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PLANT REQUIREMENTS FOR MANUFACTURE OF CEMENT

A.I.D.
Reference Center
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DEPARTMENT OF STATE
AGENCY FOR INTERNATIONAL DEVELOPMENT
COMMUNICATIONS RESOURCES DIVISION
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FOREWORD

This brochure is one of a series of reports resulting from overseas technical inquiries on factory or commercial establishments, operation, management, and engineering. The report is designed to provide only a general pic e of the factors that must be considered in establishing and operating a factory of this type. In most cases, plans for actual installations will require expert engineering and financial advice in order to meet specific local conditions.

Mention of the name of any firm, product, or process in this report is not to be considered a recommendation or an endorsement by the Agency for International Development, but merely a citation that is typical in its field.

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The original report was prepared in May 1957 by Edmund A. Pratt, Consulting Engineer, Berkeley Heights, New Jersey, for the the technical aids program through the facilities of the Office of Technical Services, U.S. Department of Commerce.

Technical information, as well as review, was provided by R. Polinkoff, Industrial Consultant, 126 Eleventh Avenue, New York 11, New York.

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This report has been revised and rewritten by George H. Andrews Engineering Associates, Inc., All Southern Building, Washington 5, D. C.

For further information and assistance, contact should be made with the local Productivity Center, Industrial Institute, Servicio, or United States Operations Mission.

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C E M E N T

SECTION I WET PROCESS CEMENT PLANT

INTRODUCTION

The purpose of this report is to present basic information for establishing a plant in a foreign country to produce portland cement.

GENERAL ASSUMPTIONS

In order to make realistic estimates in this report, certain assumptions are made. These are:

1. The costs of the building and general facilities are based on United States prices.

2. Material costs are based on sizes and specifications of materials used in the United States.

3. Labor costs are based on the average for the industry as recently published by the United States Bureau of Labor Statistics.

4. Adequate power and water are available at the plant site.

5. Adequate transportation facilities are available at the plant site.

6. The plant operates three eight hour shifts a day, seven days a week, three hundred and thirty days a year.

7. No special provision is made for the training of new personnel. It is assumed that learner's rates are paid in such cases.

8. The following items cannot be estimated realistically:

   A. Land value.
   B. Distribution and selling costs.
   C. In-freight and out-freight.
   D. Administrative costs.
   E. Taxes.

   While general estimates will be made of each of these items, for the purpose of completing cost estimates, adjustment should be made in accordance with actual local costs.

   In fact, all cost estimates contained in this report should be adjusted to conform to local conditions.

9. Columns are provided in the tables included in this report to facilitate the conversion of cost figures to conform with local costs.

PRODUCT SPECIFICATIONS

Portland cement, as defined by A.S.T.M. (American Society for Testing Materials).

Standard Specifications for Portland Cement, which are widely accepted abroad as well as in the United States follow:

> "For the purpose of these specifications, portland cement is the product obtained by pulverizing clinker consisting essentially of hydraulic calcium silicates, to which no additions have been made subsequent to calcination other than water and/or untreated calcium sulfate, except that additions not to exceed 1.0 per cent of other materials may be interground with the clinker at the option of the manufacturer, provided such materials in the amounts indicated have been shown not to be harmful by tests carried out or reviewed by Committee C-1 on cement."

Composition

The chemical analysis of portland cement shows it to be composed almost entirely of oxides of calcium, silicon, aluminum and iron, with small percentages of magnesia and sulphur trioxide, the latter being derived primarily from gypsum added as a retarder. The constitution of all the compounds formed by the combination of these oxides is not perfectly known, but it is agreed by most authorities that four principal constituents account for all but a small fraction of portland cement clinker composition. These are: tricalcium silicate ($3CaO.SiO_3$), dicalcium silicate ($2CaO.SiO_3$), tricalcium aluminate ($3CaO.Al_2O_3$) and tetracalcium aluminoferrite ($4CaO.Al_2O_3.Fe_2O_3$). For the sake of simplicity these compounds are represented by the symbols C_3S, C_2S, C_3A and C_4AF, respectively. In the manufacture of portland cement the close control of raw material proportioning and of the burning operation, so as to produce a clinker containing these compounds in the proper relative amounts, is a very important factor. By adjusting the relative proportions of the four principal constituents within narrow limits, and with modifications of processing, a variety of types of portland cement can be produced. These types differ in some of their properties and are designed to fill specific requirements of engineering construction. The bulk of production (95 per cent in the United States) is of A.S.T.M. Types I and II. Air-entraining cements of these types are designated Types IA and IIA.

Masonry Cement

A cement specially designed for making mortar suitable for cementing together masonry units such as bricks, concrete blocks, and cut stones, can readily be produced in a portland cement plant, and is made in many plants. Masonry cement, for which there are two tentative A.S.T.M. specifications, is generally a combination of crushed limestone interground with portland cement clinker, with the addition of a small quantity (about 0.2 per cent) of an air-entraining agent. Gypsum is added as in the production of regular portland cement. Masonry cements may also be made by intergrinding portland cement clinker and blast furnace slag, or mixing portland cement with diatomaceous earth.

For the purpose of this report all cost figures will be based on A.S.T.M. Type I and Type II cement, using the wet process method.

PRODUCTION CAPACITY

The capacity of this plant based on a three shift operation is 33,000 metric tons of portland cement per year.

MANUFACTURING UNIT

The manufacturing unit of this plant is one metric ton of portland cement.

MANUFACTURING OPERATIONS

For the purpose of this brochure the wet process of manufacturing cement will be used since practically all new plants being built are wet process plants. Quality control can be much more easily controlled with the wet process and less power is required.

The wet process of preparing raw materials in portland cement manufacturing, though it can be used with any raw materials, is particularly advantageous when one or more of the materials contains substantial quantities of water, or where a low grade raw material can be made usable in a flotation process. The wet process is very frequently favored because with it precise proportioning of the ingredients can be more readily achieved.

Preparation for Grinding

In using dry materials such as limestone and shale in the wet process the materials are crushed before grinding water is added to the extent of from 35 to 40 per cent of the combined weight. If one of the raw materials (for example, clay) contains considerable moisture its water content is increased and the clay-in-water suspension (known as clay slip) is added in the correct proportion to the crushed rock as it enters the preliminary mill. Where both raw materials (for example, marl and clay) contain considerable water sufficient water is added to bring the water content up to 35 to 40 per cent before grinding. Sometimes very much higher percentages of water are required for proper grinding.

Grinding

The wet raw material mix is then ground in the mills to proper size for classifying.

Classification

Classification of wet materials is then accomplished with vibrating screens by rake and bowl classifiers. Screens and rake classifiers are used with the preliminary mills and bowl classifiers with the secondary tube mill. A bowl-rake classifier can be used when grinding

is done in a single mill.

Thickening

Grinding conditions may, in some instances, be such that very high percentages (up to 85 per cent) of water are present in the slurry of ground materials. This high water content is reduced by a thickening process in large comparatively shallow tanks. Centrifugal equipment is also used to classify and separate the solids from the water in the wet process.

Blending

Slurries produced in the manner described are pumped to blending tanks where they are blended as required to produce the final kiln feed of correct composition. Slurry blending is comparatively simple and this is one of the advantages of the wet process. Tanks must, of course, be equipped with suitable mechanical or pneumatic agitating systems to prevent settlement of the solids. Before feeding the slurry to the kiln as much as possible of its water is removed in order to reduce the amount of heat required in the kiln. Commonly used equipment for this purpose is the rotary vacuum filter by which as much as half the slurry water may be taken out.

Water Supply

It is obvious that the wet process demands large quantities of water. In a slurry containing 625 kilos of solids per cubic meter (60 pounds per cubic foot) the water percentage by weight is 37.6 per cent of the total, or 60 per cent of the weight of solids. At a ratio of 1.55 to 1.00 for solid dry raw materials to finished cement the water requirement would be over 0.9 ton of water for each ton of cement produced. For the very fluid slurry referred to above more than twice this amount of water would be required. In very dry regions the problem of water supply may assume large proportions. Some water can be recovered by the use of sedimentation basins.

Production of Clinker

The Kiln

The rotary kiln is the heart of the modern portland cement plant. In it chemical changes are brought about in the raw materials so that the compound composition of the clinker is quite different from that of the raw materials. The kiln generally is the limiting factor in plant capacity.

The modern rotary kiln is a long cylindrical steel shell two to three meters in diameter and from 25 to 150 meters in length. The diameter is not necessarily uniform throughout the length of the kiln. The steel shell is lined with refractory materials (fire brick). The kiln is set at a slight angle with the horizontal and is rotated on its axis at a slow speed (usually between 30 and 80 revolutions per hour). The speed and the inclination govern the rate at which materials pass along the length of the kiln and for a given rate the length determines the time the ingredients of the mix are exposed to the hot gases. Variation in kiln speed is often utilized in preference to variation in fuel feed to meet changes in burning conditions.

Wet process kilns are equipped with looped chain sections extending for some distance from the feeding end. In this section the slurry is picked up and exposed to the gases of combustion in such a way as to accelerate the driving off of moisture.

Various items of auxiliary equipment are associated with the kiln. These include raw mix feeders (dry or wet), dust collectors, and draft fans, part of the heat of the kiln gases (this heat is not really "waste" heat if it is utilized, but the usage of the word is quite general). A widely used device for removing dust from the kiln gases is the electrical precipitator.

Kiln Fuel

The fuel burned in the rotary kiln is an item of great importance in the operation of a cement plant. Pulverized bituminous coal is the more generally used fuel, but oil and natural gas are also used. Coal must be dried and finely ground (80 to 90 per cent through the 200-mesh sieve); sometimes preliminary crushing is necessary. It is now customary to have an individual coal mill for each kiln. A compartmented tube mill is sometimes used for this purpose. The coal mill with its air classifier is an expensive and somewhat complicated machine. Fuel oil, if its use is economically feasible, is handled and controlled very readily, but tank storage, and possibly heating facilities, add to the cost of its use. Natural gas is a convenient fuel where it is available at competitive cost.

Kiln Feeding

Wet raw materials are generally fed to the kiln by means of a "Ferris wheel" type of device with buckets that dip up the slurry and feed it into the kiln at a uniform rate. Special types of feeding devices are available from the manufacturers of cement mill machinery. Kilns are available which have special arrangements for preheating the raw mix before or as it is fed to the kiln. With such arrangements a somewhat shorter kiln can be used.

