploited wholly by hand, completely mechanically or by any intermediate arrangement. In determining the amount of raw material to be extracted per working hour, it should be borne in mind that, while cement plants normally operate on a continuous basis, quarrying does not, since it is affected by factors such as weather and public holidays. The following relations may therefore be said to exist:

Cement plant output in tons/day	Extraction of loose material (tons/hour)	Other material moved at quarry to extract loose material desired (tons/hr)
20	6	10
50	13	20
100	23	40

195. If manual labour alone were used (that is, if excavation and sieving were done with hand tools and if wheelbarrows and a continuous lifting belt were used for transport), the number of men needed at each of the production rates discussed here would be roughly as follows:

	20 t	50 t	100 t
Excavation	16	32	64
Transportation	6	12	24
Miscellaneous	2	2	3
Total labour force	24	46	91

196. The first-establishment costs could include the purchase of hand tools, wheelbarrows, the continuous lifting belt, and of the needed silos and loading bins. These costs and their depreciation and maintenance, per ton of daily capacity, would be of the following order:

Plant capacity (tons per day)	Cost of first establishment (US$)	Depreciation and maintenance costs per ton of output (US$)
20	1300	0.06
50	1800	0.03
100	3000	0.02

The cost of manual labour (j) per ton of cement produced, for excavation, sieving, transportation and delivery to the kiln will be as stated below:[a]

---

[a] The daily wage j (in US$) is arrived at by dividing by 365 the total amount paid for the services of an unskilled worker during one year.

Manual labour cost for cement plants with daily output of

20 tons	50 tons	100 tons
1.70 j	1.30 j	1.20 j

The fuel or electricity costs for the operation of the continuous lifting belt can be regarded as negligible. The extraction costs (in US$) per ton of cement produced would be about as follows:

Plant capacity (tons per day)	Labour costs for excavation, sieving, and bin-loading at various wage levels (j)						
	0.50	0.75	1.00	1.25	1.50	1.75	2.00
20	0.91	1.34	1.76	2.18	2.61	3.04	3.46
50	0.68	1.01	1.33	1.66	1.98	2.31	2.66
100	0.62	0.92	1.22	1.52	1.82	2.12	2.42

197. Excavation by mechanical means can be done with a front-loading, wheeled mechanical shovel. If a mechanical shovel with a capacity of about 0.5 m^3 is utilised, the number of working hours and amount of material that can be handled at the quarry face will be as follows:

Plant capacity (tons per day)	Material handled at the quarry per day (tons)	Shovel working hours
20	80	1.5
50	160	3
100	320	6

It will be realized that the usefulness of a mechanical shovel for plants with outputs of only 20 to 50 tons per day is very questionable.

198. The first-establishment costs in all cases, covering excavating machinery, would be approximately as follows:

Loading shovel, with spare parts and accessories	US$ 14,000
Trommel, with motor	2,000
Remainder of the installation	2,000
Total	US$ 18,000

Amortization is usually calculated over 10,000 working hours, and it is normal to discount the value of scrap metal, so that depreciation of the machinery could be estimated at US $ 1.70 per working hour. Fuel and lubricants involve an expenditure, per working hour, which in terms of the price of gas oil, can be estimated at 13 CL.[a/] Maintenance can be calculated at US $ 1 per working hour. Manual labour for installation is limited to a shovel operator whose

a/ In the present report, CL is the cost per liter, in US$, of liquid fuel and lubricant (gas oil).

wages might be six times higher than those of an unskilled labourer (that is 6 j), a trommel charge hand (whose cost would be 2 j), and three unskilled labourers (3 j). Thus the total manual labour cost will amount to 11 j. Hence, for a plant with a 100 tons/day output of cement, the cost (in US$) of extracting and sieving per ton of cement would be:

Machinery depreciation	0.102
Fuel and lubricants	0.78
Maintenance	0.06
Manual labour	0.11 j

199. The influence of these costs on the per-ton cost of one ton of cement is indicated in the following table:

Labour cost (j) US$	Cement plant with 100 tons/day output CL (US$) 0.06	0.08	0.10	0.12	0.14
0.50	0.264	0.279	0.295	0.310	0.419
0.75	0.292	0.307	0.323	0.338	0.447
1.00	0.319	0.334	0.350	0.365	0.475
1.25	0.347	0.362	0.378	0.393	0.502
1.50	0.374	0.389	0.405	0.420	0.529
1.75	0.402	0.417	0.473	0.458	0.567
2.00	0.429	0.444	0.460	0.475	0.584

In a plant producing 50 tons per day of cement, the excavating and sieving costs per ton of cement would be almost double those of a plant producing 100 tons per day, if similar machinery were used. Since the machinery will be used for no more than 3 or 4 hours daily, in some cases it might be used to perform secondary tasks at the excavation site or possibly at the cement plant, when this is sufficiently close.

Excavation of marls

200. Very often marls can be excavated by hand, and they have the advantage over deposits of shells at the seashore that all or almost all the extracted material is useful. Costs for hand exploitation of such marls are as shown below:

Operations	No. of operators for plants of various capacities (tons/day) 20	50	100
Excavation	8	16	32
Transport to loading point	6	12	24
Various	2	3	5
Total number of operators	16	31	61
Hand crushing	18	36	72
Total number of operators if crushing is also done by hand	34	67	133

It should be noted that hand crushing can be done only rarely since the cost of manual labour normally makes it very expensive. However, it might be advisable to use hand labour in the initial breaking up of the larger rocks.

201. The initial-establishment costs given below include the purchase of tools, wheelbarrows, rail trucks and a transporting belt, as well as the installation of a loading silo or bin.

Plant output (tons per day)	Cost of initial establishment	Depreciation and maintenance costs per ton of cement output (US$)
20	1500	0.09
50	2000	0.05
100	3000	0.01

The manual labour cost per ton of cement, covering excavation, possible breaking up of larger rocks and the transport of the material to the loading site, will be approximately the following:

20 tons/day	50 tons/day	100 tons/day
0.97 j	0.75 j	0.74 j

Electricity and various other expenses are regarded as negligible. The aggregate costs, in US$, per ton of cement produced, will be approximately these:

Output of the plant (tons per day)	Cost (in US$) of excavating, breaking up and transport to loading site, for various values of j						
	0.50	0.75	1.00	1.25	1.50	1.75	2.00
20	0.56	0.82	1.06	1.50	1.55	1.79	2.03
50	0.43	0.61	0.80	0.98	1.18	1.36	1.55
100	0.41	0.60	0.78	0.97	1.15	1.34	1.52

202. The exploitation of soft limestone or marl deposits of the type under consideration, can also be done by mechanical means. The necessary output for a plant producing 20 tons/day could be achieved using the machinery only 2 or 3 hours daily. This would be inefficient use of the equipment and is thus not considered here. However, for a plant with a 50 ton/day output, a 0.5 m^3 shovel, which is one of the smallest that can be used for this purpose, would only have to work 5 hours daily. It could thus be used for auxiliary tasks or to help in manufacturing, if the quarry is sufficiently close to the plant. In the case of a plant of 100 ton/day capacity, such a shovel would work 6 to 9 hours daily, according to the nature of the raw material. In either case, the first-establishment cost would be:

Loading shovel, with spare parts and accessories	US$ 14,000
Other equipment	2,000
Total	US$ 16,000

203. Amortization calculated over 10,000 working hours would mean a cost of US $ 1.6 per working hour of the shovel. Based on the price of gas oil, the fuel and lubricant cost can be estimated at 13 CL. Maintenance is estimated at US $ 1 per working hour. Manual labour, expressed in unskilled labour daily wages, would be 12 j per day for the whole installation. Thus, for a plant with a daily output of 50 tons, the cost of excavation and loading affects the cost of a ton of cement produced in the following manner:

Machinery depreciation	0.214 US$
Fuel and lubricants	1.30 CL
Maintenance	0.10 US$
Manual labour	0.30 j

204. Depending on the unit costs of fuels and manual labour, the influence on the total cost of cement will be as given below:

Labour cost (j) US$	Fuel and lubricant costs of various CL (US$) plant with 50 ton/day output				
	0.06	0.08	0.10	0.12	0.14
0.50	0.542	0.568	0.594	0.620	0.646
0.75	0.617	0.648	0.669	0.695	0.721
1.00	0.692	0.718	0.744	0.770	0.796
1.25	0.767	0.793	0.819	0.845	0.891
1.50	0.842	0.868	0.894	0.920	0.946
1.75	0.917	0.943	0.969	0.995	1.021
2.00	0.992	1.018	1.044	1.070	1.096

This table demonstrates that for a plant with an output of 50 tons/day it is economically advantageous to exploit the quarry with mechanical aids whenever the unit daily wage (j) is US $ 1.00 or more.

205. In the case of plants with outputs of 100 tons/day, the cost of excavation and loading by mechanical means affects the total cost of one ton of cement as follows:

Machinery depreciation	0.110 US$
Maintenance	0.100 US$
Depreciation and maintenance	0.210 US$
Fuel and lubricants	1.04 CL
Manual labour	0.15 j

206. Depending on the unit costs of fuel and manual labour, the influence on the total cost of cement will be as shown below:

Labour cost (j) US$	Fuel and lubricant costs of various CL (US$) plant with 100 tons/day output				
	0.06	0.08	0.10	0.12	0.14
0.50	0.348	0.368	0.389	0.410	0.431
0.75	0.385	0.405	0.426	0.447	0.468
1.00	0.423	0.443	0.464	0.485	0.506
1.25	0.461	0.481	0.502	0.523	0.594
1.50	0.498	0.518	0.539	0.560	0.581
1.75	0.536	0.556	0.577	0.588	0.619
2.00	0.573	0.593	0.614	0.625	0.656

It is evident from these figures that, from the financial point of view, it is always advantageous to exploit the quarry with mechanical aids, whatever the wage level and the price of liquid fuels may be.

Excavation of compact limestones

207. Hard limestone can also be quarried by hand, but explosives are ordinarily used. The preliminary drilling is usually done by hand. After the blast, leverage bars are used to clear the quarry face. Loading is done by hand, using small rail trucks, which are generally used to transport the material to the crusher, which is installed at the quarry. The number of workers that will be required at the quarry face, when the above mode of work is used will be the following:

Operations	Output of plant (tons/day)		
	20 t	50 t	100 t
Drilling, loading and other operations to effect explosions and clean the quarry face	10	20	40
Loading and transport in rail trucks	4	8	16
Sharpening of tools and related tasks	2	4	6
Total number of workers	16	32	62

The cost of excavation and transportation to the crusher will be of the following order:

Item	Output of plant (tons/day)		
	20 t	50 t	100 t
Manual labour	1.00 j	0.80 j	0.75 j
Explosives, detonators, etc.	0.10 US$	0.10 US$	0.10 US$

20 . The first-establishment costs will be similar to those for marls, as discussed above, or approximately as follows:

Plant output (tons/day)	First-establishment cost (US$)	Depreciation and maintenance per ton of cement (US$)
20	1500	0.09
50	2000	0.05
100	3000	0.04

Similarly, the cost, in US$, per ton of cement produced, might be comparable to or slightly higher than that already considered for the case of marls.

209. Mechanization of the quarrying of hard limestones is very difficult to consider in a general report such as this, since it largely depends on the local circumstances and the quality of the rock. When such material is used in plants as small as those considered here, it is usually sufficient to set up a compressor and some breaking hammers. In a plant with a capacity of 100 tons/day it might be justified to use a compressor, drilling hammers and drills, and to complete the process either by hand-loading and transport on rail trucks or else by means of mechanical shovels. As regard costs, there are so many variables linked to local conditions that it is impossible to suggest figures even roughly.

