TECHNOLOGY OF CEMENT PRODUCTION: ISSUES AND OPTIONS FOR DEVELOPING COUNTRIES

by

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B.S. With Honors in Civil Engineering, Syracuse University
(1981)

Submitted to the Technology and Policy Program
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE
IN TECHNOLOGY AND POLICY

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
February, 1986

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ABSTRACT

The purpose of this study is to review the technological options available for producing cement, to discuss the economics of the various options, and to assess how the policy framework in the developing countries influences the selection of appropriate technology for cement plants.

A review of the technical literature was undertaken to determine the leading technologies for large and small-scale cement plants. The economics of the various options is discussed with emphasis on energy and transportation requirements. A study of the experiences of the World Bank in regard to cement policy in developing countries is taken to outline the important issues and policy instruments.

The principal conclusions of the study are that the technology of cement production is flexible with regard to different raw material and market conditions. Freight equalization, price controls and other subsidies are often used to distort markets in the developing world, thereby leading to selection of inappropriate technology for cement plants in a country. By exercising a free market approach and by concentrating research and development funds on small-scale cement plants, the developing countries together with international development agencies and the major suppliers of cement plants can improve the selection of appropriate technology for their cement plants.

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ACKNOWLEDGMENTS

I am grateful to the many individuals whose contributions of time and energy made it possible for me to complete this work. I would like to thank my advisor, Dr. Fred Moavenzadeh, for his support and guidance throughout the research and writing phases of the work. Mr. J. Christian Duvigneau and Dr. Charles Weiss of the World Bank deserve many thanks for assisting me in my research, and for providing valuable comments on the economic and policy issues discussed in the text. I am particularly indebted to Marshall Bear, Carlos Lola, and Diana Ingraham of AT International for their continual support of my research on small-scale cement plants. Christopher Hennin of the World Bank graciously offered his assistance throughout the research phase and for this I am particularly thankful. I also thank Mr. Mogens Fog of the World Bank for sharing his technical expertise with me and I am grateful to Margaret Bergman for assisting me with the editing of the text.

Finally, I would like to dedicate this work to my parents, whose love, support, and affection have always been a source of inspiration and encouragement in all my pursuits.

TABLE OF CONTENTS

PAGE:

Table of Contents

PAGE:

List of Tables

Chapter 1

Chapter 2

Chapter 4

Chapter 5

List of Tables

Chapter 7

List of Figures

Chapter 3

Chapter 4

List of Figures

Chapter 5

1.0 INTRODUCTION

Over the last fifteen years, cement has become the predominant building material in developing countries accounting for 2 to 5% of annual construction expenditures, increasingly replacing more traditional cementitious materials like lime, or gypsum. A large share of developing countries' annual aggregate investment goes into construction (typically well over 50% of Gross Fixed Investment). With rapidly growing construction needs for increasing urbanization, infrastructure projects, agricultural as well as industrial civil works, cement demand has grown rapidly in developing countries having averaged about 8% (annually compounded growth rate) in the period 1950 to 1980. The rapid growth of demand must be met with large capital in production facilities and causes high aggregate amounts of costs to produce and distribute cement. This annual investment volume in new cement production capacity in developing countries is estimated at about $5.0 billion, whereas annual operating and distribution costs for this additional capacity are estimated at $1.2 billion and $0.6 billion respectively.

Cement, or at least some form of cementing material, is an essential ingredient in virtually every type of construction in developing countries and hence a continuing and expanding supply of cement is essential to provide the infrastructure for development. Indeed, the supply of cement is much more vital to construction in many developing countries than it is in the more developed European and North American countries, which are endowed with a wide range of alternative building materials, for example, timber, steel and high quality bricks. Thus a temporary shortage of cement in a developing country can, and frequently does, completely halt crucial development programs. In countries where cement is imported, building activity often goes in cycles depending on the availability of the necessary foreign exchange to import cement. Throughout the developing world precious resources are wasted in half-completed projects which cannot be finished because there is no cement. Thus, cement must be counted among the basic commodities on which development programs rely, with an importance comparable to water, energy, and fertilizer supply; and consequently self-sufficiency in cement production is always given a high priority in development planning.