Clinkering

The raw materials pass through three stages in their conversion into clinker. In the upper portion of the kiln moisture is driven off. This naturally requires more heat with wet than with dry materials and consequently it is customary (and more economical) to use longer kilns with the wet process. In the second zone of the kiln calcination takes place (that is, CO_2 is driven off), and in the third and hottest zone the calcined mix is brought to sintering temperature, where clinker is formed. In the wet process the heat of the kiln gases is utilized and the temperature at the feed end is usually between 200°C and 320°C* (400°F and 600°F).

Clinker cooling

On leaving the kiln the clinker has to be cooled. Generally used types of clinker coolers comprise vibrating screens or perforated plates through which air is drawn and over which the hot clinker passes. Primary (burner) air and secondary air needed for combustion can be preheated in this manner, thus utilizing some of the heat leaving the kiln. The rate of clinker cooling is important because of its effect on grindability. Cooled clinker is conveyed to storage bins from which it is drawn for grinding, or it may be stored in piles in the open.

Clinker Processing

Crushing

The clinker particles are sometimes of suitable size so that crushing is not required. However, the importance of proper size is so great that crushing is usually done.

Addition of Gypsum

The gypsum added to retard the time of set of portland cement is introduced into the grinding mills with the clinker. Gypsum and clinker are proportioned automatically by weight, the former amounting ordinarily to from two to five per cent of the total. Gypsum must be free from surface

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* These are round figures and not exact equivalents of temperatures expressed in degrees F. Where temperature ranges such as these exist exact conversion to the nearest degree is misleading.

moisture (which requires covered storage) and have a particle size not too different from that of the clinker. Gypsum deposits are much less widely distributed than are those of the principal raw materials of cement, and the cement plant usually has to buy this ingredient, as it does fuel. Both may be delivered to the plant by rail or water, or otherwise as circumstances require.

Grinding

Preliminary clinker grinding is carried out in ball mills or ring-roll mills. Tube mills are used for finish grinding, working in combination with air classifying equipment. It is essential that the product of these mills not only be finely ground but also that the particle sizes be suitably graded.

Storage

After final grinding the finished cement is conveyed to storage bins or silos from which it is taken for packaging or for bulk shipment. The ratio of storage capacity to annual production capacity depends on seasonal factors and climatic conditions. In temperate climates it may be from 10 to 25 per cent of annual capacity, but averages nearer the lower figure. Storage capacity is also dependent on the variety of cements being produced at the plant. Moreover, the number of storage units required is influenced by the extent to which inspected cement has to be held, where buyers require mill inspection by a testing laboratory of their own choice.

Packaging

Cement packages (usually paper or cloth bags) are filled by automatic filling machines of which there are several types.

Bulk Shipments

The possibility of shipping in bulk depends on the availability of suitable transportation facilities and also on the existance of bulk storage facilities at the point of use. Cement is sometimes shipped in bulk from producing plants to centrally located distributing plants, where it is packaged. Air activation facilitates bulk shipment and handling.

Materials Handling Equipment

Throughout the processing of the ingredients entering into the production of portland cement the problem of conveying materials is one of considerable magnitude. Conveyors of one kind or another are required

between each step and the next. The course materials can readily be handled by conveyors and elevators of various standard types and storage bins are usually served by a traveling crane, but the finely ground raw materials and finished cement present greater difficulties and more complicated equipment is required. In modern plants, systems utilizing air activation are in general use. The air-activated materials flow like fluids and can be pumped through pipes or caused to flow by gravity. Pneumatic systems have many advantages and will satisfactorily handle fine materials for distances as great as 300 meters and through vertical lifts up to 40 meters. This allows great freedom in the design and location of storage facilities. Cement in bags is readily transported on belt conveyors or moved by hand trucks.

An advantageous arrangement of storage bins for raw materials, clinker, gypsum and coal provides for their location in a straight line and the use of a traveling crane serving all of them, supplying the bin discharge hoppers by means of a clamshell bucket. Under some circumstances portable or fixed derrick cranes can be similarly employed.

Power Plant

In the modern portland cement plant power is transmitted by individual electric motors, that is, a separate motor on each item of equipment that requires motive power for its operation. The total amount of power required usually amounts to from 130 to 150 kilowatt-hours per metric ton of cement produced. Roughly, one-third of this is required for grinding raw materials, one-third for grinding clinker, and one-third for all other plant power needs.

Electric power may either be generated at the cement plant or it may be purchased from an electric utility or other source. In the United States somewhat more than half of the electrical energy used in cement plants is purchased. Not only relative costs and capital investment, but other factors, such as the frequency of power failures, must be taken into account in determining whether to generate or to buy power. In any event, a stand-by generating unit (Diesel engine driven) is considered essential. An internal combustion (gasoline) engine is usually provided to keep the kiln turning in case of power failure.

It is essential that the electrical equipment of the cement plant have the same electrical characteristics (voltage and frequency) as any alternate power supply the use of which may be contemplated. This is an important matter in countries where electrical standardization is less advanced than it is in the industrialized countries. Alternating current is generally adopted and motor-generator sets used to

supply any direct current needed.

Power plant generators may be driven by steam engines (turbines), internal combustion engines or water power. If steam engines are used waste heat boilers may provide all or a part of the steam required, or it may be generated in conventional type boilers using the same kind of fuel as that burned in the kilns.

An item of importance associated with the power plant is the air compressor, with its receiver. A very large quantity of air is used in a cement plant; its weight may exceed the combined weight of the raw materials and fuel consumed. Much of this air is moved through blowers at comparatively low pressures, but there is still a substantial requirement for air under higher pressure.

In some cases the power plant has to supply electricity to the housing occupied by plant employees, as well as other demands, in addition to the needs of the cement plant itself.

For the purpose of this report electric power will be produced at the plant.

Control of Product

Technical Contr

The manufacture of portland cement being based on the use of naturally occurring minerals that are subject to variations in composition, constant vigilance and frequent testing are required to ensure proper proportioning and ultimate composition of the mixed ingredients. Equal care is required in the control of processing as, for instance, the fineness and gradation of particle sizes of ground materials. The chemical and physical characteristics of purchased materials such as fuel, gypsum, and other materials and supplies also require continuous observation to ensure their effective use. Finally, the product of the plant must meet established specifications, and to ensure that it does so frequent and regular tests are performed. This technical control is provided by an adequately staffed and equipped laboratory under the direction of an experienced cement chemist. These are items of appreciable expense, but they are as necessary as the machinery in the plant.

DIRECT MATERIALS

Some of the combinations of raw materials utilized for the manufacture of portland cement are:

1. Limestone and shale (or slate)
2. Limestone and clay
3. Cement rock and limestone
4. Blast furnace slag and limestone
5. Marl and clay or shale
6. Chalk and clay or shale
7. Marine shells and clay
8. Alkali waste and clay

Sometimes silica sand and iron ore are utilized as sources of silica and iron oxide, and it is apparent that there are other possible combinations of natural or artificial raw materials that will produce the required group of oxides. Location and relative cost, as well as composition, will determine which materials are most suitable in specific instances.

The exploration of the sources of raw materials should be careful and thorough so that the cement plant will be assured of reliable supplies for a considerable period of time. Account must be taken of the probable growth of the market for cement with consequent increases in plant capacity from time to time. For instance, taking twenty years' supply as a reasonable minimum, and allowing a factor of four for plant capacity increase, the potential supply of raw materials should be fifty times the initial annual requirements, to provide adequately for growth.

Limestone and cement rock are hard materials that must be quarried by blasting with explosives. The blasted material is reduced to crusher size by secondary blasting or sledging. The rock is ordinarily handled by power shovels or cranes and is transported to the cement plant by motor or rail, or sometimes by belt conveyors. Crushing is preferably done at the cement plant, though preliminary crushing can be done at the quarry, and may be desirable in some instances, as where crushed rock is also produced for road work or purposes other than cement manufacture.

Shale and chalk can generally be quarried by power shovel without blasting, and clay can always be so handled. Transportation to the cement plant is normally by motor truck, but other means may be equally suitable, depending on distances involved or other circumstances.

The winning of raw materials containing substantial percentages of water presents a different problem. Marl and marine shells may (and usually do) require dredging, and residual and glacial clays may require

washing for the removal of undesirable materials. In these cases transportation may often best be accomplished by forming a suitable slurry with water, which can then be pumped through pipe lines.

Raw materials such as blast furnace slag and alkali wastes, which are by-products of other industries, present special problems of preparation and transportation. Their use is generally conditional upon close relationship of ownership and management of the cement plant and the industrial establishment in which they originate, in order to ensure a continuous supply of suitable material.

Blast furnace slag to be used in the manufacture of portland cement must be made granular to facilitate grinding. This is commonly done by pouring the molten slag into water, which treatment, however, results in the slag taking up twenty per cent or more of its own weight of water. This water has to be removed in subsequent processing.

The proportioning of a two-component mix, such as limestone and shale, is comparatively simple, but the use of three or more components greatly increases the complexity. For preliminary purposes the assumption of a two-component mix is about all that can be expected; indeed, it is all that can be done in the absence of full knowledge of the compositions of the raw materials available.

For the purpose of this report, it is assumed that limestone and clay are available at the plant site.

Item	Units Required	Annual Cost Estimated	Annual Cost Actual
Limestone	52,000 tons	Cost in land depletion	
Clay	11,500 tons	Cost in land depletion	
Gypsum	1,600 tons	$ 8,000	_____
Bags		8,000	_____
TOTAL		$ 16,000	_____

SUPPLIES

Item	Annual Cost Estimated	Annual Cost Actual
Lubricants and hand tools	$ 300	_____
Refractories, brick, clay, cement	18,000	_____
Maintenance and repair parts	6,000	_____
Office supplies	200	_____
TOTAL	$ 24,500	_____

DIRECT LABOR

Occupation	Number Required	Hourly Rate	Annual Cost Estimated	Annual Cost Actual
Rock blaster (operates shovel part-time)	1	$2.50	$ 5,000	_____
Power shovel operator (full-time)	1	2.50	5,000	_____
Laborers (quarry)	5	1.50	15,000	_____
Maintenance	1	2.50	5,000	_____
Maintenance helpers	2	1.50	6,000	_____
Kiln specialist	1	2.50	5,000	_____
Crushing	6	1.60	19,200	_____
Drying and weighing	3	1.60	9,600	_____
Ball and tube mill	6	1.60	19,200	_____
Blending and mixing	3	2.00	12,000	_____
Packaging and shipping	6	1.50	18,000	_____

DIRECT LABOR (Continued)

Occupation	Number Required	Hourly Rate	Annual Cost Estimated	Annual Cost Actual
Power station	3	$2.50	$ 15,000	_____
Common laborers	12	1.50	36,000	_____
TOTAL			$ 170 000	_____

INDIRECT LABOR

Occupation	Number Required	Annual Cost Estimated	Annual Cost Actual
General manager	1	$ 10,000	_____
Foremen	3	18,000	_____
Chemist	1	8,000	_____
Bookkeeper	1	4,800	_____
Secretary	1	4,000	_____
Clerk	1	3,200	_____
TOTAL	8	$ 48,000	_____

PLANT LAYOUT

A work flow sheet for the manufacture of wet process cement is shown on page 33.