Excavation of clays

210. As clays are utilized in relatively small amounts, they can always be excavated by hand. The amount of labour required is only about one fifth of that needed to exploit a limestone quarry. This means about four men for a plant of 20-ton/day output of cement, six men for a plant with an output of 50 tons/day and about ten men for a plant producing 100 tons/day. First-establishment costs will be only about one fourth of those for the exploitation of limestone quarries. The influence on the cost per ton on cement will thus be about one fifth of that involved in quarrying compact limestone.

Schists, slates, and addition materials

211. In the excavation of schists and slates almost the same considerations as those for marls hold good, provided account is taken of their specific morphology. Like clays, schists and slates are used in relatively small proportions, so that they, also, can always be excavated by hand. The amount of labour required for this task and the first-establishment capital outlay would be of approximately the same order as for clay excavation. Since the quantities of addition materials that are normally used may vary considerably, they are not considered here.

Transportation of raw materials from the quarry to the plant

212. If it is assumed, as a basis for calculation, that the quarry is 15 km from the plant and that transport is by trucks of 5-ton capacity, the number of vehicles needed for cement plants of the three sizes considered in the present report will be as follows:

Plant output (tons daily)	No. of trucks	Initial capital outlay (US$)	Depreciation per ton of output (US$)
20	1	5,500	0.30
50	2	11,000	0.25
100	4	22,000	0.25

Since each truck would require a driver (4j) and an assistant (2j), the number of jobs generated would be, respectively, 2, 4 and 8 for cement plants of these three sizes.

213. The transportation cost from the quarry to a plant with an output in the range of 50-100 tons/day will be approximately as shown below:

Labour cost (j) (US$)	Fuel and lubrication cost (CL) 0.06	0.08	0.10	0.12	0.14
0.50	0.366	0.438	0.510	0.588	0.654
0.75	0.441	0.513	0.538	0.657	0.729
1.00	0.516	0.588	0.660	0.732	0.804
1.25	0.591	0.663	0.735	0.807	0.879
1.50	0.666	0.738	0.810	0.882	0.954
1.75	0.741	0.813	0.885	0.957	1.029
2.00	0.816	0.888	0.960	1.032	1.104

214. The costs of labour, fuel and maintenance per ton of cement produced would be of the following order:

Plant output (tons daily)	Labour cost (j)	Fuels and maintenance (CL)
20	0.365	4.50
50	0.300	3.60
100	0.300	3.60

CHAPTER FIVE

PRODUCTION EQUIPMENT

General remarks

215. This chapter deals with production equipment involved in the various specific processes of Portland cement production that are applicable to plants with small outputs. No account has been taken of intermediate processes such as transportation and storage of raw materials and clinker or of assembly costs of the various installations and the corresponding civil-engineering work. All of these are considered in the next chapter.

Equipment for the preparation of the raw materials

216. Primary crushing of the raw materials is usually done with crushers of the three following kinds:

(a) Jaw crushers, which are applicable for hard materials. They are fed with large rocks and are suitable for medium or large outputs;

(b) Cone crushers, which are suitable for hard materials but not for very plastic or wet materials, nor for use in places where spare parts are not readily obtainable. Crushers of this kind are fed with medium-sized rocks and are suitable for large outputs;

(c) Impact crushers, which are suitable for fragile materials but not for abrasive, plastic or wet ones. They are suitable for any scale of output. If a closed circuit is adopted, secondary crushing can be omitted.

217. The capacities of those crushers should depend upon the plant output and the method of excavation of the rock. The climatic conditions of the zone where the plant is to be situated are important. If rainfall is high, quarrying must be restricted to relatively dry periods, and peak outputs must be achieved at to compensate for periods when excavation is suspended.

218. The minimum recommended crushing capacities, in terms of tons of raw materials per hour, according to the nature of the climate would be as shown below:

Cement plant output capacity		Tons of crusher output per hour, for three types of climate		
Tons of clinker per day	Tons of cement per year a/	Dry	Moderate	Humid
20	7,000	6	7.5	8.5
50	18,000	13	16	18
100	35,000	23	30	32

a/ The cement output is based on 330 working days per year and assumes small proportions of additives. In fact, yearly clinker output would be 6600 tons, 16500 tons, 33000 tons and 66000 tons respectively.

219. The specific consumption of electrical power per ton of raw material is of the following approximate magnitude for the three types of crusher:

Crushing capacity (tons per hour)	Consumption (kWh per ton of cement)		
	Jaw	Cone	Impact
6	2.2	-	1.2
7.5	2	-	1.2
8.5	1.8	-	1.15
13	1.5	-	1.10
16	1.2	1.3	1.05
18	1.0	1.2	1.0
23	0.6	0.9	1.0
30	0.6	0.7	0.95
32	0.5	0.7	0.95

220. From the foregoing data, it is possible to determine the necessary amount of installed power and the resulting electricity consumption.

Type of climate	Plant capacity (tons per day)	Installed power (kW)	Jaw crusher		Cone crusher			Impact crusher		
			Total yearly power consumption (1000 kWh)	Power consumption (kWh per ton of cement)	Installed power (kW)	Total yearly power consumption (1000 kWh)	Power consumption (kWh per ton of cement)	Installed power (kW)	Total yearly power consumption (1000 kWh)	Power consumption (kWh per ton of cement)
Dry	20	20	19.80	2.83	-	-	-	10	10.8	1.54
	50	30	33.80	1.88	-	-	-	25	24.75	1.37
	100	25	27	0.77	30	40.5	1.2	35	45	1.29
Moderate	20	25	18	2.57	-	-	-	15	10.8	1.54
	50	30	27	1.50	30	29.2	1.63	25	23.7	1.33
	100	30	22.5	0.64	30	31.5	0.94	60	42.7	1.20
Humid	20	25	16.2	2.31	-	-	-	15	10.4	1.50
	50	30	22.5	1.25	30	27	1.50	25	22.5	1.25
	100	30	22.5	0.64	35	31.5	0.94	45	42.7	1.20

221. The costs of first establishment (in US$), applicable only to the FOB (free on board ship) cost of the machinery, including motors, are approximately as shown below. The cost of financing is included, assuming an amortization period of ten years, including 6 per cent interest charges per year.

Type of Climate	Plant output capacity (tons per day)	Jaw crusher		Cone crusher		Impact crusher	
		First establishment	Amortization	First establishment	Amortization	First establishment	Amortization
Dry	20	1,100	149	1,500	204	3,800	516
	50	3,000	408	2,400	271	6,200	843
	100	4,200	570	10,000	1,359	12,500	1,698
Moderate	20	1,300	177	1,400	190	4,200	571
	50	3,400	462	2,400	326	7,000	951
	100	4,200	570	10,000	1,359	15,000	2,040
Humid	20	1,900	258	2,000	271	5,000	680
	50	3,300	448	3,300	448	11,000	1,495
	100	4,400	598	11,800	1,603	18,300	2,488

222. From the information presented above, it can be calculated that the influence of this item (crushing) on the technical production costs will be approximately as follows, for a moderate type climate and impact-type crushing.

Plant capacity (tons/day)	Influence on the production cost of one ton of cement			
	Manual labour	Electrical energy	Spare parts and maintenance	Depreciation and financing
20	0.06 j	1.54 w	0.07	0.07
50	0.04 j	1.37 w	0.06	0.06
100	0.02 j	1.29 w	0.05	0.05

where:

j = cost of one daily wage for unskilled labour in US$

w = cost of 1 kWh in US$

Repair and depreciation costs in US$

223. Depending upon the magnitude of the manual labour cost (j) and/or the price of electrical energy (w), the amount in US$ would be as follows:

Cement plant with 20 tons/day output

Electrical power cost (w)	Labour cost (j)						
	0.50	0.75	1.00	1.25	1.50	1.75	2.00
0.005	0.178	0.193	0.208	0.223	0.238	0.253	0.268
0.010	0.186	0.201	0.216	0.231	0.246	0.261	0.276
0.015	0.193	0.208	0.223	0.238	0.253	0.268	0.283
0.020	0.201	0.216	0.231	0.246	0.261	0.276	0.291
0.030	0.217	0.232	0.247	0.261	0.276	0.291	0.306

Cement plant with 50 tons/day output

Electrical power cost (w)	Labour cost (j)						
	0.50	0.75	1.00	1.25	1.50	1.75	2.00
0.005	0.146	0.156	0.166	0.176	0.186	0.196	0.206
0.010	0.153	0.163	0.173	0.183	0.193	0.203	0.213
0.015	0.160	0.170	0.180	0.190	0.200	0.210	0.220
0.020	0.167	0.177	0.187	0.197	0.207	0.217	0.227
0.030	0.181	0.191	0.201	0.211	0.221	0.231	0.241

Cement plant with 100 tons/day output

Electrical power cost (w)	Labour cost (j)						
	0.50	0.75	1.00	1.25	1.50	1.75	2.00
0.005	0.116	0.121	0.126	0.131	0.136	0.141	0.146
0.010	0.123	0.128	0.133	0.138	0.143	0.148	0.153
0.015	0.130	0.135	0.140	0.145	0.150	0.155	0.160
0.020	0.136	0.141	0.146	0.151	0.156	0.161	0.166
0.030	0.149	0.154	0.159	0.164	0.169	0.174	0.179

224. If loose shell materials from fossilized seashores are used, initial sieving is necessary. This sieving is normally achieved with a trommel or with fine-meshed sieves. In either case both the initial cost of the equipment and the operation costs are very low. They are included under the heading of miscellaneous expenses, since they have no large influence on the total cement production cost.

225. Secondary crushing is normally done with one of the four following devices:

(a) Hammers, which are applicable to dry materials or materials with little humidity. They are especially suited for gypsum stone. They can be used for crushing materials that have undergone primary crushing, but they are not to be recommended for soft or humid materials;

(b) Cone crushers, which are applicable to hard and abrasive materials but are not recommended for humid, soft or very plastic materials;

(c) Impact mills, which are suitable for dry and slightly humid materials but not recommended for gypsums or very plastic materials;

(d) Roller mills, which are suitable for wet or highly plastic materials. They are especially effective in dealing with clays before they are suspended in water and to grind coal. They are not recommended if the diameter of the materials exceeds 50 mm.

226. The capacity of these secondary crushers is related to that of the plant and to the type of manufacturing process which in turn, is influenced by the prevailing climatic conditions to the extent that they affect quarrying operations. Furthermore, this secondary crushing is not usually necessary in the case of small plants, since the size of the materials after the primary crushing is suitable for feeding into the grinding mills. However, it is usual to set up an installation to prepare the clays.

227. In plants with outputs of 20 and 50 tons/day of clinker, one or two men may suffice to disintegrate the clay and prepare it for storage. If so, the influence on the production cost will be as shown below.

Plant capacity (tons/day)	Influence on the production cost of one ton of cement of the labour cost (j) for preparation of the clay						
	0.50	0.75	1.00	1.25	1.50	1.75	2.00
20	0.025	0.038	0.050	0.063	0.075	0.088	0.100
50	0.020	0.030	0.040	0.050	0.060	0.070	0.080

In plants with outputs of 100 tons/day, it is advisable to have a crushing roller or a disintegrating conveyor belt.

228. The influence of these requirements on the initial capital investment will vary considerably, depending on the nature of the clay, but roughly it would be necessary to allow for equipment costing US$ 3000, so that the depreciation and maintenance costs would result in a cost of US$ 0.02 per ton of cement. These initial costs are calculated on the supposition that this equipment will be used only for clays which amount to about 25 per cent of the total weight of the raw materials. The cost of manual labour would be 0.01 j per ton of cement, and the expenditure in electrical energy would be 0.9 w per ton of cement.

229. In plants operating with the wet process and having a daily output of at least 100 tons of clinker, it will be necessary to install a blunger to prepare the clay and eliminate foreign bodies (gravel, river stones, etc.) This involves the installation of 4 kW of motive power.