International trade in cement has grown rapidly since the energy crisis of the 1970s, and now accounts for over 8% of world cement consumption, compared to some 4% in 1970. World trade in cement grew at a 10.9% average annual rate between 1970 and 1981, much faster than the 3.7% annual growth rate of world cement production. Much of the growth of world cement imports occurred in the OPEC countries, reflecting their construction booms fostered by growing oil incomes over the period. The data on World Trade in cement (Table 1.1) illustrate the growing role of world trade in cement and the nations most actively involved in it. Table 1.2 provides a regional breakdown of world cement production, consumption and international trade at the end of the 1970s. Table 1.3 provides a country breakdown of cement consumption and production in selected contries. During 1978, about 1700 clinker-producing cement plants with a combined annual capacity of about 1 billion tons were in operation in 120 countries. In addition, more than 3000 very small cement plants were reported operating in communes and brigades in many provinces in the People's Republic of China, accounting for more than half of that country's capacity. The U.S.S.R. led in clinker production capacity, followed by Japan, the United States, China, Italy, West Germany, Spain, France, Brazil, Poland, India, the United Kingdom, the Republic of Korea, Turkey, Romania and Mexico. For comparison, world cement production and clinker capacity in selected countries is shown for 1983 in Table 1.4. Cement demand is forecasted to grow at 1.8% in the United States during 1983-2000 and at 3.1% in the rest of the world (Table 1.5).

Availability of cement at affordable prices in developing countries is crucial if the development plans of these countries are to be realized. Until very recently, the means by which development planners in most countries have sought to achieve an increase in the supply of indigenously produced cement, has been the setablishment of comparatively large-scale facilities, on the model of those in the industrialized countries. These factories produce Portland cement, and an associated range of products satisfying the International Standards Organization (ISO). These factories have been either entirely imported, or in countries with a more highly developed industrial sector (India, for example) locally manufactured in association with the European and American cement machinery companies. Economies of scale are substantial in cement plants and the tendency has been towards construction of larger and larger plants. Most recently, some of the developing countries notably India and China have developed small-scale technologies for producing cement. This has given developing countries a choice in selecting appropriate technology for some of their smaller urban, rural and remote markets. Questions that arise as a result of the available choices are: which technologies are to be employed?, under what circumstances? and who can reliably supply the technologies to the developing countries?

1.1 Objective

The objectives of this study are three-fold. The first objective is to describe the technological options available for producing cement. A technological option is defined to be an alternative that is available either in equipment form or as a process for a particular manufacturing stage in a cement plant. The second objective of the study is to discuss the differences in the plants by studying their economics. The final objective is to outline how economic and political instruments affect the cement production process, and to discuss the policy framework in developing countries together with three case studies.

1.2 Organization of Study

After the introduction in section 1, Section 2 presents an overview of cement technology. Sections 3 and 4 describe the options available for manufacturing cement in large and small-scale plants respectively. The technological packages offered by the leading large-scale plant manufacturers and the leading technologies available for small-scale production are described.

Section 5 discusses the economics present in the cement production process. Issues of production in small versus large scale plants and of transporting cement over large distances versus production near markets are discussed. The energy issues are discussed and, to some extent, the capital-labor issues will also be outlined.

After outlining the technological options and the economics of cement plants, Section 6 discusses the instruments that have typically been used to distort market mechanisms and which, underlie some of the political issues in the cement production process. Section 6 also provides some options for cement policy in developing countries and outlines the objectives of various groups of countries that have similar physical and resource constraints.

Case studies of three typical underdeveloped environments are taken and the issues and options that are available for selecting appropriate cement producing technologies under those conditions are discussed in Section 7.

Section 8 outlines the conclusions and recommendations of the study.

All tables and figures appear at the end of the respective chapters.

Table 1.1

WORLD TRADE IN CEMENT, 1970-1981

	1970		1973		1976		1979		1981	
	Imports	Consumption	Imports	Consumption	Imports	Consumption	Imports	Consumption	Imports	Consumption
	(millions of metric tons)									
Total World	23.5	589.5	34.3	726.0	43.5	764.1	66.4	857.4	73.2	878.0
OPEC Countries	3.5	12.8	7.2	20.3	18.4	36.2	21.5	53.0	33.3	71.3
Rest of World	20.0	576.7	27.1	705.7	25.1	707.9	44.9	804.4	39.9	806.7