PLANT SITE

In order to provide adequate raw materials the plant site should contain both limestone and clay in sufficient quantity to operate the plant at capacity for at least fifty years. It would of course be ideal if a deposit of gypsum was also available at the plant site. However, since only a small percentage of gypsum is required the important deposits are clay and limestone. Consideration should also be given to such items as transportation, water and fuel. An eighty acre tract of land with limestone and clay is estimated at $40,000. However, the cost will vary according to the location.

The cost of limestone and clay is included in the cost of the land. The labor cost is shown in direct labor.

BUILDINGS

The total floor space area required, including production, storage, office, and power is about 50,000 square feet.

The cost of buildings is estimated at $150,000.

POWER

The connected load for this plant is about 900 horsepower. Since this plant produces its own power the cost of the power is reflected in oil, labor, maintenance, depreciation and other such cost factors.

WATER

Large amounts of water are used in a wet process cement plant. The availability of an adequate supply is an import factor in selecting the plant site. The annual cost of water is estimated at $2,500. However, if water is available in a lake or stream where the only cost would be pumping, the cost of water would be greatly reduced.

FUEL

About 1,500,000 gallons of Bunker C oil will be required for the kiln. The annual cost is estimated at $105,000. The annual cost of diesel oil for this power plant is estimated at $35,000. Total annual cost of oil $140,000.

PRODUCTION TOOLS AND EQUIPMENT

The procurement of equipment for some industries, such as a machine shop, can be purchased by individual items from separate machine tool companies.

Cement plants are usually sold complete with engineering design and installation on a turn-key basis. The reason for this is that the plant must be designed in accordance with the various kinds and characteristics of the raw materials that may be available for the operation of the plant.

For this reason it is impossible to provide prices for individual prices of equipment.

There follows a representation list of equipment for a wet process cement plant with an annual capacity of 33,000 metric tons:

Air drills	Bowl classifier
Compressor	Slurry blending tanks
Diesel shovels	Slurry storage
Dump cars	Vacuum filter
Diesel locomotive	Kiln feeder
Railroad to plant	Kiln (wet process)
Crusher	Dust collector
Limestone storage	Air separator and blower
Clay wash and slurry	Fuel oil storage
Slurry feeder	Clinker and gypsum storage
Weighing feeders	Clinker crusher
Ball mills	Clinker silos
Vibrating screens	Packaging
Tube mills	Power plant

The estimated price of the above equipment is $800,000.

OTHER TOOLS AND EQUIPMENT

Item

Laboratory equipment

Pumping equipment

Maintenance equipment

Water storage

The estimated cost of this equipment is $19,000.

FURNITURE AND FIXTURES

Descreption	Number Required	Unit Cost	Cost Estimated	Cost Actual
Desks and chairs	4	$150	$ 600	_____
File cabinets	6	75	450	_____
Typewriters	2	150	300	_____
Adding machine	1	150	150	_____
TOTAL			$ 1,500	_____

DEPRECIATION

Description	Estimated Cost	Years Life	Annual Cost Estimated	Annual Cost Actual
Building	$ 150,000	20	$ 7,500	_____
Production tools and equipment	800,000	10	80,000	_____
Other tools and equipment	19,000	10	1,900	_____
Furniture and fixtures	1,500	10	150	_____
TOTAL			$ 89,550	_____

MANUFACTURING OVERHEAD

Item	Annual Cost Estimated	Annual Cost Actual
Depreciation	$ 89,550	_____
Indirect labor	48,000	_____
Power	0	_____
Water	2,500	_____
Fuel	140,000	_____
Supplies	24,500	_____
TOTAL	$ 304,550	_____

MANUFACTURING COSTS

Item	Annual Cost Estimated	Actual
Direct materials	$ 16,000	_____
Direct labor	170,000	_____
Manufacturing overhead	304,550	_____
TOTAL	$ 490,550	_____

FIXED ASSETS

Item	Cost Estimated	Actual
Land	$ 40,000	_____
Building	150,000	_____
Production tools and equipment	800,000	_____
Other tools and equipment	19,000	_____
Furniture and fixtures	1,500	_____
TOTAL	$1,010,500	_____

WORKING CAPITAL

Item		Cost Estimated	Cost Actual
Direct materials	30 days	$ 1,333	_____
Direct labor	30 days	14,200	_____
Manufacturing overhead	30 days	25,400	_____
Reserve for sales collections	30 days	66,000	_____
TOTAL		$ 106,933	_____

CAPITAL REQUIREMENTS

Item	Cost Estimated	Cost Actual
Fixed assets	$1,010,500	_____
Working capital	106,933	_____
TOTAL	$1,117,433	_____

SALES REVENUE

The annual capacity of this plant is estimated at 33,000 metric tons of portland cement. The annual sales revenue for this plant based on a selling price of $24.00 a metric ton is estimated at 33,000 metric tons x $24.00 or $792,000.

RECAPITULATION OF COSTS, SALES AND PROFITS

Item	Estimated Cost		Actual Cost
Direct materials	$ 16,000		_____
Direct labor	170,000		_____
Manufacturing overhead	304,550		_____
Total manufacturing cost		$490,550	_____
Interest on loans	33,500		_____
Insurance	3,350		_____
Legal	3,500		_____
Auditing	4,500		_____
Unforeseen expense	20,600		_____
Total administrative costs		$ 65,450	_____
Sales commissions		30,000	_____
Travel, bad debts, discounts and allowances, freight-out		10,000	_____
Profits before taxes		196,000	_____
Total annual gross sales		$792,000	_____

BUDGET CONTROL:

A requisition form designed to provide accurate records of procurement and indicate the purpose of procurement with the least amount of time and effort is shown on the following page.

This form has an account number for each type of the various expenditures which the manager will review in detail, monthly or oftener, in order to control his expenses. Some items, such as power and water, are usually under contract and are easily checked by reference to monthly bills. For simplification, items (marked with an asterisk below) are omitted from the purchase requisition. Variations in the labor costs are easily reviewed by examination of the payroll vouchers. The simplified type of control thus provided makes certain that the manager can control expenditures promptly.

Following the requisition form, a sample voucher check is shown. Voucher checks should be used for the payment of all expenditures and the appropriate book account number placed on each voucher.

At the end of each month the manager will receive a statement of all expenditures broken down by budget accounts. If the expenditures exceed the budgeted monthly allowances of any of the accounts, the bookkeeper will furnish the manager with a break-down of all expenditures relative to the budgeted accounts exceeded. All these supporting data can be secured by reference to the purchase requisitions and the check vouchers. This reference will enable the manager to determine what caused the over-expenditure and take corrective action.

If at any time during each month it becomes apparent that expenditures will exceed any of the budget accounts, the bookkeeper will bring this to the attention of the manager for his information and action.

BUDGET CONTROL ACCOUNTS:

Account Number		Monthly Expense	Monthly Budget	Annual Budget	Actual
10	Administrative	$_____	$ 3,737	$44,850	$_____
20	Sales	_____	3,333	40,000	_____
30	Direct Materials	_____	1,333	16,000	_____
40	Supplies	_____	2,041	24,500	_____
51	Power*	_____			_____
52	Water*	_____	208	2,500	_____
53	Fuel	_____	11,666	140,000	_____
60	Unforeseen Expense (Reserve Account)	_____	1,716	20,600	_____
71	Direct Labor*	_____	14,166	170,000	_____
72	Indirect Labor*	_____	4,000	48,000	_____
80	Depreciation (Reserve Account)	_____	7,462	89,550	_____

PURCHASE REQUISITION	COMPANY NAME	DATE

- ☐ 10 ADMINISTRATION
- ☐ 20 SALES
- ☐ 30 MATERIALS
- ☐ 40 SUPPLIES
- ☐ 50 UTILITIES
- ☐ 60 UNFORESEEN EXPENSE

INDICATE BELOW THE USE OF MATERIALS

- ☐ DIRECT MATERIALS
- ☐ MAINTENANCE MATERIALS
- ☐ MAINTENANCE SERVICES
- ☐ OPERATING SUPPLIES

	PLEASE ORDER THESE MATERIALS OR SERVICES	DELIVERY WANTED	
QUANTITY	DESCRIPTION	UNIT	TOTAL

QUOTES FROM		REQUISITIONED BY	
QUOTES FROM		APPROVED BY	
QUOTES FROM		ORDER NO.	ORDER DATE

R. W. MITCHELL MANUFACTURING COMPANY

1422 BOSWORTH STREET, S. E.

65-22
514

ANYWHERE, U. S. A._____ _____19____ No. 10000

PAY _____ DOLLARS $ _____

TO THE ORDER OF

R. W. MITCHELL MANUFACTURING COMPANY

TO FIRST NATIONAL BANK
ANYWHERE, U. S. A.

BY SAMPLE CHECK

VICE PRESIDENT

ACCOUNT NUMBER

Sample voucher check to be used for the payment of all expenditures in connection with Budget Control.

R. W. MITCHELL MANUFACTURING COMPANY

ENGINEERS:

The services of professional engineers are desirable in the design of this plant, even though the proposed plant is small.

A correct design is one which provides the greatest economy in the investment of funds and establishes the basis of operation that will be most profitable in the beginning and will also be capable of expansion without expensive alteration.

The addresses of professional engineers who specialize in industrial design, some of whom may be willing to undertake such work on low cost projects overseas, can be secured by reference to the published cards in various engineering magazines. They may also be reached through their national organizations, one of which is the

National Society of Professional Engineers
2029 K Street, Northwest,
Washington 6, D. C.

Manufacturers of industrial equipment employ engineers familiar with the design and installation of their specialized products. These manufacturers are usually willing to give prospective customers the benefit of technical advice by those engineers in determining the suitability of their equipment in any proposed project.

The equipment manufacturers also know, and can recommend, professional engineers in private practice, who are willing and able to provide appropriate consulting services.

TRAINING:

Manufacturing an inferior quality of product during the training period could create sales resistance that might be difficult to cope with later. To avoid such possibilities, the quality of the product should be maintained at all times, including the training period.

In some areas skilled operators may be available locally. In other areas all the operators may have to be trained.

If skilled operators are not available, adequate training would be assured by using one or more of the following methods:

A. If the plant is designed and installed by a competent engineering firm, the contract should be negotiated, if possible, on a turn-key basis. On this basis the contractor agrees to operate the plant and produce the quality and quantity of the product stated in the contract for an agreed period of time. Such a contract would assure adequate personnel training, since full quantity and quality could not be produced with an untrained organization.