230. The initial capital investment for the blunger will be of the order of US$ 35,000. The influence of this outlay on the technical production cost would be as follows, assuming an amortization period of fifteen years, for a plant with a cement output of 100 tons/day.

Manual labour	Electrical energy	Spare parts and maintenance	Depreciation
0.02 j	0.15 w	0.020	0.103

Because the amount of electrical power required for this purpose is small, the influence of this item on the total cost, depending on the level of manual labour cost (j), would be only as given below:

j	Amount, in US$
0.50	0.134
0.75	0.139
1.00	0.144
1.25	0.149
1.50	0.154
2.00	0.164

231. The expansion of a plant from a clinker output 100 to 300 tons/day would be simple and economical as regards the blunger, since the additional investment would be of the order of only US$ 10,000, plus a slight adjustment in the feeding and discharge system.

<u>Drying and grinding of raw materials</u>

232. When there is no provision for simultaneous drying and grinding in the raw materials mill, or when some of the raws are very moist, a separate drying process will be needed. This will be done when the crushed material is ready for feeding into the grinding mill. In rotary driers, the consumption of energy is between 900 and 1300 kcal/kg evaporated water, depending on the initial humidity of the raw material and the type of drier. As the initial moisture content of the raw material can vary widely, a figure for the number of calories that will be consumed in drying a ton of raws or of cement cannot be given.

233. The capacity of the drying installation should be similar to that of the grinding mill, or higher if a small reserve of dried raw materials is to be established. Under these circumstances, and for the plants that are envisaged in this report, the drying requirements, assuming that all the raw materials must be dried, will be:

Output of the plant (tons/day)	Drying capacity in tons/hour, allowing for storage of dried material
20	2.1
50	5.2
100	10.4

234. The specific consumption, in kWh per ton of cement, and the installed motive power, assuming that all the raws require drying, will be as specified below.

Plant capacity (tons/day)	Electrical consumption (kWh/ton of cement)	Installed motive power (kW) if all raws need drying
20	1.32	3
50	1.12	6
100	1.02	12

235. The specific consumption of fuel to dry raw materials (in kilograms of fuel per ton of material to be dried), as a function of the humidity, is as shown below.

Type of fuel	Quantity of water, as percentage of wet material							
	3	6	9	12	15	18	21	24
Coal[a]	9.2	13.8	19	24.8	30.5	37	43.2	50
Fuel oil[b]	6	9	12.3	16.1	19.8	24	28	32.5

236. The consumption of fuel to dry the raw materials, in kg/ton of cement, assuming that all of them need drying, is as follows:

Type of fuel	Quantity of water, as percentage of wet material							
	3	6	9	12	15	18	21	24
Coal[a]	13.8	20.7	28.5	37.2	45.7	55.5	64.8	75
Fuel oil[b]	9	13.5	18.4	24.1	29.7	36	42	48.7

a/ Caloric value 6500 kcal/kg.

b/ Caloric value 10,000 kcal/kg.

237. The initial capital investment, referring only to the cost, FOB, of machinery, including motors, is approximately as given in the following table. This also includes amortization costs over a period of ten years, including 6 per cent annual interest charges.

Plant capacity (tons/day)	Drying, with intermediate storage	
	Investment (US$)	Financing costs (US$)
20	25,000	3,397
50	40,000	5.435
100	47,000	6,385

238. As the influence of the drying costs on the final cost of the cement depends on the humidity of the raws, it will be assumed, in the interest of brevity, that the raw material has a 6 per cent water content. It is understood that if the raw material has only 1 per cent humidity there will be no need to dry it. Conversely, if it has between 1 per cent and 8 per cent water content, drying can be done at the same time as grinding. Only if the humidity is 8 per cent or more will it be essential to incorporate prior drying installation into the plant. Based on these assumptions, the following results are obtained:

Plant capacity (tons/day)	Influence on the cost per ton of cement				
	Manual labour	Electrical energy	Spare parts and maintenance	Financing costs	Fuel (fuel oil)
20	0.2 j	1.32 w	0.20	0.48	13.5 CL
50	0.08 j	1.12 w	0.10	0.30	13.5 CL
100	0.06 j	1.02 w	0.08	0.18	13.5 CL

239. Assuming a mean price (w) for each kilowatt hour equal to US$ 0.015, the influence on the total cost, per ton, due to the drying of the raw materials can be given approximately by the following tables:

Plant of 20 tons/day capacity

CL	Labour cost (j)						
	0.50	0.75	1.00	1.25	1.50	1.75	2.00
0.02	0.962	1.012	1.062	1.112	1.162	1.212	1.262
0.03	1.097	1.147	1.197	1.247	1.297	1.347	1.397
0.04	1.232	1.282	1.332	1.382	1.432	1.482	1.532
0.05	1.367	1.417	1.467	1.517	1.567	1.617	1.667
0.10	2.042	2.092	2.142	2.192	2.242	2.292	2.342

Plant of 50 tons/day capacity

CL	Labour cost (j)						
	0.50	0.75	1.00	1.25	1.50	1.74	2.00
0.02	0.726	0.746	0.766	0.786	0.806	0.826	0.846
0.03	0.861	0.881	0.901	0.921	0.941	0.961	0.891
0.04	0.946	1.016	1.036	1.056	1.076	1.096	1.116
0.05	1.131	1.151	1.171	1.191	1.211	1.231	1.251
0.10	1.806	1.826	1.846	1.866	1.886	1.906	1.926

Plant of 100 tons/day capacity

CL	Labour cost (j)						
	0.50	0.75	1.00	1.25	1.50	1.75	2.00
0.02	0.575	0.590	0.605	0.620	0.635	0.650	0.665
0.03	0.710	0.725	0.740	0.755	0.770	0.785	0.800
0.04	0.845	0.860	0.875	0.890	0.905	0.920	0.935
0.05	0.980	0.995	1.010	1.025	1.040	1.055	1.070
0.10	1.655	1.670	1.685	1.700	1.715	1.730	1.745

where:

CL = price of 1 kg fuel oil in US$

j = cost of a daily wage in US$

240. Grinding is accomplished with a ball or a vertical mill, in closed or open circuit, in accordance with one of the following five alternatives:

(a) With the wet process it is usual to use a compound, open circuit, tubular mill;

(b) The most economical system for the dry process, in terms of initial capital investment, is the tubular mill, open circuit. It is also the easiest to operate;

(c) The tubular mill, closed circuit, with mechanical elevator, permits grinding and drying to be done simultaneously when initial humidities are below 4.5 per cent;

(d) The tubular mill, closed circuit, with pneumatic elevator, permits grinding and drying to be done simultaneously with initial humidities as high as 8 per cent. This system is very suitable for light materials;

(e) The vertical mill, closed circuit with air, requires less initial capital investment and may be operated more economically than tubular mills.

241. Milling normally is done for 16 hours/day. In plants with 20 and 50 tons/day capacity, it is suggested that the same grinding circuit be used for grinding both the raws and the cement.

	Grinding mill capacity (tons per hour)	
Plant capacity (tons/day)	Only for raws, grinding 16 hours/day	Grinding raws and cement
20	2	4.6
50	5	10.6
100	10	20.2

242. The electrical energy consumption for each grinding system varies according to the quality of the raw material. As an indication, the following data are provided:

Grinding system	Process used	Simple mills (kWh/ton)	Mills with internal devices (kWh/ton)
Open circuit	Dry process	33 to 37	30 to 33
	Wet process	32 to 36	29 to 32
Closed circuit	Circulation by air	30 to 33	27 to 30
	Circulation with buckets	27 to 30	25 to 28
Vertical mills	Circulation by air	26 to 30	

243. The electrical power to be installed for grinding, following the above data, is given below for cement plants of the three sizes that are considered in this report.

		Simple mills		Mills with internal devices	
Grinding system	Process used	16-hour grinding	Grinding raw and cement	16-hour grinding	Grinding of raws and cement
Open circuit	Dry process	60 - 70	120 - 140	55 - 60	110 - 120
	Wet process	58 - 66	116 - 132	53 - 57	106 - 114
Closed circuit	Air circulation	55 - 60	110 - 120	50 - 55	100 - 110
	Bucket circulation	50 - 55	100 - 110	47 - 53	94 - 106
Vertical kilns	Air circulation	47 - 54	-	-	-

Cement output of 50 tons/day

Grinding system	Process used	Minimum installed power (kilowatts) (16-hour grinding): Simple mills	Mills with internal devices
Open circuit	Dry process	150 - 170	136 - 150
	Wet process	145 - 165	132 - 145
Closed circuit	Circulation by air	136 - 150	122 - 136
	Circulation with buckets	122 - 136	116 - 119
Vertical mills	Circulation by air	116 - 135	-

Cement output of 100 tons/day

Grinding system	Process used	Minimum installed power (kilowatts) (16-hour grinding): Simple mills	Mills with internal devices
Open circuit	Dry process	300 - 340	275 - 300
	Wet process	290 - 330	270 - 290
Closed circuit	Circulation by air	275 - 300	250 - 275
	Circulation with buckets	250 - 275	235 - 260
Vertical mills	Circulation by air	232 - 270	-

244. For a plant with an output of 20 tons/day of cement, the possibility of setting up a single ball mill that can grind 50 tons of clinker in a 16-hour day should be considered. Such a mill could be used to grind raw materials on some days and clinker on others. The cost of such a mill (including fittings such as feeders and sieves) is about US$ 35,000. The amortization period for such machinery is relatively long, 15 years is an acceptable period. This would mean an annual outlay of about US$ 3,600, including financing charges, which corresponds to US$ 0.50 per ton of cement.

245. The maintenance and replacement of the grinding elements are important items. In older installations with relatively small outputs, the attrition of the lining and balls is about 1.4 kg per ton of cement. This rate of wear has been greatly reduced in newer plants, but in a plant of 20 tons daily output the rate of wear will be similar to that given above. This means a cost per ton of clinker of the order of US$ 0.03 to US$ 0.10 per ton of raw material ground: that is, about US$ 0.05 per ton of cement. Total maintenance and replacement costs, such as those for grinding elements, linings, lubrication and spare parts can amount to US$ 0.20 per ton of cement, the total cost of depreciation and maintenance may therefore total US$ 0.55 per ton.

246. The manual labour absorbed by the grinding process in a plant producing 20 tons of cement daily is three men working in two shifts; that is, about 0.3 j per ton. The consumption of electrical energy will be of the order of 60 kWh/ton including both the grinding of the raw materials and of the cement. Thus, the total influence of the grinding on the cost of one ton of cement will be 0.55 + 0.3 j + 60 w.

247. Depending on the value of the mean wage (j) and the cost (w) of one kilowatt hour, the actual cost of grinding per ton will be as given in the following table:

Electrical power cost (w)	Labour cost (j)						
	0.50	0.75	1.00	1.25	1.50	1.75	2.00
0.005	0.680	0.955	1.030	1.100	1.180	1.250	1.330
0.010	1.400	1.475	1.550	1.620	1.700	1.770	1.850
0.015	1.750	1.820	1.900	1.970	2.050	2.120	2.200
0.020	2.050	2.125	2.200	2.270	2.350	2.420	2.500
0.030	2.650	2.720	2.800	2.870	2.950	3.020	3.100

248. The grinding requirements for plants producing 50 tons of clinker daily can be assumed to be essentially similar to those of the smaller plants considered above. The only difference is the addition of a mill to prepare the raws. It is assumed in the present discussion to be a vertical mill with an initial cost of US$ 30,000, including a full set of equipment. Depreciation and maintenance are somewhat lower than for a ball mill and can be estimated at US$ 0.35 per ton.