IMPORTS AS A PERCENT OF CONSUMPTION

	1970	1973	1976	1979	1981
Total World	4.0%	4.7%	5.8%	7.7%	8.3%
OPEC Countries	27.3%	35.5%	50.8%	40.6%	46.7%
Rest of World	3.5%	3.8%	3.5%	5.6%	4.9%

NATIONS MOST ACTIVE IN WORLD CEMENT TRADE IN 1981

	Imports			Exports	
	(000 mt)	%		(000 mt)	%
Saudi Arabia	12,500	17.08	Spain	12,026	16.34
Iraq	6,000	8.20	Japan	9,731	13.22
Nigeria	5,000	6.83	Greece	6,663	9.05
U.S.A.	3,595	4.91	Korea, Rep. of	5,757	7.82
Egypt	3,500	4.78	Turkey	3,389	4.60
Hong Kong	3,397	4.64	USSR	3,000	4.08
Kuwait	3,200	4.37	Bahrain.	3,000	4.08
Netherlands	2,964	4.08	France	2,822	3.83
India	2,000	2.73	Rumania	2,800	3.80
Bahrain	2,000	2.73	Canada	2,465	3.35
Singapore	1,930	2.64	Germany, Fed. Rep.	2,110	2.87
Germany, Fed. Rep.	1,770	2.42	Belgium	1,938	2.63
Libya	1,300	1.78	Taiwan	1,691	2.30
Syria	1,200	1.64	Kuwait	1,550	2.11
Venezuela	1,163	1.59	Korea, P.D.R. of	1,500	2.04
Algeria	1,000	1.37	China	1,000	1.36
Malaysia	956	1.31	Yugoslavia	767	1.04
Ivory Coast	930	1.27	Lebanon	730	0.99
Tunisia	837	1.14	Luxembourg	707	0.96
Yemen	800	1.09	Kenya	652	0.89
Bangladesh	756	1.03	Colombia	644	0.88
Sub-total	56,798	77.59		64,942	88.24
Total World	73,200	100.00		73,600	100.00

Source: References 11&16

Table 1.2

World Production, Consumption and International Trade in Cement
(Figures in million metric tons unless otherwise specified)

	Production		Imports		Exports		Apparent Consumption		Apparent Consumption Per Capita (In Tons)	
	1979	1981	1979	1981	1979	1981	1979	1981	1979	1981
Developed Countries	328.4	311.0	15.4	9.9	28.1	23.1	317.6	298.5	.467	.436
Western Europe	154.2	144.5	6.6	6.1	13.2	10.3	146.4	140.4	.485	.474
North America	81.5	75.2	8.8	3.8	4.2	2.7	83.5	74.7	.342	.294
Japan	87.2	84.4	-	-	10.6	9.7	81.8	77.9	.705	.659
Oceania	5.9	6.9	0.01	0.03	0.1	0.4	5.9	5.5	.326	.314
Centrally Planned Countries /a	187.9	187.6	3.31	1.62	11.0	7.8	181.4	181.7	.476	.472
Developing Countries	307.9	360.1	31.9	36.2	29.3	38.0	304.3	353.0	.095	.100
Sub-Saharan Africa (excluding South Africa)	10.3	10.5	9.2	9.5	1.0	2.0	14.3	15.4	.045	.042
South Africa	6.2	8.1	-	0.03	0.1	0.1	6.1	8.1	.215	.269
North Africa	12.4	13.5	3.2	5.4	0.02	0.02	15.4	18.1	.170	.201
Middle East	6.2	7.2	4.6	4.4	0.5	0.7	10.0	10.2	.366	.352
Southern Europe	86.5	90.1	1.4	1.3	18.9	26.2	68.9	65.2	.472	.441
Asia (excluding China)	72.2	79.7	9.2	12.0	3.8	9.2	75.8	79.4	.062	.054
China	47.0	82.0	0.4	0.2	1.1	1.0	46.5	81.1	.049	.080
Latin America and Caribbean	67.1	76.0	2.9	3.4	3.9	2.2	67.3	76.3	.195	.206
Capital Surplus Oil Exporting Countries /b	20.4	24.2	13.1	25.5	0.3	4.7	31.3	44.8	.523	.666
Total World /c	844.7	882.9	63.7	73.2	67.8	73.6	834.5	878.0	.192	.190

/a Eastern Europe, USSR, North Korea and Cuba.
/b Iran, Iraq, Kuwait, Libya, Qatar, Saudi Arabia and United Arab Emirates.
/c Figures may not add exactly to totals due to rounding.