B. The engineering firm that designs and installs the plant can usually make training arrangements to have key personnel placed, for training purposes, in a foreign industry that produces the same type of product. This would provide training for the key personnel while the plant is being installed.

C. If neither of the above methods is possible, then qualified and experienced individuals should be employed for the key positions, either permanently or temporarily, to perform the key operations and assist in training the organization, even if they must be secured outside the country.

D. The manager should have years of successful experience in this type of business and be fully qualified in all phases of management, including the training of employees.

SAFETY:

There is always danger of accident and injury in any industrial plant. Because of this, the manager should take specific action to bring to the attention of each employee the importance of safety precautions and intelligent first aid.

Practically all machines have safety appliances, and the manager should see that these are in good working condition and that the operators are making full use of them.

In addition to constant watchfulness to make sure that all practicable safety precautions are taken, first aid supplies should be readily available. One complete first aid kit should be maintained near the manager's office, and others at appropriate places throughout the plant. Some of the employees should be trained to provide first aid service.

The use of accident posters in the plant have proved to be of value in reducing accidents. It is recommended that such posters be used, and that some direct special action be taken by the manager, at least once each month, to bring to the attention of all personnel the importance of safety precautions.

A fire brigade should be established and each member trained as to his responsibility in case of fire. Fire drills should be conducted periodically.

It is recommended that the employees be encouraged to offer suggestions or recommendations relative to prevention of accidents, removal of fire hazards and maintaining general interest in all safety factors.

OTHER CONSIDERATIONS

There are other important subjects, shown below, that should be fully investigated and considered. Information on these subjects is usually available from such sources as banks, government agencies, exporters and importers, wholesalers, retailers, transportation companies and manufacturers.

MATERIALS AND SUPPLIES

1. Are all materials and supplies available locally?
2. Is the local material market competitive?
3. Is satisfactory delivery of local materials assured at reasonable prices?
4. What materials and supplies must be imported?
5. Are they available in world markets at competitive prices?
6. Would prompt delivery of imported materials and supplies be assured so that large inventories would not be required?

MARKET FACTORS

1. Is there already a demand for the product?
   - A. Who are the principal consumers?
   - B. Who are possible new consumers?

2. How is demand for the product now satisfied?
   - A. By local production? If so, what is the volume of annual production?
   - B. What percentage of consumption is filled by local production?
   - C. By imports? If so, what is the volume of annual imports?
   - D. What percentage of consumption is met by imports?
   - E. From what areas are imports derived?

3. What is the estimated annual increase in local consumption over the next five years?
   - A. How were such estimates made?
   - B. By reference to official figures on population growth, family budgets, imports, etc.?
   - C. By consultation with trade or industry, ministries, associations, bankers, commercial houses, wholesalers, retailers, industrial consumers, etc.?

4. If the product is already being manufactured, can the existing and estimated future local market absorb production of the new plant without price-cutting or other dislocations?

5. Would the estimated sales price and quality of the new product make it competitive with an imported equivalent?
   A. After adjusting cost to local conditions, is the estimated sales price of the product so high that tariff protection is necessary to protect it from imports?

EXPORT MARKETS:

1. Could the product compete in export markets on the basis of price, quality and dependability of supply?
2. Can export markets for the product be developed?
3. If so, in what areas and in what annual volume?
4. What procedures would be necessary to develop export markets?
5. What would it cost?

MARKETING PROBLEMS:

1. In calculating costs of the product, has adequate allowance been made for the expense of a sales department, advertising and promotion that might be required?

2. Do consumer prejudices against locally manufactured products exist?
   A. If so, why?
   B. Would they apply to the new product?
   C. If so, how could they be overcome and what would it cost to do so?

3. Do marketing and distribution facilities for the product exist?
   A. If not, can they be set up?
   B. What would it cost to do so?

4. Will the product be sold to:
   A. Wholesalers?
   B. Retailers?
   C. Direct to consumer?
   D. Other industries?
   E. Government?

ECONOMIC FACTORS:

1. How much foreign exchange (and in what currency) is required to import machinery, equipment and supplies:
   - A. How much foreign exchange (and in what currency) is required for annual interest payments and amortization of any loans contracted to import machinery and equipment, or for payment of royalties and technical services?
   - B. How much foreign exchange (and in what currency) is required for annual import of raw materials and supplies?
   - C. What are estimated annual foreign exchange earnings and in what currencies?
   - D. Has careful consideration been given to the possibility of depreciation in the foreign exchange value of the local currency?
   - E. Has careful consideration been given to the possibility of import controls, or restrictions on availabilities of foreign exchange necessary to operate the business?
   - F. What benefits would the new business bring to the economy in the use of local raw materials: in employment and in technology?
   - G. Do dependable facilities exist for transportation, power, fuel, water and sewage?
     - (1) If not, can existing deficiencies be eliminated satisfactorily?
     - (2) What would be the cost to do so?

PERSONNEL:

1. Is there an adequate labor supply near the plant location?
   - A. If not, how can the problem be solved?

2. Can the problem of training competent management and supervisory personnel be solved?
   - A. Also, the training of skilled labor?
   - B. Is technical advice available in the locality?
   - C. If not, where can it be obtained and what will it cost?

LAWS AND REGULATIONS:

1. Do existing labor laws, government regulations, laws and taxes favor establishment of new business?
   - A. If not, can existing obstacles be removed?
   - B. If so, how and when?

FINANCIAL FACTORS:

1. Technical advice on selection of machinery and equipment.
   A. In selecting the machinery and equipment for the new plant, have reputable and competent engineers and technicians been consulted?
   B. Have they been asked for advice on the most suitable types of machinery and equipment for the process and locality?
   C. Have they carefully compared costs of various sup
   D. Credit terms offered purchasers?

FINANCIAL REQUIREMENTS OF THE PROJECT:

1. In estimating the cost of the project, has careful consideration been given to:
   A. The effect on costs of delays in construction schedules?
   B. In delivery and installation of machinery and equipment?
   C. In import of essential raw materials and supplies?

2. In calculating cash flow and working capital requirements, has careful consideration been given to:
   A. Maintaining adequate inventories of raw materials?
   B. Supplies and spare parts?
   C. Seasonal fluctuations in the business?
   D. The time required to liquidate credit sales to customers and bad debts?
   E. The period necessary to get the plant into production?
   F. Cash required to amortize its principle loans?

3. If the economy is in a period of inflation, has full allowance been made for the influence of rising prices and wages on the cost of the project and on working capital requirements?

SHORT TERM BANK CREDITS:

1. Has it been possible to make arrangements with local banks to finance short-time working capital requirements of the business?

FINANCIAL PLAN:

1. Has a definite plan to finance the project been worked out?
   A. Is sufficient capital available locally?
   B. If not, what is the plan to obtain the required capital?

BIBLIOGRAPHY

Textbooks -

"The Technology of Cement and Concrete"
R. F. Blanks and H. L. Kennedy
Volume I. 1955. Illus. 422 pp. $11.75.
John Wiley and Sons, Inc.
440 Park Avenue South
New York 16, New York

Manufacture of portland cement, additions, and admixtures

"Portland Cement Technology"
J. C. Witt. 1947. $10.00
Harlem Book Co.
221 Fourth Avenue
New York 3, New York

Periodicals -

"Rock Products"
Monthly. $3.00.
Rock Products
79 West Monroe Street
Chicago, Illinois

"Pit and Quarry"
Monthly. $3.00.
Pit and Quarry Publications, Inc.
431 South Dearborn Street
Chicago 5, Illinois