249. The power installed would be about 100 kW, and the electrical energy consumption would be about 21-25 kWh/ton. Grinding costs would therefore be:

raw materials (vertical mill)	GR = 0.55 + 0.15 j + 24 w
cement (ball mill)	GC = 0.40 + 0.15 j + 32 w
raw materials and cement	GR + GC = 0.95 + 0.30 j + 56 w

It will be realized that, within the approximate estimates made in this report, there is no appreciable difference between the cost of grinding, per ton of cement, for plants of 20 and 50 tons/day capacity. However, this is because a single mill can be used in the 20-tons-per-day plant, which can practically never be done in larger plants.

250. Plants with outputs of 100 tons/day can be planned similarly as those with 50 tons daily output. As an example, an estimate is made assuming the use of a vertical mill for grinding the raw materials and of a ball mill for grinding the clinker. The initial capital investment for a completely equipped vertical mill would be about US$ 70,000. Its depreciation and maintenance cost can be estimated at US$ 0.45 per ton. The installed electrical power to grind the raw materials will be about 200 kW, and the electrical energy consumption per ton will be about 21-25 kWh.

251. To grind the cement, the initial capital investment for the mill will be about US$ 100,000. Its depreciation and maintenance costs will be US$ 0.40 per ton. In this case the grinding costs, involving an energy consumption of about 21 - 25 kWh per ton for raw materials, and 30 - 34 kWh per ton for cement will be:

raw materials (vertical mill) $GR = 0.45 + 0.08\ j + 24\ w$

cement (rotary mill) $GC = 0.40 + 0.08\ j + 32\ w$

Homogenisation

252. In a plant with a daily output of 20 tons of clinker, homogenisation can be done by quartering and mixing the ground material. One method would be to use four silos with a distributor in which the ground raw material is separately stored. Mixing is done by emptying simultaneously the four silos into a bucket elevator, which lifts the raws up to the above mentioned distributor, thus completing the mixing cycle (see figure III). The cost of such an installation may be estimated at US$ 28,000, to be amortized in ten years. This would mean a yearly depreciation cost of US$ 2,882, including financing. Maintenance can be calculated at US$ 1,500 per year, and the influence of both items on the cost of a ton of cement would be US$ 0.63.

253. The necessary electrical power supply would be 10 kw, and its influence on the cost will be 8 w. Manual labour (2 men) will mean an additional 0.20 j. From the foregoing, the influence on the cost of one ton of cement will be 0.63 + 8 w + 0.20 j. For different values of w and j, this would give:

Electrical power cost (w)	Labour cost						
	0.50	0.75	1.00	1.25	1.50	1.75	2.00
0.005	0.790	0.840	0.890	0.940	0.990	1.040	1.090
0.010	0.830	0.880	0.930	0.980	1.030	1.080	1.130
0.015	0.870	0.920	0.970	1.020	1.070	1.120	1.170
0.020	0.910	0.960	1.010	1.060	1.110	1.160	1.210
0.030	0.990	1.040	1.090	1.140	1.190	1.240	1.290

254. When the daily plant output is 50 tons, homogenization will be done essentially in the same manner as for the smaller plant, but with the aid of compressed air. The initial investment will amount to US$ 30,000, involving a yearly depreciation of US$ 3,123. Maintenance cost will be US$ 2,000 per year. The total effect on the cost per ton of cement will be US$ 0.29.

255. The electrical power required will be 30 kw, resulting in an increment of 9 w to the per-ton cost of the cement, and the manual labour requirement (3 men) involves a cost increment of 0.1 j. From the foregoing it can be seen that the total influence of homogenization on the cost per ton of cement will be as given in the relation 0.29 + 10 w + 0.1 j. For various values of w and j, it will be as follows:

Electrical power cost (w)	Labour cost (j)						
	0.50	0.75	1.00	1.25	1.50	1.75	2.00
0.005	0.390	0.415	0.440	0.465	0.490	0.515	0.540
0.010	0.440	0.465	0.490	0.515	0.540	0.565	0.590
0.015	0.490	0.515	0.540	0.565	0.590	0.615	0.640
0.020	0.540	0.565	0.590	0.615	0.640	0.665	0.690
0.030	0.640	0.665	0.690	0.715	0.740	0.765	0.790

256. In plants producing 100 tons of cement daily, homogenization will be done entirely by compressed air. The initial capital investment for the equipment needed will amount to US$ 57,000 which, if amortized in ten years, will result in an annual cost of US$ 5,869. Maintenance is estimated at US$ 3,000. The influence of this item on the total cost will be US$ 0.26 per ton of cement.

257. The installed electrical power requirement will be 50 kW, adding 5 w to the total cost. The manual labour requirement (3 men) has an influence of 0.05 j. The resulting total increment in cost of one ton of cement due to homogenization will be 0.26 + 5 w + 0.05 j. For varying values of w and j, the results will be as follows:

Electrical power cost (w)	Labour cost (j)						
	0.50	0.75	1.00	1.25	1.50	1.75	2.00
0.005	0.310	0.323	0.335	0.348	0.360	0.373	0.385
0.010	0.335	0.348	0.360	0.373	0.385	0.398	0.410
0.015	0.360	0.373	0.385	0.398	0.410	0.423	0.435
0.020	0.385	0.398	0.410	0.423	0.435	0.448	0.460
0.030	0.435	0.448	0.460	0.473	0.485	0.498	0.510

Calcining

258. The consumption of electrical energy, in terms of kilowatt hours per ton of cement, for various types of kiln are given below, as a general orientation.

Plant capacity (tons/day)	Vertical kiln	Lepol kiln	Long rotary kiln (dry process)	Kiln with heat-recuperators (powder fed)	Kiln (wet process)
20	2[illegible].6	29	37.6	39.6	42.4
50	14.5	22	24.5	30.0	26.0
100	11.5	17.7	19.4	25.2	20.1

259. The minimum installed electrical power in connexion with the kiln and accessories would be as follows:

Plant capacity (tons/day)	Vertical kiln	Lepol kiln	Long rotary kiln (dry process)	Kiln with heat-recuperators (powder fed)	kiln (wet process)
20	25	-	45	-	50
50	45	65	70	-	75
100	70	100	115	145	120

It is assumed here that the Lepol kiln is not used for outputs below 50 tons/day and that heat recuperators are not used for outputs below 100 tons/day.

260. The specific fuel consumptions for the various types of kilns, in kcal/kg of clinker, are as stated below.

	Type of kiln	Daily output 20 tons	50 tons	100 tons
Dry process	Vertical	1150	1050	970
	Long rotary	1800	1575	1470
	Lepol		1130	1050
	Rotary, with heat-recuperator			1050
Wet process	Rotary kiln	2000	1950	1810

261. From the foregoing data the specific fuel consumption can be established: for coal with 6500 kcal/kg (medium-grade coal), for fuel oil of 10,000 kcal/kg and for natural gas of 8500 kcal/m^3.

262. Specific consumption in tons of coal (6500 kcal/kg) per ton of cement.

Type of kiln	20 tons	50 tons	Daily output 100 tons	200 tons	400 tons	1000 tons
Vertical	0.177	0.161	0.149	0.146	0.146	0.146
Long rotary	0.277	0.243	0.226	0.205	0.194	0.161
Lepol	-	0.174	0.161	0.155	0.151	0.135
Rotary, with heat-recuperator	-	-	0.161	0.155	0.151	0.135
Kiln with wet process	0.308	0.300	0.278	0.268	0.257	0.223

263. Specific consumption in tons of fuel oil (10,000 kcal/kg) per ton of cement

Type of kiln	20 tons	50 tons	Daily output 100 tons	200 tons	400 tons	1000 tons
Vertical	-	-	-	-	-	-
Long rotary	0.180	0.157	0.147	0.133	0.126	0.105
Lepol	-	0.113	0.105	0.101	0.098	0.087
Rotary with heat-recuperator	-	-	0.105	0.101	0.098	0.087
Kiln with wet process	0.200	0.195	0.181	0.174	0.167	0.145

264. Specific consumption in cubic meters of natural gas (at 15°C, 750 mm Hg, 8500 kcal/m^3) per ton of cement

Type of kiln	20 tons	50 tons	Daily output 100 tons	200 tons	400 tons	1000 tons
Vertical	-	-	-	-	-	-
Long rotary	210	184	173	156	184	123
Lepol	-	133	123	119	116	105
Rotary with heat-recuperator	-	-	123	119	116	105
Kiln with wet process	235	230	213	205	196	170

265. The influence of calcining on the cost of one ton of cement in a plant producing 20 tons of clinker daily is calculated below. The most suitable kilns for this type of plant are the vertical ones built on the site, the vertical kiln with a metal-plate shell or the tunnel kiln. The first of these only is considered here. It would consist of an approximately cylindrical body, built of bricks and stabilized by a simple metal structure of vertical joists and metal hoops. It will be lined with refractory bricks. Accessories such as the grill, the feeding opening and the proportioning and granulating equipment would be mechanically operated. A kiln of this type might cost about US$ 59,000. Assuming an amortization period of fifteen years, the annual depreciation charge would amount to US$ 6,074, if 6 per cent financing charges are included. The influence on the cost per ton of cement will be US$ 0.867.

266. Maintenance costs are assumed to be US$ 4600 annually; their influence on the cost per ton of cement will be US$ 0.65. The increment in cost of one ton of cement due to the above items will therefore be: 1.517 + 0.6 j + 21.6 w + 0.177 CP depending on the actual magnitude of the daily wage (j), the cost of one kilowatt hour of electrical energy (w) and the price of one ton of the 6500 kcal/kg type of coal (CP). The actual cost in US$ of burning one ton of cement is given below; it is assumed that w is US$ 0.015.

Fuel cost	Labour cost (j)						
(CP)	0.50	0.75	1.00	1.25	1.50	1.75	2.00
13.5	4,530	4,680	4.830	4.980	5.130	5.280	5.430
15	4.796	4.946	5.096	5.246	5.396	5.546	5.696
16.5	5.061	5.211	5.361	5.511	5.661	5.811	5.961
18	5.327	5.477	5.627	5.777	5.927	6.077	6.227
19.5	5.592	5.742	5.892	6.042	6.192	6.342	6.492
21	5.858	6.008	6.158	6.308	6.458	6.608	6,758

267. Kilns suitable for plants producing 50 tons/day of clinker include the vertical automatic kiln, the tunnel kiln and the rotary kiln with heat-recuperator. The first of these is used here to demonstrate the influence of calcining on the final price of the cement. Its cost is estimated at US$ 100,000. If amortised over fifteen years, on the annual depreciation charge of US$ 10.296 will result including financing charges.

268. The resulting influence on the cost per ton of cement will be US$ 0.572. Maintenance costs are estimated at US$ 6500 annually, and the influence on the cost per ton of cement will be US$ 0.361. The total influence of calcining on the cost per ton of cement will therefore be: 0.933 + 0.3 j + 14.5 w + 0.161 CP. This actual amount will depend on the labour cost (j), the cost of electrical energy (w) and fuel costs (CP). The actual cost is as follows, depending on the values of j and CP and assuming w to be 0.015.

Fuel costs (CP)	Labour costs (j)						
	0.50	0.75	1.00	1.25	1.50	1.75	2.00
13.5	3.474	3.549	3.624	3.699	3.774	3.849	3.924
15	3.715	3.790	3.865	3.940	4.015	4.090	4.165
16.5	3.956	4.031	4.106	4.181	4.256	4.331	4.406
18	4.197	4.272	4.347	4.422	4.497	4.572	4.647
19.5	4.438	4.513	4.588	4.663	4.738	4.813	4.888
21	4.679	4.754	4.829	4.904	4.979	5.054	5.129

269. Kilns recommended for plants producing 100 tons/day of clinker include the automatic vertical kiln, the long rotary kiln, the rotary kiln with heat-recuperator and the short rotary kiln. The first of these is used here to demonstrate the influence of calcining on the cement price. The price of this equipment is about US$ 190,000, and its life can be estimated at fifteen years. Annual depreciation charges would thus be US$ 19.563, including 6 per cent annual financing charges. The influence on the cost per ton of cement is US$ 0.558.