Source: References 11 & 16

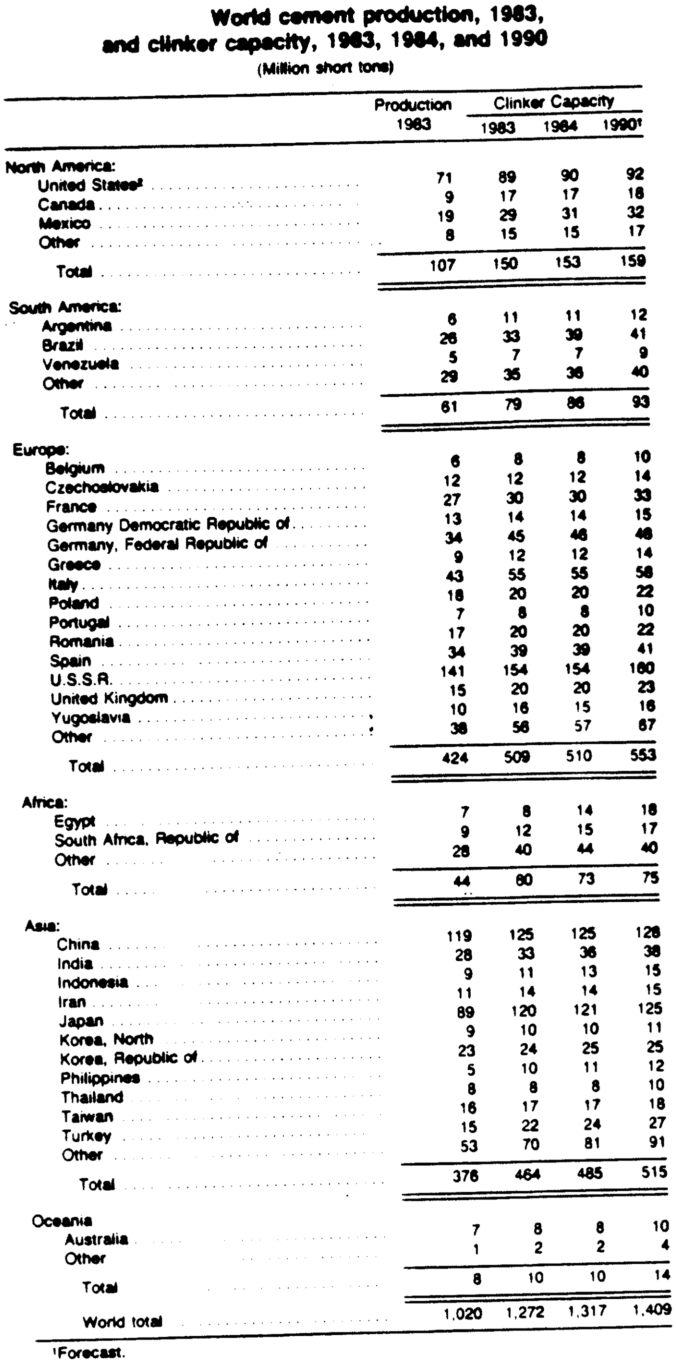
Table 1.3

CEMENT PRODUCTION AND CONSUMPTION IN SELECTED COUNTRIES

	Production (Million Tons)				Consumption (Million Tons)				Per Capita Consumption (Kg)		
	1950	1973	1981	% Share of World Prod. in 1981	1950	1973	1981	% Share of World Cons. in 1981	1950	1973	1981
Industrial Countries (ICs)											
- France	7.2	31.9	29.5	3.4	6.4	28.9	27.0	3.0	155	573	501
- FR of Germany	10.9	40.9	30.2	3.4	9.6	39.7	29.3	3.3	200	640	475
- Italy	5.0	36.7	43.1	4.9	5.2	35.7	42.7	4.8	111	648	746
- Japan	4.5	77.7	84.4	10.2	4.0	77.7	77.9	8.8	48	715	659
- USA	38.0	73.9	65.0	7.4	38.0	78.4	66.5	7.5	251	374	289
- Spain	2.1	22.6	30.5	3.5	2.0	21.6	18.5	2.1	73	619	491
- Others	26.9	85.1	63.4	6.5	21.9	88.7	69.5	8.1			
Subtotal	94.6	368.8	346.4	39.3	87.1	370.7	331.4	37.5			
Centrally Planned Economies (CPEs)											
- USSR	10.2	109.4	127.0	14.4	10.2	106.7	124.6	14.1	53	427	465
- Czechoslovakia	1.8	8.3	10.6	1.2	1.6	9.1	10.7	1.2	132	624	702
- Poland	2.5	15.5	14.2	1.6	2.4	17.0	13.9	1.6	95	510	388
- Others	2.1	16.1	21.6	2.4	2.1	15.8	19.5	2.2			
Subtotal	16.6	149.3	173.4	19.6	16.3	148.6	168.7	19.1			
High Income Oil Exporting Countries (HIOECs)											
- Kuwait	-	0.3	1.5	0.2	-	0.7	1.9	0.2	-	769	1,300
- Saudi Arabia	-	1.0	3.4	0.4	-	1.5	15.6	1.7	-	178	1,670
- Others	-	0.2	5.0	0.6	-	2.6	8.0	0.9			
Subtotal	-	1.5	9.9	1.2	-	4.8	25.5	2.9			
Developing Countries (DCs)											
Oil Importing DCs (OIDCs)											
- Argentina	1.6	5.2	6.7	0.8	2.0	5.2	6.5	0.6	120	215	240