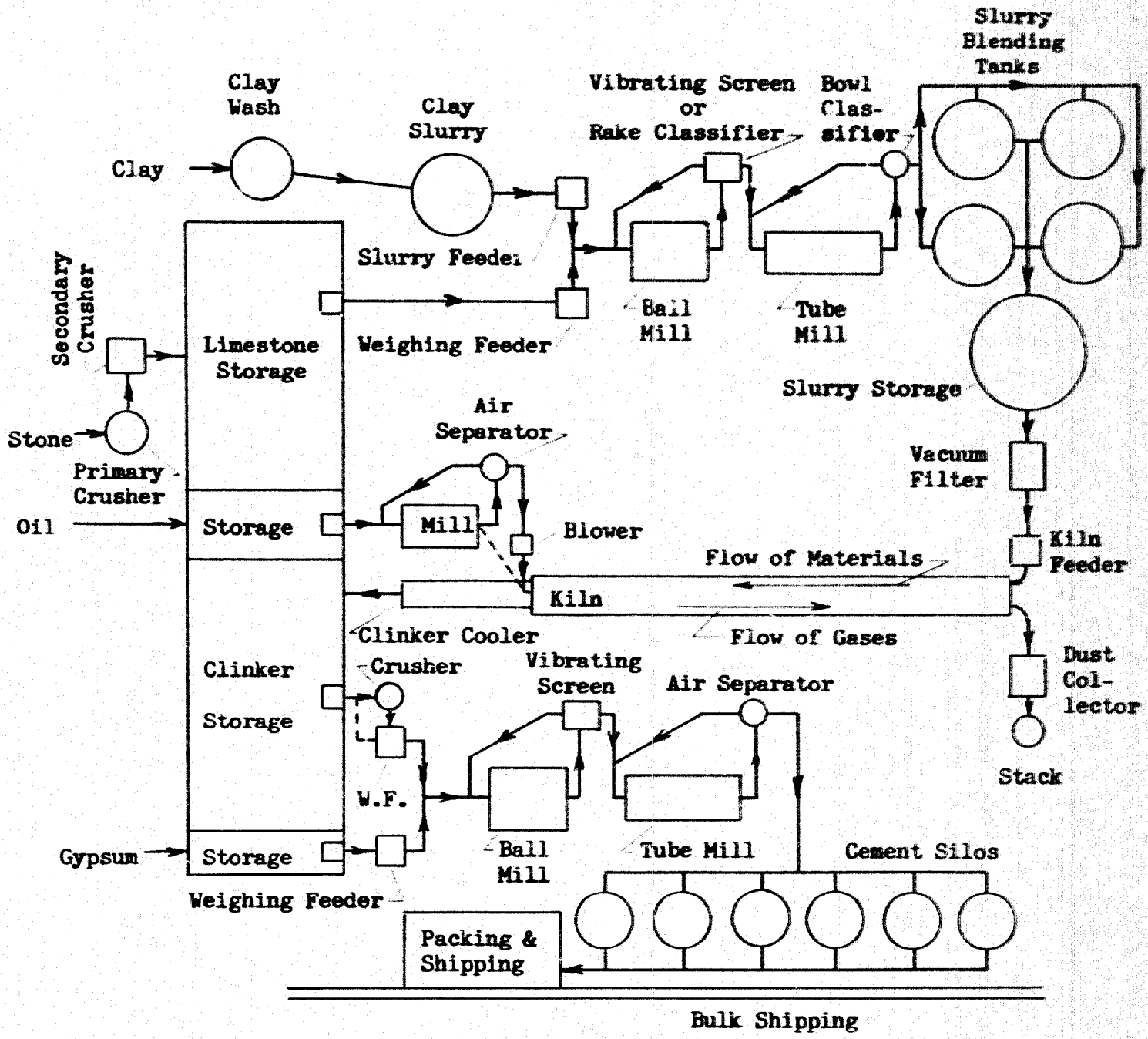
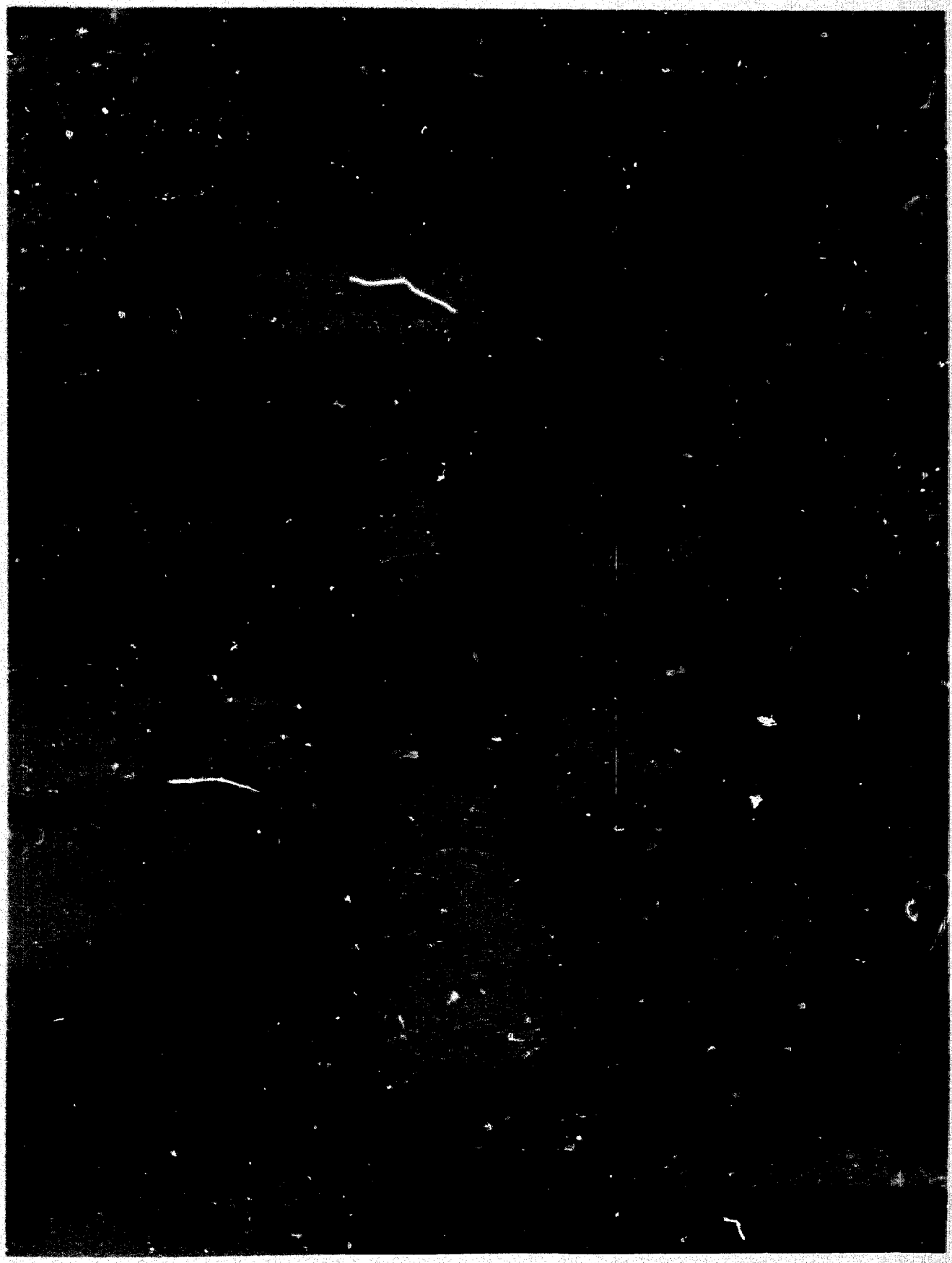