270. Maintenance cost would be US$ 12,000, which would increase the cost per ton of cement by US$ 0.343. The total effect on the cost per ton of cement due to calcining will be: 0.90 + 0.2 j + 11.5 w + 0.149 CP. Below is given the effect on the price of cement due to calcining costs, for various values of j and CP, and assuming w = US$ 0.015.

Fuel costs (CP)	Labour costs (j)						
	0.50	0.75	1.00	1.25	1.50	1.75	2.00
13.5	3.183	3.233	3.283	3.333	3.383	3.433	3.483
15	3.407	3.457	3.507	3.557	3.607	3.657	3.707
16.5	3.631	3.681	3.731	3.781	3.831	3.888	3.931
18	3.855	3.905	3.955	4.005	4.055	4.105	4.155
19.5	4.079	4.129	4.179	4.229	4.279	4.329	4.379
21	4.303	4.353	4.403	4.453	4.503	4.553	4.603

271. A rotary kiln may be used with the wet process. Its price would be about US$ 360,000, including all accessories. If the life of the kiln is assumed to be fifteen years, and 6 per cent annual financing charges are allowed for, the yearly amortization costs will be US$ 37,067. Maintenance cost per year will be US$ 20,000. The effect of this item on the cost of 1 ton of cement will be US$ 1.630. The total effect on the cement price, using this type of kiln, and assuming manual labour to be three men per shift, will be 1.630 + 0.1 j + 20.5 w + 0.378 CP. Below the actual cost is given for various values of j and CS if w is assumed to be US$ 0.015.

Fuel costs (CP)	Labour cost (j) 0.50	0.75	1.00	1.25	1.50	1.75	2.00
13.5	5.740	5.790	5.840	5.890	5.940	5.990	6.040
15	6.157	6.207	6.257	6.307	6.357	6.407	6.457
16.5	6.574	6.624	6.674	6.724	6.774	6.824	6.874
18	6.991	7.041	7.091	7.141	7.191	7.241	7.291
19.5	7.408	7.458	7.508	7.558	7.608	7.658	7.708
21	7.825	7.875	7.925	7.975	8.025	8.075	8.125

Cement grinding

272. The clinker from the kiln must be mixed with a small proportion of gypsum and then ground finely until a residue of between 5 and 10 per cent remains after passing through an 88-micron (4900 holes/cm^2) mesh. It is assumed here that grinding is done for 16 hours daily, and the possibility has also been considered of reducing the initial investment by using the same grinding equipment for both the raw materials and the clinker in plants producing 20 tons/day. Under these conditions the daily capacity of the mills would have to be as follows:

Plant output (tons/day)	Grinding of cement only	Grinding of both raws and clinker
20	1.4	2.8
50	3.5	-
100	7	-

273. As examples, the specific electrical energy consumption in kilowatt hours per ton of clinker for each grinding system and for each degree of fineness that is to be attained (residue remaining after passing through an 88-micron mesh).

Grinding system	Kiln used	Per cent residue with 88-micron mesh	Type of mill	
			Simple	With internal devices
Open circuit	Vertical	10	22 to 25	20 to 22
		5	28 to 30	24 to 26
	Rotary	10	25 to 28	22 to 25
		5	35 to 38	30 to 32
Closed circuit	Vertical	10	20 to 22	18 to 20
		5	25 to 27	22 to 24
	Rotary	10	23 to 25	20 to 22
		5	32 to 35	27 to 29

274. Following the above data, the electrical power (in kilowatts) to be installed for grinding purposes in cement plants of the three sizes considered in the present report will be as shown below.

Plant with 20 tons/day output

Grinding system	Kiln type	Per cent residue with 88-micron sieve	Power requirement (kW)	
			Simple mills[a] Cement grinding	Combined mills[a] Grinding of the raws only
Open circuit	Vertical	10	45 - 50	40 - 45
		5	55 - 60	50 - 55
	Rotary	10	50 - 55	45 - 50
		5	70 - 75	60 - 65
Closed circuit	Vertical	10	40 - 45	35 - 40
		5	50 - 55	45 - 50
	Rotary	10	45 - 50	40 - 50
		5	65 - 70	55 - 60

a/ These figures refer only to the grinding of clinker. If the mill is also used to grind raw materials, the electrical power requirement would reflect the requirements of electrical power for this purpose. This is considered above under Drying and grinding of raw materials.

Plant with 50 tons/day output

Grinding system	Kiln type	Per cent residue with 88-micron mesh	Power requirement: Simple mills	Power requirement: Mills with internal devices
Open circuit	Vertical	10	110 - 120	100 - 110
		5	140 - 150	120 - 130
	Rotary	10	120 - 140	110 - 120
		5	170 - 190	150 - 160
Closed circuit	Vertical	10	100 - 110	90 - 100
		5	120 - 130	110 - 120
	Rotary	10	110 - 120	100 - 110
		5	160 - 170	130 - 140

Plant with 100 tons/day output

Grinding system	Kiln type	Per cent residue with 88-micron mesh	Power requirement: Simple mills	Power requirement: Mills with internal devices
Open circuit	Vertical	10	220 - 240	200 - 220
		5	270 - 290	230 - 250
	Rotary	10	240 - 270	220 - 240
		5	340 - 370	290 - 310
Closed circuit	Vertical	10	200 - 220	180 - 200
		5	240 - 260	220 - 230
	Rotary	10	220 - 240	200 - 220
		5	310 - 340	260 - 280

275. The effect of the cement grinding on the cost per ton of cement has been calculated for each type of plant under the heading "Drying and grinding of raw materials" and therefore is not considered here.

Packing and shipment

276. In a plant with a cement output of 20 tons/day, packing is normally done with a simple filling device, and quantity is controlled with a weighing machine. Paper bags are usually used for packing; their cost is about US$ 1.80 per ton of cement. The initial cost of this equipment is estimated at US$ 5000. If amortized in ten years, this represents a yearly cost of US$ 680. The yearly cost of maintenance can be assumed to be US$ 200. The effect on the cost per ton of this part of the installation will be US$ 0.126. The electrical power requirement will be 10 kW, and the number of men required will be five. Thus, the influence of manual labour and electrical energy will be, respectively, 0.3 j and 3.2 w.

277. The total cost of packing and shipment will consequently be as follows: US$ 1926 + 3.2 w + 0.3 j. For various values of w and j, this implies the following values:

Electrical power cost (w)	Labour cost (j) 0.50	0.75	1.00	1.25	1.50	1.75	2.00
0.005	2.160	2.970	2.234	2.271	2.308	2.345	2 382
0.010	2.200	2.237	2.274	2.311	2.348	2.385	2.422
0.015	2.240	2.277	2.314	2.351	2.388	2.425	2.462
0.020	2.280	2.317	2.354	2.391	2.428	2.465	2.502
0.030	2.360	2.397	2.434	2.471	2.508	2.545	2.582

278. In a plant with a daily output of 50 tons of cement, packing is normally done with an automatic cement-packing machine with two outlets. The initial cost of this equipment is US$ 30,000, which, if amortized over a ten-year period, means a yearly cost of US$ 4.076. Annual maintenance costs will be about US$1,000. The effect of both on the cost of one ton of cement will be US$ 0.281. The electrical power needed for this will be consumed two hours per day. The effect on the cost of 1 ton of cement will be 0.8 w. If manual labour is assumed to be five men, this item will amount to 0.15 j. The cost of the bags, assuming they are of paper, is US$ 1.80 per ton of cement, so the cost of packing, bags and shipment, per ton of cement, will consequently be 2.081 + 0.8 w + 0.15 j. Considering difference values of w and j, the following actual values are obtained.

Electrical power cost (w)	Labour cost (j) 0.50	0.75	1.00	1.25	1.50	1.75	2.00
0.005	2.160	2.97	2.234	2.271	2.308	2.345	2.382
0.010	2.200	2.237	2.274	2.311	2.348	2.385	2.422
0.015	2.240	2.277	2.314	2.351	2.388	2.425	2.462
0.020	2.280	2.317	2.354	2.391	2.428	2.465	2.502
0.030	2.360	2.397	2.434	2.471	2.508	2.545	2.582

279. In a plant with a cement output of 100 tons/day, packing is done by an automatic packing machine with two outlets and a conveyor belt (20 m long) running from the silos to the delivery quay. The initial cost of this equipment will be US$ 33,000, and its working life is assumed to be ten years. Its annual depreciation cost will therefore be US$ 4,484, and annual maintenance costs will be US$ 1,000. The effect these charges have on the cost per ton of cement will be US$ 0.157. The electrical power to operate this will be about 25 kW, and it will operate approximately four hours per day. The cost of electricity per ton of cement will therefore be 0.8 w. Manual labour is estimated at three men. Thus, manual labour cost per ton of cement is 0.1 j. (It

will be advisable to have nine men to load trucks.) The cost of paper bags per ton of cement is US$ 1.80. Total cost of packing and shipping per ton of cement is therefore 1.957 + 0.8 w + 0.1 j. The following are the actual amounts for different values of w and j.

Electrical power cost (w)	Labour cost (j)						
	0.50	0.75	1.00	1.25	1.50	1.75	2.00
0.005	2.011	2.036	2.061	2.086	2.111	2.136	2.161
0.010	2.015	2.040	2.065	2.090	2.115	2.140	2.165
0.015	2.019	2.044	2.069	2.094	2.119	2.144	2.169
0.020	2.023	2.048	2.073	2.098	2.123	2.148	2.173
0.030	2.028	2.056	2.081	2.106	2.131	2.156	2.181

Preparation of fuels and additives

280. Because of their great variety and the wide range of differences in the proportions of them that are used, it is difficult to evaluate the influence of the costs of fuels and additives on the cost of the finished cement. Consequently, only the influences of the costs of drying and grinding of coal and of the crushing of gypsum are considered here.

281. The amounts of coal and of electrical energy used per ton of finished cement can be estimated as equivalent to about 15 per cent as much as is required for the drying of the raw materials. The capacity of the coal-drying installation, assuming that it operates for eight hours daily and that drying is done separately from grinding, should be:

Plant capacity (tons/day)	Capacity of drying installation (tons/hour)
20	1
50	2.5
100	5

282. The consumption of electrical energy for coal-drying, per ton of cement, and the installed electrical power required for this purpose will be as follows:

Plant capacity (tons/day)	Consumption of electrical energy (kWh/ton of cement)	Installed power required (kW)a/
20	0.20	1.5
50	0.17	2.5
100	0.15	5.5

a/ If all raw materials must be dried.

283. The amount of fuel, in terms of kilograms per ton of cement, required to dry the coal would be as follows:

Fuel used	Water content of the coal (per cent)							
	3	6	9	12	15	18	21	24
Coal (6,500 kcal/kg)	2.1	3.1	4.3	5.8	6.9	8.4	9.8	15.0
Fuel oil (10,000 kcal/kg)	1.4	2.1	2.8	3.6	4.5	5.4	6.4	7.4

If the gases from the cooling clinker are also used in the drying of the coal, fuel consumption can be reduced as shown below, since about 15 kcal of heat can be recovered per kilogram of clinker.

Fuel used	Water content of the coal (per cent)							
	3	6	9	12	15	18	21	24
Coal (6.500 kcal/kg)	-	0.8	2.0	3.5	4.6	6.1	7.5	9.0
Fuel oil (10,000 kcal/kg)	-	0.6	1.3	3.1	3.0	3.9	4.9	5.9

Nevertheless, the use of these gases from cooling cannot eliminate the need for an auxiliary oven, since the clinker cooler operates only intermittently.