- Brazil	1.4	13.4	26.0	2.9	1.8	13.5	26.0	2.9	34	133	204
- Burma	-	0.2	0.4	-	-	0.2	0.3	-	-	7	7
- China	-	40.8	82.0	9.3	-	39.8	81.1	9.2	-	49	80
- Greece	0.4	6.5	13.1	1.5	0.4	6.1	6.5	0.7	52	581	670
- Hungary	0.8	3.4	4.6	0.5	0.8	4.6	5.1	0.6	84	444	480
- India	2.6	15.0	20.1	2.3	2.7	14.8	22.3	2.5	7	26	33
- Korea	-	8.2	15.6	1.8	-	7.2	12.4	1.4	-	215	321
- Morocco	0.3	1.6	3.6	0.4	0.6	1.7	3.6	0.4	63	102	176
- Pakistan	0.4	2.7	3.7	0.4	0.4	3.4	4.1	0.5	6	53	49
- Philippines	0.3	4.0	4.0	0.4	0.3	2.8	3.5	0.4	17	71	71
- Portugal	0.6	3.2	6.0	0.7	0.5	3.2	6.4	0.7	63	368	636
- Romania	1.0	9.8	14.8	1.7	1.0	8.1	12.0	1.4	60	387	532
- Thailand	0.2	3.7	6.3	0.7	0.2	3.1	6.1	0.7	10	77	126
- Togo	-	0.1	0.4	-	-	0.1	0.2	-	13	56	82
- Turkey	0.4	9.2	15.1	1.7	0.5	8.3	11.8	1.3	25	216	259
- Yugoslavia	1.2	6.2	10.1	1.1	0.9	6.7	10.0	1.1	56	321	444
- Others	n.a.	33.5	53.6	6.2	n.a.	31.0	54.7	6.4			
Subtotal	n.a.	166.7	286.7	32.4	n.a.	159.8	272.6	30.9			
Oil Exporting DCs (OEDCs)											
- Algeria	0.3	1.0	4.5	0.5	0.5	2.2	5.5	0.6	56	162	279
- Ecuador	0.1	0.5	1.2	0.1	0.1	0.6	1.6	0.2	20	96	181
- Egypt	1.0	3.6	3.4	0.4	1.0	3.0	6.9	0.8	47	86	159
- Indonesia	0.1	0.8	6.8	0.7	0.2	2.1	6.7	0.7	3	17	44
- Mexico	1.4	9.7	18.0	2.0	1.4	9.6	18.1	2.0	54	171	255
- Nigeria	-	1.2	2.5	0.3	0.2	1.9	7.2	0.8	5	32	91
- Tunisia	0.2	0.5	2.0	0.2	0.2	0.7	2.1	0.2	56	125	319
- Others	n.a.	13.9	28.1	3.2	n.a.	13.5	36.6	4.1			
Subtotal	n.a.	31.2	66.5	7.5	n.a.	33.6	84.7	9.6			
Subtotal for all DCs	n.a.	197.7	353.2	39.9	n.a.	193.4	357.3	40.5			
World Total	133.0	717.5	882.9	100.0	133.0	717.5	882.9	100.0	55	188	190