Figure 1 - FLOW SHEET FOR WET PROCESS OF CEMENT MANUFACTURE

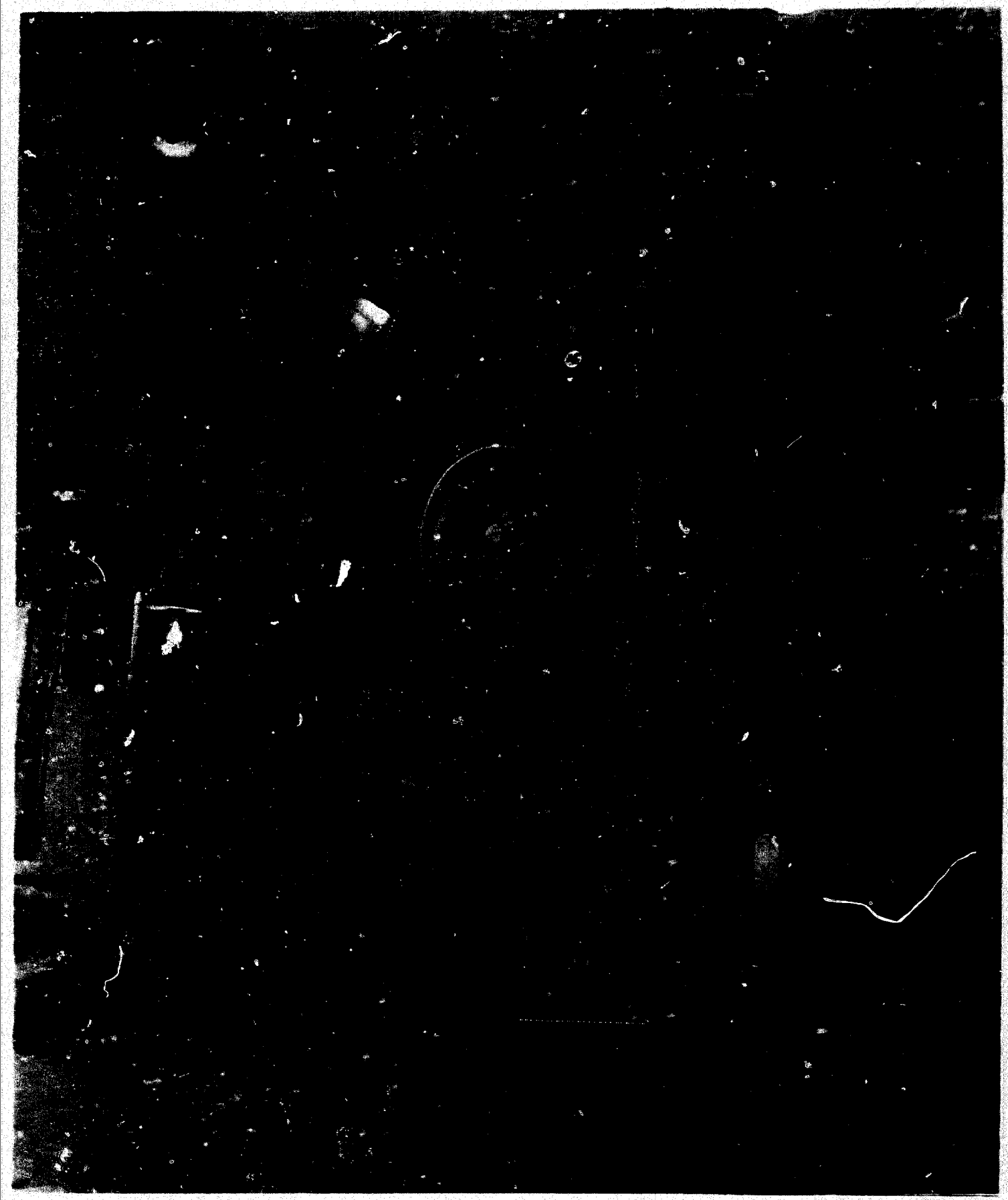
Courtesy
ALLIS-CHALMERS

Model SH *Ripl Flo* screen with rubber air springs



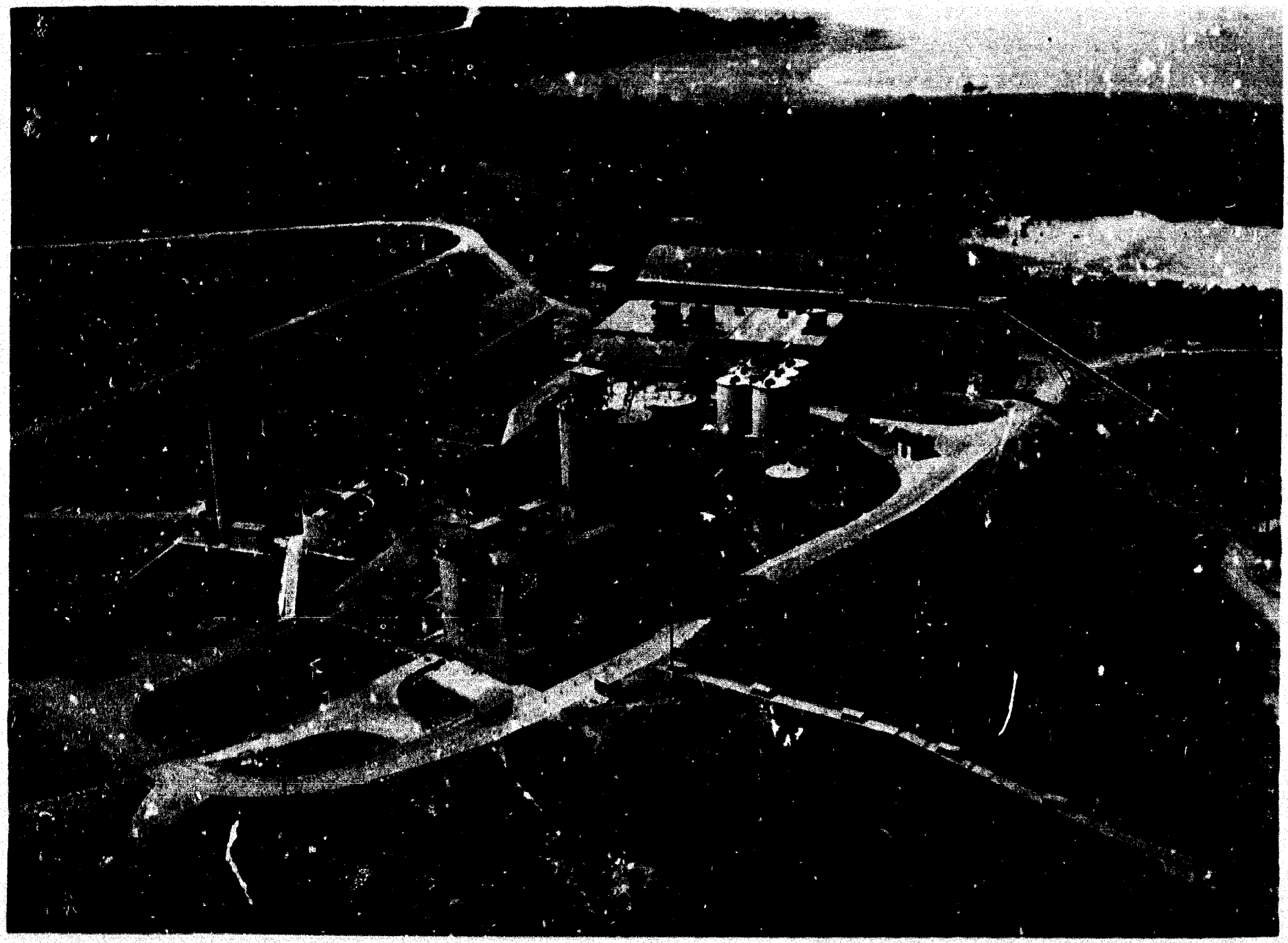
Courtesy
ALLIS-CHALMERS

9'6" x 300'0" rotary kiln at Cia Peruana de Cemento, Lima, Peru, S. A.



Courtesy
ALLIS-CHALMERS

Superior crusher with *Hydroset* mechanism. Lone Star Cement Co., Nazareth, Pa.



Courtesy
Allis-Chalmers

Aerial View of Cement Plant in Brazil

SECTION II
DRY PROCESS CEMENT PLANT

INTRODUCTION

As previously stated in this report, manufacturing experience has proven that the wet plant is superior to the dry plant in many ways. Very few (if any) dry plants are being currently constructed. However, for comparison purposes the manufacturing operations and a list of equipment together with a flow sheet for dry process cement manufacture is included herewith.

MANUFACTURING OPERATIONS

Dry Process

Crushing and Drying

In the dry process the quarry products (limestone or shale) are first crushed in jaw or gyratory crushers from which they pass to secondary pulverizers such as hammermills or crushing rolls. After secondary crushing the materials are placed in storage bins from which they are taken as needed for grinding. They may be proportioned and then dried, or dried separately before mixing and grinding. For drying, rotary dryers may be used, or drying may take place during the preliminary grinding, utilizing the heat generated in the grinding process, augmented if necessary by waste heat from the kiln or by separate heating units. Where the argillaceous component of the raw materials is clay this material is sufficiently dried, after previous granulation if necessary, to facilitate its handling and storage, final drying then taking place as described above.

Grinding

The grinding of the raw materials usually takes place in two steps, the first, or preliminary, grinding reducing the size of the particles to about 20-mesh* fineness and the finishing mills completing the reduction to 200-mesh.* Preliminary grinding is generally carried out in ball mills or ring-roll mills, in which the size of particles is so reduced that about 45 per cent pass the 200-mesh sieve. Vibrating screens may be used to classify the ground material, the screen tailings being returned to the preliminator for further grinding. Final grinding of raw materials is done in single or compartmented tube mills. A conically shaped ball mill is also available. In ball and tube mills the grinding media are forged steel balls of diameters suited to the size of ground material being produced. These balls, of course, wear out and their replacement is an item of expense (ball wear is of the order of 0.75 kilo per metric ton of cement). In the final grinding of raw materials mechanical air separators are used to take out that part of the product of grinding which is already sufficiently fine for kiln feed, or other processes of air separation may be employed. This improves the grinding efficiency of the secondary (tube) mills. Since different materials have different grinding characteristics, and also because it may be desirable to have one constituent ground finer than another, the practice of grinding the materials separately is sometimes adopted. In some installations raw materials are ground in a single stage, utilizing compartmented tube mills, rather than the combination of ball and tube mills. The flow sheet shows ball and tube mills in "closed circut" with vibrating screens and air separators, respectively. These units can be "hooked up" in several different ways, one of which is shown in the diagram.

Blending and Storage

After final grinding the raw materials are stored in bins or silos from which they pass, as required, to the kiln feeder. Blending silos are frequently employed and facilitate the exact proportioning according to chemical composition. Dust collected from the kiln gases, or from grinding operations, the amount of which is substantial, can in the dry process be added to one of the ground raw materials, to the raw mix, or even directly into the kiln. In the wet process the problem of dust disposal is more difficult. In any event, the effect of the stack dust on the mix composition has to be taken into account.

After the blending and storage has been completed for a dry plant all

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* The mesh numbers refer to the number of wires to the lineal inch of the testing sieves. These are standard sizes.

operations from that point on are exactly the same as the wet plant with one exception. In the dry process kiln temperatures increase from between 760°C and 980°C* (1400°F and 1800°F) at the feed end to between 1400°C and 1620°C* (2550°F and 2950°F) at the hottest point in the lower part of the kiln.

PRODUCTION TOOLS AND EQUIPMENT

Air drills	Blending and storage bins
Compressor	Kiln (dry process)
Diesel shovels	Kiln feeder
Dump car	Dust collector
Diesel locomotive	Fuel oil storage
Railroad to plant	Clinker coolers
Crusher	Exhaust fans
Limestone storage	Clinker storage
Vibrating screens	Gypsum storage
Weighing feeders	Clinker crusher
Ball mills	Clinker silos
Tube mills	Packaging
Mechanical air separator	Power plant
Conveyors	

The estimated price of the above equipment is $800,000.

OTHER TOOLS AND EQUIPMENT

Item
Laboratory equipment
Pumping equipment
Maintenance equipment

The estimated cost of this equipment is $19,000.

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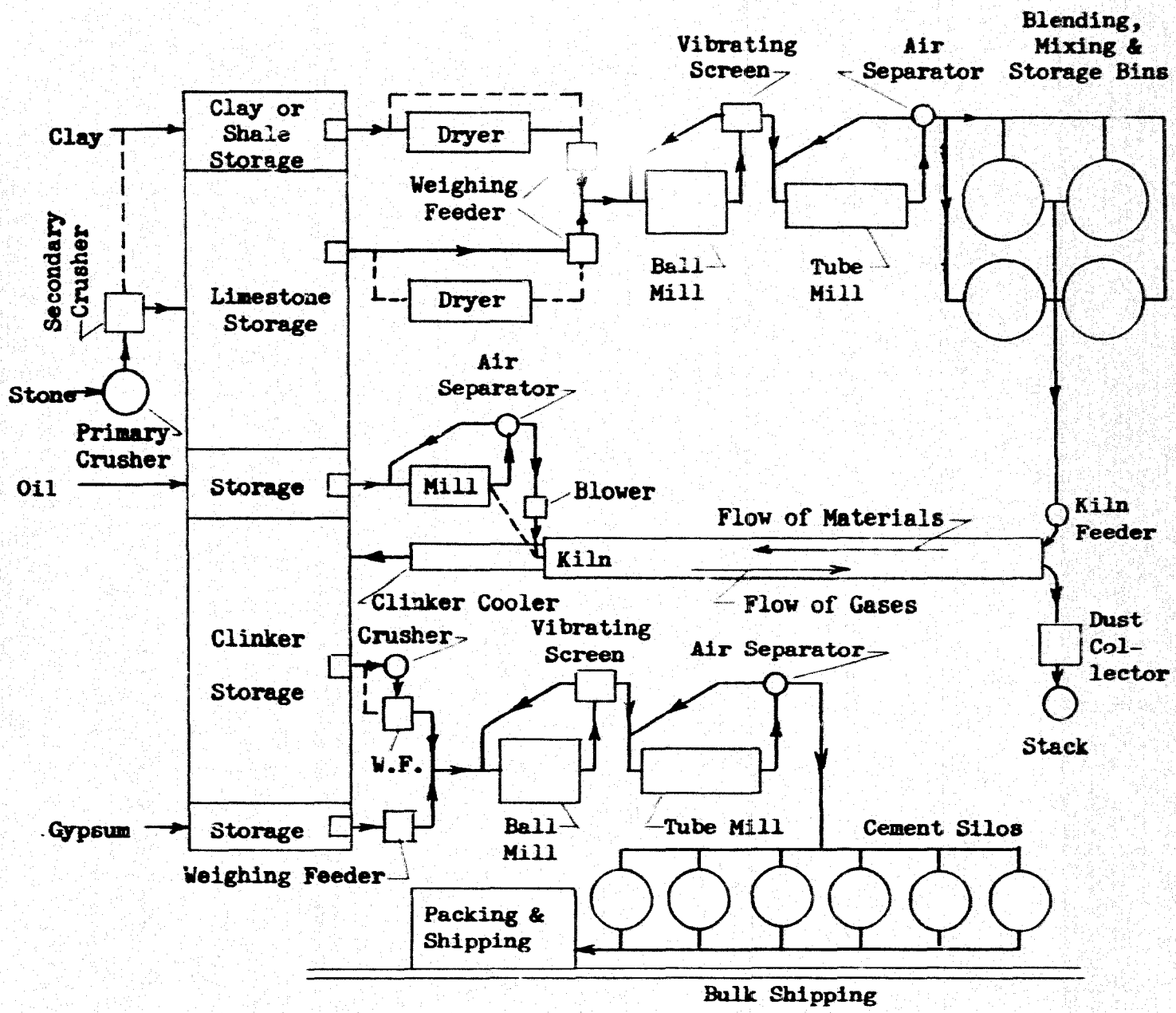
* These are round figures and not exact equivalents of temperatures expressed in degrees F. Where temperature ranges such as these exist exact conversion to the nearest degree is misleading.



FLOW SHEET FOR DRY PROCESS OF CEMENT MANUFACTURE

SECTION III
VERTICAL KILN

INTRODUCTION

The manufacture of cement by vertical or shaft type kilns was discontinued in the United States around the turn of the century. Most plants, at that time converted to the method described in Section I, which uses the rotary kiln. To our knowledge, there are only five vertical kilns in operation in the United States today.