284. Before use in conventional vertical kilns or grinding for use in kilns of other kinds, coal must be crushed so that the particle diameter will not exceed 30 mm. This can be accomplished in roller mills with a consumption of electrical energy similar to that for the crushing of raw materials. Assuming operation for sixteen hours daily, consumption of electrical energy and the requirement for installed power would be as follows:

Plant capacity (tons/day)	Electrical energy consumption (kWh/ton)	Installed power (kW)
20	0.54	2
50	0.54	4
100	0.52	6

285. Coal is normally ground in closed-circuit mills (open-circuit mills are rarely used) at the same time that it is dried. Fuel consumption is about the same as when the drying is done separately, as described earlier.

286. Vertical or ball mills are generally used. The consumption of electrical power in terms of kilowatt hours per ton of cement would be as follows, assuming a 16-hour day, for coal of various degrees of hardness:

Type of coal	Vertical mill	Fanned ball mill	Ball mill with open circuit
Soft	10.0	17.5	24.4
Semi-hard	12.5	19.0	26.0
Hard	14.5	21.8	28.0

The requirement for installed electrical power for coal-grinding, still 16 hours' daily operation of the mill, would be as follows in each case:

Plant capacity (tons/day)	Vertical mills			Fanned ball mill			Ball mill with open circuit		
	Soft coal	Semi-hard coal	Hard coal	Soft coal	Semi-hard coal	Hard coal	Soft coal	Semi-hard coal	Hard coal
20	20	25	30	32	35	40	45	50	55
50	45	55	65	80	85	95	110	115	125
100	90	110	125	155	165	190	210	230	245

287. To calculate the unit cost attributable to the drying and grinding the coal, it is assumed that drying is done in the coal mill, that the initial humidity of the coal is 6 per cent, and that gas from the clinker cooler is utilized. Reference will be made only to a plant with a cement output of 100 tons/day, as it is assumed here that plants with 20- and 50-tons/day capacities are fitted with vertical kilns, for which the coal needs only crushing, not grinding.

288. The initial cost of the coal-grinding mill is about US$ 20,000, including auxiliary equipment. If amortized over fifteen years, the annual depreciation cost will be US$ 2059. Maintenance will be US$ 200. The two items imply a cost per ton of cement of US$ 0.065. Cost of electrical energy, in accord with data cited above, is 19 w and fuel cost is 0.8 CP. Labour cost, assuming that two men are needed, is 0.04 j per ton of cement. Thus, total cost per ton of cement attributable to drying and grinding of coal will be US$ 0.965 + 19 w + 0.0008 CP + 0.04 j. Assuming the cost of manual labour is US$ 1, the cost per ton of cement, depending on the values of CP and w, will be:

Electrical power cost (w)	Fuel costs (CP)					
	13.5	15	16.5	18	19.5	21
0.005	0.211	0.213	0.216	0.218	0.221	0.223
0.010	0.306	0.308	0.311	0.313	0.316	0.318
0.015	0.401	0.403	0.406	0.408	0.411	0.413
0.020	0.496	0.498	0.501	0.503	0.506	0.508
0.030	0.686	0.688	0.691	0.693	0.696	0.698

289. Gypsum crushing is done in a hammer mill with an initial cost of about US$ 600. If the life of this mill is six years, the annual amortization charge will be US$ 125. The annual maintenance costs will amount to US$ 80. Hence

the cost of this item per ton of cement is US$ 0.006. The required installed electrical power is 15 kW, with a cost of 0.063 w. Manual labour, involving one man, will be 0.01 j. Thus power and labour costs per ton of cement will total US$ 0.006 + 0.063 w + 0.01 j. Assuming w = 0.015 and j = 1.00, the cost of gypsum crushing per ton of cement will be US$ 0.017.

CHAPTER SIX

INSTALLING CEMENT PLANTS IN DEVELOPING COUNTRIES

General

290. The problem of cement manufacture in a country in the first stages of industrial development should be considered in relation to its economy as a whole. The initial research includes the aspects that have been mentioned at the beginning of the second chapter of the present report. Using such data, it is possible to develop an initial programme that includes the determination of the number of plants to be installed, the capacity of each and the possible expansions of these plants in the immediate future; that is, within the next ten to fifteen years. The cost of these prior investigations should not be ascribed to a given plant, since it is a preliminary task that applies to the entire construction industry and to the general development programme of the country.

291. Following the decisions taken as described above, a specific study for each particular plant should follow. These specific studies establish the location, volume and accessibility of deposits of raw materials, the characteristics of which should be checked by appropriate field and laboratory tests. The findings should be used to determine plant location, system of manufacture to be used, and decide among alternative methods for exploiting the deposits.

292. The economic studies required to determine the financial commitments that will arise at various stages of the plant-development programme will include these four elements: (a) general study of the plant, (b) initial capital investment, (c) exploitation of the deposits of raw materials and (d) marketing of the cement that is to be produced. If the findings of these economic studies justify the establishment of a cement plant, a contract for its design and construction should be negotiated. It is advisable to assign the contract for the entire project, including the supervision of construction, to a specialized organization that can co-ordinate and inspect the manifold phases of design and construction. The number of contractors, sub-contractors, suppliers, erection specialists and the like will be large, and close co-ordination and supervision will be necessary to prevent confusion, delays and unacceptable work.

293. The contract should cover all of the following aspects of the proposed operation:

(a) Arrangements for the exploitation of the raw materials and their transportation to the plant

(b) Provision of access roads, communications, and water and electrical power supplies

(c) Design of the plant itself, which would include civil engineering (including site conditioning, sanitary engineering, sanitary installations, buildings and internal communications), selection, arrangement and installation of the machinery, and provisions for the distribution of high- and low-tension electrical power. (In some cases, the installation of an electrical power plant will be necessary.)

(d) Manufacturing and exploitation methods

294. The actual construction of the plant will involve (a) civil engineering, including scheduling of construction, (b) surveying of the plant site, (c) inspection of the work, when completed as well as while in progress, (d) approval of payments to the contractor, and (e) final settlement of amounts due to suppliers, subcontractors and the like.

295. Machinery installation will include the following phases: (a) scheduling of machinery erection, (b) reception, transportation to the site and storage of imported and locally manufactured machinery, (c) inspection of the machinery erection in general, and the completion of the secondary installations, (d) period of operation of the machinery without load, (e) operation of the machinery with loads and fuel, (f) tuning the machinery to full working order and (g) settlement of outstanding claims. The electrical installation and other services will pass through phases of development similar to those described for machinery.

<u>Plant with a cement output of 20 tons/day</u>

296. Since many new cement plants will be needed throughout the world, especially in the developing countries, it would appear to be desirable to rationalize their construction by the design of standardized elements, which might be termed "basic elements", envisaged for mean operating conditions with respect to fuels, raw materials, communications and supply of electrical energy. These basic elements should be easy to transport and assemble, have uncomplicated mechanisms and be low in cost. They should be centred on grinding (with either separate mills for raw materials and fuel or a single mill for both purposes) and calcining. These basic elements, with their connexions, attachments and the like, could be combined into standard groups or assemblies.

297. Each 20-ton-per-day plant should be so planned that it could be set up using alternative combinations of these basic elements. Only rarely should modifications

be required that would involve a greater degree of mechanization than that provided by the basic elements. These plants should be easily capable of easy and economical expansion to daily capacities of 50 to 60 tons of cement. The functional pattern of such a plant has been sketched in figure VII.

298. Such standardization would serve at least the five following purposes: (a) reduction of the design cost for individual plants, (b) reduction in the cost of machinery, (c) standardization of plant assembly, thus permitting economies in both time and cost, (d) facilitation of the interchange of spare parts and (e) centralization of the training of personnel. Centres having pilot plants with production capacities in the range of 5-10 tons/day could be suitable for the purpose of investigating the feasibility of such standardization.

299. The amounts of capital and labour required, the electrical power supply to be installed and the technical production costs for such a 20 ton/day plant can be estimated on the basis of the data presented in the third, fourth and fifth chapters of this report. A typical example is presented in tabular form, based on the following assumptions: (a) general conditions in the country - dry climate, easy access to plant site, mean daily wage (j), US $1.00; (b) costs of materials - electrical energy per kilowatt hour (w), US $0.015; fuel and lubricant (gas oil) cost per litre (CL), US $0.06; (c) fuel - coal (6500 kcal/kg) per ton (CP), US $16.00; fuel oil per kilogram (F_0), US $0.03; (d) raw materials - carbonate-rich marls (6 per cent humidity), clay in easily exploited deposits. No calculations are made for fusion and corrective agents.

300. The installed power (kW), the number of employees (NE) and the cost of machinery and assembly (in US $1000) are approximately as follows:

	kW	NE	US $1000
I - Preparation of materials			
Management and control	-	2	-
Quarrying (by hand)	5	10	3.0
Transport to crusher	-	10	5.5
Crushing	20	3	4.8
	25	25	13.3

	kW	NE	US $1000
II - Transportation and storage			
Management and control	-	1	-
Transportation to silos	-	4	1.5
Homogenization in silos	-	2	-
	0	7	1.5
III - Conditioning of raw materials			
Management and control	-	2	-
Transportation of materials	-	4	-
Drying of raw materials	3	1	31
Grinding	120	5	43
Homogenization	10	2	35
	133	14	109
IV - Calcining			
Management and control	-	2	-
Transportation to kiln	-	7	-
Kiln, including granulation	25	8	78
Transport of crushed clinker	-	5	2
	25	22	80
V - Cement grinding			
Similar to "Conditioning of raw materials", as shown above.			
VI - Homogenisation of cement and storage			
Management and control	-	2	-
Transportation to cement silo	-	3	13.00
Packing, shipping and various	15	6	2.50
	15	11	15.50
Miscellaneous			
Storage of fuel and water etc.	5	2	11.50
Workshop, stores, laboratory etc.	10	12	19.00
Planning of site and approaches	2	-	3.00
Electricity grid	-	-	28.00
	17	14	61.50

Summary	kW	NE	US $1000
Preparation of materials	25	25	13.30
Transport and storage	0	7	1.50
Conditioning of raw materials	133	14	109.00
Calcining	25	22	80.00
Cement grinding	0	0	0
Homogenization and storage of cement	15	11	15.50
Miscellaneous	17	14	61.50
	215	93	280.80

301. The establishment of a plant with a clinker output of 20 tons/day, i.e. producing about 7,000 tons/year, might involve a capital outlay of the following magnitude:

Machinery and assembly	US$ 280,800
Civil engineering works	220,000
Miscellaneous	60,000
Total	US$ 560,800

302. Production costs would vary considerably, but in accord with the data given in the preceding chapter, they can be evaluated approximately as follows:

Financial charges (amortization of US$ 560,800 over 15 years, at 6 per cent	US$ 8,248
Labour	4,350
Electrical energy	1,650
Fuel	2,320
Executive[a] and administrative staff	2,300
Miscellaneous	1,900
Total	US$ 21,268

a/ This item is very variable. For a small-scale operation such as that described here, the expense of an executive staff of about five persons would increase the total production cost excessively. It is therefore assumed, in this example, that the cost of the executive team is distributed among three similar plants.

303. If the cement is to be shipped in paper bags, their cost must be allowed for. As already noted, this cost can be estimated roughly at US $1.30 per ton of cement. Hence the cost of the cement, at the plant loaded on trucks, would amount to about US $23.10 per ton. The selling price of the cement would of course be higher, since overhead expenses, distribution costs, marketing, taxes, profits and the like must be added. Account also must be taken of the cost of transporting the machinery to the site, especially if it has been imported, in which case customs duties, import licenses and the like must be included as well. (See Annex table.)