Source: References 11 & 16

Table 1.4



World cement production, 1983, and clinker capacity, 1983, 1984, and 1990

(Million short tons)

	Production	Clinker Capacity		
	1983	1983	1984	1990[1]
North America:				
United States[2]	71	89	90	92
Canada	9	17	17	18
Mexico	19	29	31	32
Other	8	15	15	17
Total	107	150	153	159
South America:				
Argentina	6	11	11	12
Brazil	26	33	39	41
Venezuela	5	7	7	9
Other	29	35	38	40
Total	61	79	86	93
Europe:				
Belgium	6	8	8	10
Czechoslovakia	12	12	12	14
France	27	30	30	33
Germany Democratic Republic of	13	14	14	15
Germany, Federal Republic of	34	45	46	48
Greece	9	12	12	14
Italy	43	55	55	58
Poland	18	20	20	22
Portugal	7	8	8	10
Romania	17	20	20	22
Spain	34	39	39	41
U.S.S.R.	141	154	154	160
United Kingdom	15	20	20	23
Yugoslavia	10	16	15	16
Other	38	56	57	67
Total	424	509	510	553
Africa:				
Egypt	7	8	14	18
South Africa, Republic of	9	12	15	17
Other	28	40	44	40
Total	44	60	73	75
Asia:				
China	119	125	125	128
India	28	33	36	38
Indonesia	9	11	13	15
Iran	11	14	14	15
Japan	89	120	121	125
Korea, North	9	10	10	11
Korea, Republic of	23	24	25	25
Philippines	5	10	11	12
Thailand	8	8	8	10
Taiwan	16	17	17	18
Turkey	15	22	24	27
Other	53	70	81	91
Total	376	464	485	515
Oceania				
Australia	7	8	8	10
Other	1	2	2	4
Total	8	10	10	14
World total	1,020	1,272	1,317	1,409

[1] Forecast.

Source: Reference 54

Table 1.5

Summary of forecasts of U.S. and rest-of-world cement demand, 1990 and 2000

(Million short tons)

	1983	2000 Forecast range		Probable		Probable average annual growth rate 1983-2000 (percent)
		Low	High	1990	2000	
United States:						
Total	74	85	115	90	100	1.8
Cumulative	—	1,400	1,600	580	1,500	—
Rest of world:						
Total	946	1,300	2,000	1,300	1,600	3.1
Cumulative	—	19,000	24,000	8,000	21,000	—
World:						
Total[1]	1,020	1,385	2,115	1,390	1,700	3.1
Cumulative	—	20,400	25,600	8,580	22,500	—

[1] Data may not add to totals shown because of independent rounding.

Source: Reference 54

2.0 AN OVERVIEW OF CEMENT TECHNOLOGY

The objective of this chapter is to outline how technology affects each stage of the cement production process. It begins by describing what cement is and how the historical development of cement technology has taken place. Next it describes the raw materials commonly used in its manufacture and how these materials are processed in the various types of kilns available. Finally this chapter describes the most common types of cement end-products and outlines the environmental effects of producing cement.

2.1 What is Cement?

Cement is a finely ground manufactured mineral product, usually gray in color, consisting essentially of compounds of lime and silica, with smaller amounts of iron and alumina. Cement is mainly made from various naturally occurring raw materials. It is mixed with water (which is why it is also called hydraulic cement) and sand, gravel, crushed stone, or other aggregates to form concrete, the rock like substance that is the most widely used construction material in the world. Portland Cement is the most widely used type of hydraulic cement.