The reasons for the conversion to the rotary kiln were that they offered the following advantages:

1. Better control and more uniform burning of the clinker.

2. More capacity.

3. Reduced labor cost.

In recent years, engineers have perfected a vertical kiln that affords the same advantages. Information on this kiln appeared in an article The De Roll Vertical Kiln by H. Herbert Hughes, Vice President for Europe, Porter International Company, published in Mining Engineering, December 1956, a publication of the American Institute of Mining, Metallurgical, and Petroleum Engineers, 29 West 39th Street, New York 18, New York.

According to this article, there are 30 kilns in operation and 10 more in various stages of construction, all of these outside of the United States.

The vertical kilns are built in two standard sizes; 1) the 75-ton kiln, 6 foot diameter, with output of 75 to 85 metric tons of clinker in 24 hours, and 2) the 150-ton kiln, 8 foot diameter, with output of 150 to 170 tons.

Plant design customarily provides for installation of two 150-ton kilns; thus, a 300-ton plant (600,000 barrels per year) may be

considered a standard installation. The second kiln, of course, may be installed at any time after the original one, along with the additional equipment necessary for doubling capacity for raw meal and finished product. Actual original construction costs to provide for such expansion are somewhat higher than for a one-kiln 150-ton plant, but far less than to add later a separate 150-ton installation.

Raw Materials and Equipment

Certain operations in a vertical-kiln plant are virtually identical with those in a rotary plant. Quarrying, raw meal preparation, and cement finishing are about the same in any cement plant irrespective of type of kiln. The description starts with the raw meal and fuel ready to be charged and will end with clinker ready for the finishing department.

Raw Meal: Broadly, chemical composition of the raw meal for the shaft kiln is the same as for a rotary kiln. It is, of course, essential to have uniform distribution of the various constituents, uniform fineness and an homogeneous condition. For proper clinkering in a shaft kiln, however, it is important too that the content of iron and alumina should be high, both actually and in proportion to silica. It may, in some instances, be necessary to add alumina in the form of clay, or even as bauxite, to increase the alumina content, and under certain conditions, it may be advisable to add roasted pyrites or iron ore to increase the iron content. The most favorable relationship for shaft kiln raw material is the following:

Lime Standard

$$\frac{100\ CaO}{2.8\ SiO_2 + 1.1\ Al_2O_3 + 0.7\ Fe_2O_3} = 95 \text{ to } 100.$$

Silica Ratio $\frac{SiO_2}{Al_2O_3 + Fe_2O_3} = 1.8 \text{ to } 2.5$

Alumina Ratio $\frac{Al_2O_3}{Fe_2O_3} = 1.2 \text{ to } 1.8$

These figures are not absolute, however, as variations from these standards are giving excellent results in some shaft kiln installations. But it is important that once a given composition has proved satisfactory it should be kept as uniform as possible, especially in regard to the lime standard.

As for the fineness of the raw meal, increased fineness gives improved quality of the finished cement. Obviously, however, the cost of electric

power for grinding demands selection of some optimum standards and for the shaft kiln this limit lies between 10 and 15 percent retained on a 170-mesh screen. Some variation in this way may be possible. Raw material that is readily burned, easily disintegrated, very uniform, homogeneous, and of marly nature may be somewhat less finely ground and give excellent results. On the other hand, poorly clinkering material of irregular composition, blended from constituents having wide extremes in chemical analysis, will require finer grinding to insure good clinker.

Fuel: All kilns presently in use burn solid fuel, and fuel consumption is relatively low. Heat requirements normally are slightly less than 1800 British thermal units per pound of clinker, or about 650,000 British thermal units per barrel of 376 pounds. Typically 58 pounds of anthracite buckwheat N°4 or N°5 are needed per barrel of cement.

Either coke or anthracite is required because the fuel must contain as small a proportion of volatile constituents as possible; otherwise such high volatile fractions are distilled in the drying and calcining zone of the kiln and thus are not available for combustion in the clinkering zone. Also, the calorific value should be as high as obtainable, preferably 11,700 to 12,600 British thermal units per pound. The minimum is about 9,900 British thermal units per pound in a grade of coke having 22 percent ash and 10 percent water content. Lower calorific values affect the kiln output and the quality of the clinker, for there is danger of under burning unless the required temperature is maintained uniformly throughout the burning zone of the kiln. The nature of the ash too is important. Its analysis is allowed for as part of the charge to be converted to clinker.

To be completely satisfactory the fuel should comply with the following specifications, although fuel varying from these standards has been used satisfactorily in some installations:

Item	Anthracite	Coke
Volatiles, percent	6 to 8	2 to 4
Ash, percent	6 to 15 (approximately)	6 to 15 (approximately)
Water, percent	4 to 6	4 to 10
Calorific value, British thermal units per pound	11,700 to 12,600	11,700 to 12,600

Particle size likewise is important, although coke or anthracite screenings of maximum 3/8 inch generally may be used as delivered without drying or crushing. A high proportion of fines, under 3/64 inch, should be

avoided, as they increase the quantity of carbon monoxide in the stack gases. Also, an excess proportion of particles above ¼ inch is undesirable, as these large pieces burn longer, increasing depth of the burning zone which results in too high a clinker temperature at the discharge gates. Both an excess of fines and an excess of coarse particles have an unfavorable effect on fuel consumption.

Two new developments in fuel utilization promise to expand widely the potential application of the shaft kiln. The first is that petroleum coke, although not yet regularly in commercial production of cement has been tested on a commercial scale, and the results of such tests show that it is eminently satisfactory as a fuel. The second, is the introduction of an oil-fired (or gas-fired) shaft kiln and this will be discussed after the detailed description of the solid fuel kiln. In this sequence the modifications will be more clearly understood.

Weighing and Mixing: Referring to the schematic diagram, the first operation unique to the shaft kiln is the weighing and mixing of raw meal and solid fuel in proper proportions. In present installations this is done by automatic batch weighers, one for raw meal and one for coal, the intermittent batches passing directly to a helical mixer to distribute the fuel uniformly throughout the charge.

This system, however, is being superseded by electronic-control continuous weighing machines, and already thoroughly tested in one installation. With continuous feed in exact proportions at all times, the two weighing machines discharge into a worm conveyor (either directly or after elevators, depending on location of weighing machines) that delivers the proper mixture to the nodulizer. The helical mixer is no longer required.

Exact proportions of raw meal and fuel must be determined for each blend of raw meal and grade of fuel. A common example is 84 percent raw meal and 16 percent fuel.

The new continuous weighing machines cost a little more than the old system but the opportunity for closer control makes far better burning conditions, which are reflected in increased output with a measurable saving in fuel consumption. All recent orders for shaft kilns include the improved weighing system. In present installations horsepower for the raw meal weigher is 1.5 horsepower, for fuel 0.3 horsepower, and for worm conveyor three horsepower.

Nodulizer: Although no one part of an integrated manufacturing process can be singled out as the key to such an operation, the nodulizer that prepares the physical form of the charge to the shaft kiln is of major significance.

Proper clinkering in a shaft kiln requires that the charge be permeable to the combustion gases. This nodulizing of the raw meal and fuel mixture, not only to control closely the shape, size, constituency, and fuel distribution of each nodule, but also to provide permeability, makes possible the uniformity of the clinker, and consequently that of the finished cement. This system of kiln feed preparation, combined with the combustion and clinker discharge controls of the shaft kiln, produces clinker with characteristics comparable to that produced in any other type of kiln.

The nodulizing disk consists essentially of a large inclined pan 8 feet 2 inches diameter and 2 feet deep, rotated by a direct V-belt drive from a motor with installed capacity of 10 horsepower. Total weight of the nodulizer is about 3.5 tons and the actual charge in the pan about three tons.

Speed of rotation and angle of inclination are constant, being adjusted to fit the characteristics of the material to be nodulized. For flexibility of operation, however, to vary the size or density of the nodules, two controls are possible -- rate of feed charged and rate of water flow. Nodules are discharged from the rotating disk by the centrifuge effect.

Capacity of the nodulizer is roughly 11 tons of nodules per hour, the rate necessary to produce 150 tons of clinker in 24 hours on the basis of 1.56 tons of raw meal per ton of clinker and about a 5.25 to 1 relationship between raw meal and fuel. The device is designed to produce 92 percent of nodules in the range of 5/16 inch to 5/8 inch with 8 percent over 5/8 inch and none smaller than 5/16 inch. In actual operating practice somewhat larger nodules may be charged to the kiln, and tendency of some material to build up an occasional quite large nodule before it is finally discharged is of no consequence, for a few such large lumps make no difference in the kiln.

Caking on the sides and bottom of the pan varies with the character of the feed, but normally it is no great problem. What little there is usually can be removed by improvised hand tools. A simple mechanical scraping device may be attached to the pan if actually needed.

The nodulizing disk finds applications elsewhere than for preparation feed. Some European cement manufacturers have switched recently to this dry method of feeding nodules into rotary kilns and have effected substantial savings in fuel consumption. Also interesting is its use for fertilizers, fine ores, and various products of the chemical industry.

Charging Hopper: Nodules are fed into the kiln through a charging hopper of special design. Its principal feature is a revolving chute

that discharges nodules uniformly over the full diameter of the kiln. Inclination of the chute and its speed of rotation may be varied to provide proper charging. The mechanism is driven by a 2.5 horsepower motor.

Kiln: The kiln proper is a vertical cylinder made of steel plate, about 33 feet high and 9 feet in outside diameter. When lined with proper refractories inside diameter is about 8 feet. Except for the grate at the bottom, there are no parts of any kind, moving or stationary, throughout the entire height.

Over the top of the kiln, above the burner platform, is a sheet metal hood in which the charging chute rotates and from which the stack gases are drawn. For visual inspection of the top of the charge this hood is equipped with doors through which long steel rods are occasionally plunged downward manually to make sure that the charge is moving properly through the clinkering zone.

Average temperature at the top of the charge is around 100°C (212°F). The top five feet of the kiln constitute the drying and calcining zone, both of temperature at 1450°C (2632°F) and rate of movement of the charge downward through the zone, are imperative for producing good clinker. The bottom 18 feet of the kiln is the cooling zone, discharge temperature about 250°C (482°F).

Much research has gone into the problem of finding the best possible kiln lining, and with good results, but details are not available for publication. For the top drying and calcining zone, the lining must be unaffected by humidity and resistant to wide change of temperature. In the clinkering zone, specifications call for a refractory that will take up to 1850°C (3352°F). In the cooling zone, resistance to abrasion is the main problem along with specification for 1710°C (3100°F).