Plant with cement output of 50 tons/day

304. As in the previous case, the cement plant with an output of 50 tons/day should be subject to a general study to determine a number of basic elements, designed and tested to work with various calcining methods (vertical kiln, tunnel kiln etc.) and using different types of raw materials. The design of the standard elements should involve a thorough technical investigation to bring into full development the various manufacturing phases, as emphasized in the course of this report. If an installation similar to that at the Instituto Eduardo Torroja be used, the development of the principal standardized elements should take only about two years. Basically, the aspects that would require detailed study and development are those relating to calcining in vertical kilns, tunnel kilns and short rotary kilns, with and without heat recuperators. The drying of raw materials should be made simpler and less costly and their in-plant transportation should be standardized as far as possible. The drying and grinding units would require most attention in research, since in very small plants the fuel consumption for drying may be disproportionately higher than that for calcining.

305. The sketch in figure VIII gives a general pattern of a cement plant with an output of 50 tons/day that is envisaged as an extension of a 20 tons/day plant, the basic difference being that the larger plant has two mills; one for raw material and one for clinker. The raw materials mill will preferably be a vertical one, since mills of this kind are relatively inexpensive. The cement mill is the same as for the smaller plant, but it only grinds cement, and not raw materials. Quarrying operations will be rather more mechanized than for the smaller plant, and in many cases it would even be advisable to have a loading shovel. The crusher used in the smaller plant could serve in this larger one, but the feeding system should be improved to regulate production. Summarizing

the data given in previous chapters, it is relatively easy to obtain the approximate amounts of invested capital, installed power, number of employees and working costs for a plant producing 50 tons of clinker daily; i.e. about 18,000 tons of cement annually.

306. As an orientation, and on the same basis as was done above for the 20 tons/day plant, calculations are given below for a plant with an output of 50 tons/day. The installed power (kW), the labour requirement (NE) and the cost of machinery and assembly (in US$) would be approximately as follows:

		kW	NE	US $1000
I	Preparation of materials			
	Management and control	-	2	-
	Quarrying (by hand)	5	31	2.5
	Transport to crusher	-	14	11
	Crushing	25	3	8.5
		30	50	22
II	Transportation and storage			
	Management and control	-	1	-
	Transport to silos	5	8	12
	Homogenization in silos	-	5	-
		5	14	12
III	Conditioning of raw materials			
	Management and control	-	2	-
	Transport of materials	-	8	2
	Drying of raw materials[a]	6	2	46
	Grinding (vertical mill)	130	5	38
	Homogenization	30	3	47
		166	20	133
IV	Calcining			
	Management and control	-	2	-
	Transportation to kiln	-	10	1
	Kiln, including granulator and feeder	45	8	130
		45	20	131

---

a/ Drying need not be a separate operation; it can be done together with the grinding.

		kW	NE	US $1000
V	Cement grinding			
	Management and control	-	1	-
	Transportation of ground clinker	10	3	10
	Complete mill	130	5	43
	Cement homogenization, powder removal and various	20	2	37
	Transportation to cement silo	10	2	18
		170	13	108
VI	Packing and shipment			
	Management and control	-	1	-
	Packing, shipment and various	30	12	42
		30	13	42
Miscellaneous				
	Storage of water, fuel etc.	5	2	15
	Workshops, stores, laboratory etc.	30	15	25
	Planning of site and approaches	5	2	4
	Electricity grid	-	-	45
		40	19	85
Summary				
	Preparation of materials	30	50	22
	Transport and storage	5	14	12
	Conditioning of raw materials	166	20	133
	Calcining	45	20	131
	Cement grinding	170	13	108
	Packing, shipment and various	30	13	42
	Miscellaneous	40	19	85
	Total	486	149	533

307. The plant producing 50 tons of clinker daily, i.e. about 18,000 tons of cement annually, might involve the following capital investment:

Machinery and assembly	US$ 533,000
Civil-engineering works	421,000
Various	80,000
Total	US$ 1,034,000

308. Although production costs can vary considerably, they should be basically as described in the previous chapter and can be evaluated approximately as follows:

Financing charges (amortization of US$ 1,034,000 over 15 years, at 6 per cent annually)		US$ 5,915
Labour cost		3,021
Electrical energy		1,787
Fuel		2,578
Executive and administrative staff		2,300
Miscellaneous (10 per cent)		1,560
	Total	US$ 17,004

309. As with the smaller plant, if the cement is to be shipped in paper bags, their cost (approximately US$ 1.80 per ton of cement) must be considered. Thus the approximate production cost, per ton of cement at the plant, loaded on trucks, would be about US$ 17.30. Here, also, the actual selling price would be higher, since it would have to include marketing costs, overhead, profits, distribution taxes, and the like. Also, as in the earlier example, the cost of transporting the machinery to the plant site must be considered, especially if it is imported, in which case customs duties, import licences and the like become important cost elements. (See Annex table.)

<u>Plant with a cement output of 100 tons/day</u>

310. The operations of relatively large-scale plants (that is, those with outputs of 100 tons/day) differ considerably from those of the smaller ones (outputs of 20 and 50 tons/day) that have been considered. For the conditioning of the raw materials alone, two administrative posts would be required. Quarrying and transportation of the marls is done in a manner that will maximize the use of manual labour, with the use of wheelbarrows, so that 61 persons would be thus employed. The initial investment in this situation would be very low, of the order of US$ 3,000, and the effect on the cost per ton of cement, attributable to quarrying would be US$ 0.78, assuming a daily wage of US$ 1.00. The excavation of clay materials would imply an investment of about US$ 1,000 and would involve the employment of 10 persons. The influence of this item on the cost per ton of cement would be US$ 0.16. Thus the excavation of marls and clays would provide employment for 71 manual labourers and would involve an investment of US$ 4,000. Its influence on the price per ton of cement would be about US$ 0.940.

311. Transportation, although done primarily with hand labour, would probably also require the use of two trucks, for various purposes. This would involve an investment of about US$ 11,000, amortized over five years, and the employment of four persons. The influence of this added transportation cost on the per-ton cost of cement would be US$ 0.25 if the mean wage were US$ 1.00 and gas-oil cost were US$ 0.06 per litre.

312. The use of an impact crusher would require the installation of about 50 kW of electrical power and a yearly electricity consumption of 42,700 kWh. The initial investment costs would be US$ 15,000 for the machinery and motors and US$ 7,000 for assembly costs, including auxiliary elements and the electrical grid for this part of the plant. Two labourers would be needed. If the cost of one kilowatt hour is US$ 0.015 and the mean daily wage (j) is US$ 1.00, the influence on the cost of the cement attributable to manual labour, energy and maintenance, would be about US$ 0.170.

313. The preparation of the raw materials would therefore involve the following costs:

Labour requirement (NE)	
Management	2
Marl quarrymen	61
Clay quarrymen	10
Drivers and mechanics	4
Crusher operators	2
Total NE	79
Capital investment	
Tools and trucks, amortized over 5 years	US$ 15,000
Machinery, amortized over 15 years	22,000
Civil-engineering works, amortized over 20 years	58,000
Total investment	US$ 95,000
Financing charges for the amortization at 6 per cent interest of the invested capital given in the previous heading	
Tools and means of transport	US$ 3,561
Heavy equipment	2,265
Civil-engineering works	4,057
Total	US$ 10,883

Influence on the cost per ton of cement

Quarrying		US$ 0.910
Transportation		0.245
Crushing		0.165
Financing charges		0.310
	Total	US$ 1,630

314. Production costs can be reduced easily by mechanization of quarrying and transportation. This would mean an additional investment of about US$ 60,000, but the number of jobs would be reduced by more than half, and this might not be desirable where one of the objectives of industrialization is to provide permanent employment in some sections of the population.

315. If most of the manual labour used in the 100 tons/day operation for transportation and storage is concentrated at the quarry face and in outdoor transportation, it is to be understood that the plant should be considerably more mechanised than the 20- and 50-ton/day plants that have been considered, since indoor transportation by hand is unsuitable for the large-scale operation considered here. Two persons can organize and operate the transportation from the crusher and clay bin to the materials storage. Transport from the crusher to storage can be done with a conveyor belt whose cost will depend upon its length and slope, but in general terms it will amount to US$ 18,000. To conserve foreign currency, the plant can be planned so that the same belt can carry both the limestone and the clay. This could be done by the addition of supplementary length, that might cost about US$ 8,000.

316. The distribution of materials within the storage facility should be done from above, and it is natural that this also be done by a conveyor belt system whose cost, including bins, guides, etc., might be of the order of US$ 20,000. Its operation should occupy two men. Although the electrical power required to operate indoor transport may vary considerably, it can be roughly estimated at about 20 kW. The silo capacity should be about 15,000 m^3, to deal with a three-month output, and it could be provided with a bridge crane or one with under-side unloading.

317. Experience has shown that, in cases similar to this, it is cheaper to unload at the end, with the aid of tubs, which are carried by conveyor belts and bucket elevators. However, it would be advisable to have a loading shovel for auxiliary operations. This might cost about US$ 12,000 and require one man to operate it.

Within the general system whereby unloading is done at one end, there are many variants. The simplest of these is to load the material on hand trucks and move it to the mill bins. This can be done when the ground has a suitable slope, and might provide employment for 20 men. An alternative would be to use a travelling hopper with a special scraper. This arrangement has the advantage of providing good homogenization, but the equipment is very expensive and needs two men to operate it. Finally, fixed bins can be utilized, unloading straight on the conveyor belts. This third system is simpler and cheaper to operate than the second one. It also requires two operatives.

318. For the purposes of the example under consideration, and only to provide a general orientation, transportation by hand is assumed. This requires very cheap installations, costing only about US$ 10,000. Storage and homogenization costs consequently give the following figures:

Labour requirement (NE)	25
Capital investment	
Machinery (amortization over 15 years)	US$ 58,000
Civil work (amortization over 20 years)	63,000
Total	US$ 121,000
Financing charges per year to amortize machinery and civil works, at 6 per cent annually	US$ 11,426
Influence on the cost per ton of cement	
Manual labour	US$ 0.211
Energy, fuel, maintenance and miscellaneous	0.119
Financing charges	0.657
Total	US$ 0.987

319. Production costs can be reduced by almost the total of the manual labour costs, i.e. US$ 0.15 per ton of cement, merely by mechanizing transportation. This would entail an investment of about US$ 35,000, but would deprive about 18 men of their livelihoods, but this solution will have to be adopted in many cases if conditions are less favourable than they are assumed to be in the above example.

320. In the conditioning of the raw materials, the tasks of inspection and control might occupy two men. If, as has been assumed, the raw materials have a low humidity (approximately 6 per cent), they could be dried in the mill itself, merely by the addition of an auxiliary oven. However, to take a more typical situation, we shall assume the need for prior drying and the employment of two men for this purpose. The drying installation will require the installation of 12 kW of electrical power and the investment of US$ 45,000, amortized over 10 years. The influence of labour, electrical energy, spare parts, maintenance and the like on the cost per ton of cement is about US$ 0.83.

321. Transportation from the drying installation to the mill should be done automatically. The cost of elevators and conveyors might be about US$ 5,000, and necessary installed electrical power about 5 kW. The grinding equipment should include a vertical mill with a capacity of about 10 ton/hour, with recirculation circuit by air, filters, cyclones and fans, and costing about US$ 70,000, to which another US$ 10,000 should be added for accessories and assembly. The required electrical power installation would be about 200 kW. Five men would be needed to operate this equipment; the cost of labour, maintenance, electrical power, lubricants, spare parts and so on would mean a further cost of US$ 0.69 per ton of cement. Homogenization requires an investment of US$ 57,000 and the installation of 50 kW of electrical power. Three operators will be needed. The assembly of this section and its accessories will cost approximately US$ 8,000. The influence on the final cost of the cement attributable to supply of power, maintenance and labour is US$ 0.215 per ton.