2.2 Historical Development of Cement Technology

Significant changes in manufacturing equipment have accompanied the growth of Portland cement production over the past century and a half. Initially, in the manufacture of natural and Portland cements, dry raw materials were placed in a vertical kiln with alternate layers of coal, and burned. Disadvantages of this intermittent process stimulated the invention of a continuous rotary kiln in Germany. In turn, the introduction of the rotary kiln, together with subsequent technological improvements, permitted efficient operation at much larger scales than vertical kilns. This offered important savings per ton of output in both capital and operating costs. While the technically efficient limit on the scale of vertical shaft kilns has remained, in typical situations, to about 200 tons per day or 60,000 tons per year capacity, major advances in rotary kiln technology have occurred in the past thirty years. Rotary kiln technology increased from a limit of 300 tons per day (about 95,000 tons per year) in the early 1950s to 4500 tons per day (about 1.4 million tons per year) in the early 1970s. Even more recently, precalcining technology, developed in Japan, has opened the possibility of greatly improved operating reliability in larger kilns, as well as 2-2.5 times as much output from the same sized kiln. Kilns as large as 8,000 tons per day (2.5 million tons per year) are in operation.

Accompanying these advances, a shift began from wet process to dry process rotary kilns, which accelerated in the 1970s in response to rising energy costs and growing environmental concerns. Combined fuel and power costs can be as much as halved by the dry process, although even with this process, energy costs in efficient new plants still typically represent about 40% of the full cost of production (including returns on investment). But the dry process offers the additional advantage of reduced volume of exit gases to be cleaned for dust control, thus lowering the cost of investments to meet environmental standards. Nevertheless, prior to the energy crisis the wet process was still favored for many new plants because capital costs were lower by about 20% and operations were simpler. Even after energy prices increased sharply in the 1970s, the wet process still made economic sense in special situations of surplus energy or of particularly suitable raw materials.

The energy crisis also created strong economic incentives to lower energy consumption in existing plants by adding preheaters or precalciners, and by converting from the wet process to the dry. Further energy cost reductions could be achieved by switching to less expensive fuels (coal, for example) and also by resort to additives, for example, slag, in cement manufacture.

In the United States, for example, energy consumption per ton of cement produced was reduced by almost 10% between 1972 and 1980. This is believed to be due primarily to three types of adjustments to existing plants: the installation of preheaters and precalciners; improved heat transfer in kilns through installation of chains; and closure of marginal older wet process plants plus conversion of others to the dry process. The proportion of total clinker output produced in wet process plants in the United States declined from 59% in 1972 to 52% in 1980. Meanwhile, over the same period, the capacity of coal burning plants, increased from 41% of the total to 76%; and it is expected to reach 90% by 1990. Oddly enough, very little progress has yet been made in the United States in the increased use of additives.

Outside the United States, world cement industry patterns of response to higher energy costs seem to have been different. In some cases the response has been much quicker than the United States, in others it has barely got underway. Europe and Japan for instance, have consistently been at the forefront of technical innovation in the cement industry, spurred by historically higher energy costs, as well as by much greater import-dependence for energy. Energy saving options such as the use of additives, process conversions, and energy substitution have generally been adopted much earlier there than in the United States. In France, for example, the level of additives used in manufacturing cement averaged, in 1979, about twice that of the United States. Some Japanese and European producers have recently even gone so far as to experiment with municipal refuse and waste tires, together with coal, as substitutes for higher-cost forms of energy (gas and fuel oil).

In most other parts of the world, the response has been slower, and particularly so in the developing countries. While the simpler step of greater use of additives has already been taken in a number of countries, it could be pursued more aggressively in others. Meanwhile, the more complex steps of technological change have not, in general, proceeded as rapidly as in the more advanced countries. In some countries, cheap, suitable coal has not always been readily available. In other countries, the industry has been either structurally less well suited to energy conversion (very old plants, vertical kilns) or less in need of it (facilities are, for instance, relatively new, energy is still cheap). The prolonged world recession has been responsible for delayed investment decisions in some countries. Necessary structural adjustments were sometimes deferred during the 1970s, particularly in the developing countries: where authorities were hesitant to permit increases in the prices of energy, or cement to bring them into line with real changes in international prices.

Paralleling the technological advances in cement production, there have been some cost saving innovations in the handling and shipment of cement by sea. In the first place, international trade in clinker has now become much more important since clinker is generally less costly and easier to ship and store than cement. Moreover, most of the energy cost of cement manufacture is accounted for at the clinker stage, so plants with prohibitively high energy costs can stay in operation by switching to clinker grinding only. By the end of the 1970s, half of total cement imports was in the form of clinker, compared to less than 10% a decade earlier.