The task of relining the kiln is relatively simple. In the first place, only the clinkering zone of about 10 feet has to be relined on a definite schedule. Of the 30 kilns in operation, none has yet been relined in top and bottom zones, although some have now been operating for more than five years. For the clinkering zone, relining is necessary about once a year, although in actual practice kilns are being operated as long as 400 to 500 days before relining. A typical relining job requires a nine-day shutdown -- three for cooling, three for relining, and three for reheating. There has been no problem of material adhering to the sides of the kiln to complicate the relining job.

A unique feature of this vertical kiln is that it may be shut down for 24 to 48 hours, with the fire banked, and production can be resumed simply by again starting the machinery in operation. Actually, however,

such operating practice as a six-day week is not recommended, for it does take three to four hours to bring the kiln back up to proper heat after it has been shut down, and thus production is lost for about half a shift. For emergency repairs to equipment, for special holidays, or for any other such reason, the ease of shutting down is distinctly advantageous. Kilns have been down for as long as one week without losing fire but, after so long a shutdown, priming with extra fuel is necessary to start up again.

Rotary Grate: For continuous discharging of clinker, a rotary grate is mounted at the bottom of the kiln. It consists essentially of a base body steel casting that supports grate plates with cast-on scrapers covered by a welded protective lining of high abrasion-resisting material. The grate itself, exclusive of the drive shaft and driving mechanism, is shaped roughly like half a grapefruit, higher in the center, 8 feet 2 inch diameter and 3 feet 4 inch thick at its central point.

The grate revolves horizontally very slowly, from one to six revolutions per hour, depending upon individual kiln conditions. No grate in any installation has yet been replaced, but the special hard abrasion-resistant tips on the teeth of the scrapers have to be renewed by welding every two or three years. The grate requires a special three-phase motor of the shunt collector type for continuous speed variation. Installed capacity is 7.5 horsepower.

Discharge Gates: The three-compartment discharge gates are of special design to prevent loss of combustion air from the kiln as clinker is discharged. Each gate is about 3 feet 4 inches high by 3 feet 4 inches wide by 4 feet deep, so the complete discharge gate mechanism is about 10 feet high. Operation of the gates is mechanical, timed for 3.3 cycles per minute. At each gate the clinker passes downward from one to the other on a staggered basis so that no more than one gate ever is open at one time.

The gates must be built for heavy duty to resist the abrasive action of the clinker. They discharge 6.3 to 6.5 tons of clinker per hour, thus dropping 60 to 70 pounds every 18 seconds. In particular, the frames that are hinged at the top, and open and close to allow passage of the clinker take a lot of punishment. Even so, made of special cast steel, they require replacing only about once a year. As they are designed for ease of maintenance, this job can be done in less than half a day. Clinker is discharged directly on a shaker conveyor which takes it to a small crusher -- maximum 1½ inch - and then to clinker storage. Plants in Europe now operating both rotary kilns and vertical shaft kilns at the same location combine their clinker from both types of kilns indiscriminately in clinker storage.

Blower: Each shaft kiln requires blower capacity of about 5,000 cubic feet of air per minute. This quantity may vary somewhat with the characteristics of the raw meal and the nature of the fuel. Also, for flexibility of operation, and as a safeguard against shutdown, there is an advantage in installing two or three smaller blowers rather than one large one. In either case, the blower installation will require 80 to 100 horsepower, installed capacity. No heat exchanger has been used on the solid-fuel kiln.

Electrical Installations: A multiple-panel switchboard with controls and recorders for all operations is installed with each kiln. Among such controls are those for the weighing machines, kiln feeding, combustion air, and kiln extraction, as well as for the silos ahead of the kiln and clinker transport following discharge. Recorders measure quantity and pressure of combustion air, temperature of exit gases, and speed of rotary-grate motor.

A measuring diaphragm for combustion air, a thermoelectric pyrometer, a solenoid valve for the water supply to the nodulizer, and various remote control push-button boxes are mounted separately as convenient.

Failure of any part of the plant immediately shows up on the appropriate panel, and all other operations relating to the stoppage are halted automatically.

Electric current consumption for the entire kiln department is 12 to 14 kilowatt-hours per ton of clinker, or 2 to 2.4 kilowatt-hours per barrel.

Dust Collecting System: There is nothing unique about dust collection in a shaft-kiln plant except that the system, of course, has to be designed to fit the problem. Otherwise, it is the same as in any cement plant.

Employees

In European practice, no fewer than two men per shift are required for a vertical shaft kiln installation of one or two kilns. Direct labor in the kiln department averages about 0.04 man-hour per barrel of cement.

The first man, of no particular skill, works most of the time on the nodulizer floor, keeping a visual check on the nodulizer to see that it is functioning to produce nodules of proper size and consistency. He also cleans the entire kiln building and looks after all manually lubricated bearings. The second job must be filled by someone of

greater skill. This man, the burner, works all the time on the burner floor at the top of the kiln. He must maintain proper clinkering temperature in the kiln by controlling combustion air, and must regulate, too, the proper rate of charging nodules and discharging clinker. By experience he learns to feel the kiln charge by plunging long steel rods down into the clinkering zone of the kiln and, using only this one manual aid along with the various controls under his jurisdiction, he is responsible for both quality and quantity of clinker.

Although the human element is important to proper functioning of the kiln installation, automatic control devices are employed wherever possible, particularly in case of trouble. If anything goes wrong, all other related operations are stopped automatically until the trouble is corrected.

Each shift foreman, of course, checks periodically on all phases of the kiln operation during his rounds of the plant.

Maintenance

Already mentioned is the need for rewelding, every two or three years, the abrasion-resistant tips on the teeth of the rotary grate scrapers and for replacing about once a year the frames that open and close to permit discharge of the clinker through the specially designed gates. In addition, of course, a continuous maintenance program comparable to that in any installation of heavy industrial equipment must be maintained.

The bank of spare parts to be carried at any kiln installation varies widely, however, depending largely where the kiln is located with respect to access to manufacture factories. For example, for a plant in Africa or any other remote location, spares may amount in cost price to as much as 10 to 12 percent of the original equipment itself. This is for a one-kiln installation. For two kilns, or even for three or four, the total bank of parts need be only nominally higher. The most expensive item commonly carried is a set of grate plates. No kiln in operation has yet needed new grate plates, but most plant operators are unwilling to risk not having a spare set available. Whether the plant comprises one kiln or four kilns, one spare set of grate plates may be considered as adequate protection.

Most of the inventory consists of bearings, gears, rings, bolts, comparable relatively low-cost items required for day-to-day preventive maintenance and for replacement of parts likely to cause unexpected shutdowns. Maintenance has not proved a major problem in vertical kiln installations.

Economics

To mention briefly the economic advantages of the vertical kiln, perhaps the most significant feature is that plants with an annual capacity of 1,200,000 barrels, 600,000 barrels, 300,000 barrels, or, with the use of one 75-ton kiln, even 150,000 barrels are competitive. In fact, capital costs per barrel of annual capacity are substantially lower than for other types of kilns.

In the U. S. emphasis has been on expansion of capacity in units far larger than the average vertical kiln plant. However, for a plant strategically located to serve a particular metropolitan market area, perhaps even a single central-mix concrete plant or for a plant in a remote location to be amortized during a specific dam project or some other heavy construction job, vertical kiln installations are attracting increasing attention.

Engineers studying the problem of designing a vertical kiln plant for maximum ease and economy in relocating the plant after its need in its original location has ended are confident that 80 to 90 percent of the first cost can be recovered for relocation elsewhere. Packaged power gas-turbine generator units of 5,000 and 10,000 kilowatts especially designed for ease of relocation, already are in use for other purposes in remote areas. Instead of mass concrete foundations these units rest on structural steel skid-type bedplates, which in turn are leveled by jack screws on plain concrete slabs poured at grade. Applying the same principle to the rest of the plant, it would be designed with steel silos and bins, steel frame bolted construction, air conveyor systems, service lines above grade, and other built-in features to minimize relocation expense.

This ease of relocation should not be unduly emphasized. Operating costs to produce a barrel of cement in such an installation compare favorably with other types of plants. Thus any potential plant location in which a supply of proper raw materials is combined with an adequate market to absorb the output of the plant is worthy of consideration. Especially this is true if the location is such that substantial freight savings over existing sources of supply of cement are possible.

Oil-Fired Kiln

Virtually ready for announcement by the manufacturer is a modification of the present shaft kiln to burn either oil or gas as fuel. The most essential new feature of the design is an oil-burning (or gas burning) device surrounding the kiln at the clinkering zone from which the hot gases at proper temperature are drawn through the charge as it passes down through the kiln, which probably will be oblong in cross section rather than round.

Another important feature is a heat exchanger with both the cooling air from the discharge end of the kiln and part of the stack gases used to preheat the combustion air. Fuel efficiency, of course, is directly dependent upon the effectiveness of the heat exchanger. More air is needed than for the solid fuel kiln, so a different and bigger blower installation is required, and total power consumption will be a little higher.

On the other hand, charging is simplified compared to the solid fuel kiln, with no coal handling and no mixing equipment necessary. Otherwise, there is no change in operation -- the nodulizer, charging hopper, rotary grate, and discharge gates function in exactly the same manner as with a kiln burning coal or coke. The same employees are required, although the burner has somewhat different duties.

The oil-fired shaft kiln may be expected to be more expensive than the present solid-fuel unit. There is every indication, however, that clinker capacity also may be increased, so on a comparative basis of capital cost per barrel of annual capacity there may well be a completely favorable relationship.

Patents have been applied for. Further details on the oil-fired shaft kiln are not yet available but probably will be revealed in the near future.

Actual introduction of the oil-fired (or gas-fired) kiln will intensify mounting U. S. interest in the vertical kiln.

Credit for the information presented should be given to H. Herbert Hughes, Vice President for Europe, Porter International Company, author of the article, "The De Roll Vertical Kiln." The article is reproduced through the courtesy and with permission of the publishers of Mining Engineering, The American Institute of Mining, Metallurgical and Petroleum Engineers.

Estimate of Over-All Cost

Equipment	Kiln 150 Tons per 24 hours	Kiln 75 Tons per 24 hours
Preliminary crushing	$ 49,000	$ 47,000
Crane	50,000	50,000
Drying and grinding	122,000	120,000
Homogenizing plant	55,000	28,000
Vertical kiln	104,000	93,000
Cement grinding	98,000	90,000
Cement silo & packing equipment	47,000	19,000
Gypsum crushing installation	8,500	5,000
Electrical switch panels	80,000	51,000
Foundation and structure Est. at 100% cost of machinery	610,000	506,000
Totals	$1 223,500	$1,009,000