322. Hence, in a cement plant with a daily capacity of 100 tons, the conditioning of the raw materials involves the following total costs:

Labour requirement (NE)	10
Capital investment	
to be amortized over 10 years	US$ 50,000
to be amortized over 15 years	145,000
Total	US$ 195,000
Civil-engineering works, to be amortized over 20 years	US$ 143,000

The amortization charges at 6 per cent yearly on the above investment are as follows:

US$ 50,000 over 10 years	US$ 6,794
US$ 145,000 over 15 years	15,945
US$ 143,000 over 20 years	12,468
Total	US$ 35,207

The influence on the cost per ton of cement can be estimated as:

Depreciation		US$ 1,004
Exploitation		1,683
	Total	US$ 2,687

The requirement of installed electrical power will be about 270 kW.

323. If, for calcination, a vertical automatic kiln is adopted, two men may be needed for its supervision and control. Allowance should be made for automatic transport by means of a bucket elevator, which may cost about US$ 4,000, including assembly and accessories, to be amortized in 10 years. The installed electrical power will be 10 kW. The cost of transportation, including manual labour, repairs, electricity etc. will be about US$ 0.05 per ton of cement.

324. The vertical kiln for a plant of this size will be approximately 1.80 m in diameter and 8 m high. It will cost US$ 190,000, and its assembly and putting into operating order will amount to US$ 50,000, including all accessories and the more essential spare parts. Eleven men will be needed to operate it, and the installed electrical power necessary will be 70 kW. Civil-engineering works will cost about US$ 88,000, including clinker-storage, silo, conveyor belt, coolers etc. Annual maintenance cost, including replacement of refractory material, is about US$ 12,000. The cost per ton of cement attributable to labour, maintenance, electrical energy, fuel etc. is about US$ 3.18. Consequently, the calcination part of the cement-production process entails the following costs:

Labour requirement (NE)		13
Capital investment		
Amortized over 10 years		US$ 4,000
Amortized over 15 years		328,000
	Total	US$ 332,000
Financing charges to amortize the installation:		
Amortization in 10 years		US$ 544
Amortization in 15 years		33,772
	Total	US$ 34,316

The effect on the cost per ton of cement will be US$ 1.00. Effect for the calcination process on the cost of production, per ton of cement, will be

Depreciation		US$ 0.970
Exploitation		3.134
	Total	US$ 4.104

325. Cement grinding in this typical cement plant of 100 tons/day capacity would be done by tubular open-circuit mill, with fans and dust installation but without electrostatic filters. Only one operator would be needed. The installation cost would be US$ 100,000, plus US$ 10,000 for assembly and accessories. The manual labour requirement might be 5 men, and installed electrical power about 350 kW. Cost including manual labour, repair of steel shell and lining, grinding elements, maintenance, electricity etc. might amount to US$ 0.76 per ton of cement. Cement homogenization, transportation etc. would require 2 men and 50 kW of electrical power, with a cost of US$ 50,000, including assembly and spare parts. This would add US$ 0.16 to the per-ton cost of cement. Hence, milling and homogenizing gives the following figures:

Labour requirement (NE)	8
Capital investment in machinery and assembly	US$ 160,000
Civil-engineering works	US$ 50,000
Installed electrical power	370 kW
Financing: yearly charges for amortization over 15 years, at 6 per cent interest, would be	US$ 21,624
Yearly cost per ton of cement will be:	
Depreciation	US$ 0.773
Exploitation	0.736
Total	US$ 1.509

326. Storage, packing and shipment will require 4 men for administration and control and 12 labourers. The required installed electrical power will be 50 kW, the civil-engineering works (including the silos) will cost US$ 132,000, and machinery will cost US$ 45,000. The influence on the cost, due to supply of power, maintenance and labour, of storage, packing and shipment is US$ 0.140 per ton of cement. The financing charges to amortize the machinery over 10 years, at 6 per cent interest, and the amortization of the civil-engineering works over 20 years will be as follows:

Machinery	US$ 6,114
Civil-engineering works	11,508
Total	US$ 17,622

This implies a cost of US$ 0.55 per ton of cement.

327. Storage in silos and packing involves the following expenses:

Labour requirement (NE)	16
Machinery investment (including assembly)	US$ 45,000
Civil-engineering investment	US$ 132,000
Installed power	50 kW

The cost of the above items per ton of cement will be:

Depreciation	US$ 0.533
Exploitation	0.136
Total	US$ 0.669

328. Various other items such as workshops, stores, water and fuel tanks, and laboratories will mean an investment of about US$ 70,000 in civil-engineering works, to which a further US$ 133,000 should be added to cover prior work such as site-levelling, construction of approach roads and site planning. A total of US$ 203,000 will be involved, to be amortized over 20 years. The financing charges for the above would be US$ 17,700 per year, implying a cost of US$ 0.521 per ton of cement.

329. Electrical installation, workshop equipment and the like might amount to US$ 80,000 which, if amortized over 15 years at 6 per cent interest, would cost US$ 8,237 per year. This would mean an effect of US$ 0.142 on the cost per ton of cement. The labour requirement for these ancillary services, such as workshop, laboratory and maintenance, will be about 25 men; this would add US$ 0.25 to the cost per ton of cement. These various services will involve the following amounts:

Labour requirement (NE)	25
Capital investment in machinery	US$ 80,000
Civil-engineering	US$ 203,000
Installed electrical power	50 kW

The cost of these services, per ton of cement, will be:

Depreciation	US$ 0.643
Labour cost	0.243
Energy and miscellaneous	0.133
Total	US$ 1.019

330. The summary of costs per ton for a plant with a clinker output of 100 tons per day, will consequently be as shown below:

Item	Installed electrical power (kW)	Labour requirement (NE)	Investment machinery[a]	Civil-engineering works (US$ 1000)	Influence on the cost per ton of cement
Preparation of raw materials	50	79	37	58	1.630
Transportation and storage	20	25	58	63	0.987
Conditioning of raw materials (incl. homogenizing and drying)	270	10	195	143	2.687
Calcining	80	13	244	88	4.104
Cement grinding	370	8	160	50	1.509
Storage and packing	50	16	45	132	0.669
Miscellaneous	50	25	80	203	1.019
Total	890	176	819	737	12.605

a/ Including assembly and installation.

331. The initial capital investment for a cement plant with an output of 100 tons/day, under the circumstances specified in this report, would require an outlay of the order of US$ 1,556,000, to which transportation, customs duties, taxes and other expenses must be added. The total requirement for installed power will be about 900 kW, and the number of employees (NE) required will be about 176. The production cost will be, as shown above, US$ 12.605 to which US$ 1.30 must be added for technical and administrative staff, plus US$ 0.705 for various other items not considered in the estimate. Consequently, the production cost per ton of cement in the plant described will be about US$ 15.00, to which the price of the cement bags, which may be about US$ 1.80 per ton, should be added. The final cost of producing a ton of cement would thus be US$ 16.80.

332. Obviously, as in the cases of the smaller plants described earlier, the selling price of the cement will be much higher, as it must also include overhead expenses, distribution and marketing costs, taxes, profits and the like. Similarly, account must be taken of the cost of transportation of the machinery to the

site of the plant, especially when it must be imported and charges such as customs duties and import licences must be considered. See Annex table for a comparison of the costs of cement plants of the three sizes (outputs of 20, 50 and 100 t 100 tons/day.)

CHAPTER SEVEN

SUMMARY AND CONCLUSIONS

Summary

333. In this report consideration is given to the possibility of manufacturing artifical cement on a small scale, that is, in plants with clinker outputs of 20, 50 and 100 tons/day.

334. Chapter one, contains a brief study of the most important cements made at present, as well as details of their output and consumption.

335. In chapter two the technical and economic aspects of the initial capital investment and the cost of running this type of industry are analyzed.

336. Chapter three describes the systems and processes involved in the manufacture of Portland cement, as well as the methods that are regarded as most suitable to make cement on a small scale (that is, 20, 50 and 100 tons/day of clinker).

337. Chapter four enumerates, defines and studies the most suitable and the most unsatisfactory characteristics of the raw materials, fuel, electrical energy, that are basic needs to manufacture Portland cement. The extraction and transport of the raw materials is also discussed.

338. In chapter five the production equipment involved in the various processes are shown and also the capital investments involved in each of them, as well as the required numbers of employees, thermal and electricity consumption and the like. The influence of these factors on the per-ton cost of cement is also given.

339. In chapter six a technical-economic study is made covering the establishment of three possible types of cement plants in developing countries, with manufacturing outputs of 20, 50 and 100 tons/day respectively. Plants of these three sizes are compared in tabular form in the Annex to this report.

Conclusions

340. First, the report has been compiled primarily on the basis of global figures, so as to give an idea of the general order of magnitude of the pertinent factors.

341. Second, the influence of the varying costs of the principal items of expenditure, among them labour requirements, fuel costs, electrical energy needed, costs of machinery assembly, civil engineering costs, and provisions for lubricants, spare parts and the like has made it possible to arrive at over-all total costs, which should be taken into account when considering the possibility of applying these solutions in the various countries for which they are intended.

342. Third, from the above analysis it becomes clear that it is possible to establish in many cases, plants with clinker outputs of 50 tons/day that should solve the cement-production problem in many developing regions.

343. Fourth, the setting up of plants with 20 tons/day outputs of clinker may constitute, in exceptional instance, the basis for providing jobs, and making the utmost use of available manual labour. Nevertheless, it should always be remembered that this should not be taken as a general type of solution.

344. Fifth, plants that are capable of producing 100 tons/day of clinker fall within current industrial practice, and such plants could solve the cement problem in relatively extensive zones.

345. Sixth and finally, it is explained that specific research will be required to bring certain manufacturing processes or standard manufacturing units that are involved in the plants considered in this report; this applies especially to plants with a clinker output of 50 tons/day. Plants such as these would be particularly suitable for countries now in development. Such research could be done with relative rapidity and at reasonable cost.

ANNEX

Comparative Cost Data on Portland Cement Manufacture in Plants of 20,50 and 100 tons/day Outputs

	20 tons/day			50 tons/day			100 tons/day		
	Installed electrical power (kW)	Employees needed	Machinery and assembly (US$ 1000)	Installed electrical power (kW)	Employees needed	Machinery and assembly (US$ 1000)	Installed electrical power (kW)	Employees needed	Machinery and assembly (US$ 1000)
Comparison:									
Preparation of materials	25	25	13.3	30	50	22	50	79	37
Transportation and storage	—	7	1.5	5	14	12	20	25	58
Conditioning of raws	133	14	109.0	166	20	133	270	10	195
Calcining	25	22	80.0	45	20	131	80	13	244
Cement grinding	-	-	-	170	13	108	370	8	160
Packaging, storage and various	-	-	-	30	13	42	50	16	45
Homogenization and storage of clinker	15	11	15.5	-	-	-	-	-	-
Miscellaneous	17	14	67.5	40	19	85	50	25	80
	215	93	280.8	486	149	533	890	176	819

	20 tons/day	50 tons/day	100 tons/day
Capital outlay			
Machinery and assembly	US$ 280,000	US$ 533,000	US$ 739,000
Civil engineering	220,000	421,000	537,000
Miscellaneous	60,000	80,000	283,000
Total capital outlay	US$ 560,800	US$ 1,034,000	US$ 1,559,000
Production costs per ton (approximate)			
Financing charges (amortization of total capital outlay over 15 years at 6% per annum)	US$ 8.248	US$ 5.915	US$ 12.605
Labour cost	4.85	3.021	-
Electrical power	1.65	1.787	-
Fuel	2.[illegible]	2.578	-
Staff	2.30	2.300	1.30
Miscellaneous	1.90	1.560	0.705
Production cost (unpackaged)	21.268	17.161	14.610 - 15.00/ton
Packaging	1.800	1.800	1.80
Final cost per ton of cement	US$ 23.068	US$ 19.061	US$ 16.80

18. 5. 73