Innovations in shipping and distribution facilities have also been important in special market situations. Large scale bulk shipping of cement has now been made economically attractive where at the receiving end special cement terminals have been built with pneumatic unloading equipment, cement silos and bagging plants. Likewise floating bagging plants have made international trade in bulk cement feasible where previously it would have been in bags, thereby helping to offset the effects which increased energy prices would otherwise have had on freight costs.

2.3 Raw Materials

Portland Cement, the most frequently used cement in the world, is a closely controlled chemical combination of lime, silica, alumina, iron and small amounts of magnesiun oxide, sulphur, and alkalies. The four basic compounds which are required in the raw mix are: (a) calcium carbonate ($CaCO_3$); (b) silica (SiO_2); (c) Alumina (Al_2O_3); and (d) Iron Oxide (Fe_2O_3).

A normal raw mix will contain approximately 80 percent calcium carbonate and 12.5 percent silica. The rest is made up principally with iron oxide and alumina, which are necessary because without these two compounds the mix is very difficult to burn.

The raw materials which are commonly used in the manufacture of cement are not pure compounds. Limestone, while being made up primarily of calcium carbonate, is found with different grades of purity and contains varying amounts of silica, alumina and iron oxide. Sometimes an important impurity will be magnesium carbonate. The impurity will often change within a quarry, and the limestone is called either a low lime rock or high lime rock, depending on the percentage of calcium carbonate it contains. Other sources of calcerous materials used in the cement industry are deposits of chalk or marl and, in a few cases, oyster shells found near the sea coast. Argillaceous materials such as shales, clays, slates or blast furnace slag contain large percentages of all the four major compounds. Sand is often a concentrated source of silica. Bauxite and iron pyrites, which have high percentages of alumina and iron oxide respectively, are sometimes added to increase the percentage of these two compounds in the raw mix if the other raw materials are deficient in either iron oxide or alumina.

No two cement plants will have exactly the same raw mix design formula because of the vast range of raw materials and their different compositions. For example, one cement plant may have 70 percent limestone and 30 percent clay, and another may have 95 percent chalk and 4.5 percent silica and 0.5 percent iron oxide, in order to arrive at the same chemical composition in the resulting raw mix. In other words, the proportions of the different constituents which go into a raw mix are determined by the chemical composition of these same constituents. The proportioning or blending of the raw materials is one of the major steps in the manufacture of cement. Frequent quality control checks of the raw mix are necessary so that corrections can be made in the raw materials to maintain a consistent mix.

Unlike large plants which need large quantities of limestone of assured quality, i.e., extensive and separate cement grade limestone deposits, small plants may have wide and varied sources for their prime raw materials. The requirements being comparatively lower for small plants, the needs may be met from small limestone deposits, cement grade limestone wastes from other limestone mines or from various industrial wastes. The layouts of limestone mines will depend upon the mode of occurrence of the limestone deposit and the method to be adopted for its exploitation together with the level of production desired. The limestone deposits may be in hilly or plain terrains. The method of mining of limestone will also depend on the nature of the deposit and the capacity of the plant.

2.4 Processing of Raw Materials in the Kiln

Burning (or pyroprocessing) is the most important operation in manufacturing cement because: (i) fuel consumption is the major expense in the process, (ii) capacity of a plant is measured by kiln output, and (iii) strength and other properties of cement depend on the quality of clinker produced. The kiln is both a heat exchanger and a chemical reactor. Two types of kiln are used in the industry: vertical or shaft kilns (accounting for only about 5% of world production) and rotary kilns. Vertical kilns are only cost efficient at capacities of about 60,000 tons per year, whereas rotary kilns are cost efficient at capacities well beyond a million tons per year. A rotary kiln is a refractory-lined steel cylindrical shell that rotates around an axis inclined at 4 degrees to the horizontal. Kilns range in size from 1.8 meters in diameter and 36 meters long to 7.5 meters in diameter and 200 meters long, and rotate at up to 2.5 revolutions per minute. Vertical shaft kilns consist of a vertical refractory-lined cylinder with solid fuel and raw materials fed into the top of the kiln and combustion air fed into the bottom. A grate for removal of clinker is fitted at the bottom.

Rotary kilns are amenable to both wet and dry processes, whereas vertical kilns are limited to dry process only. Blended dry mix or slurry enters the upper, or feed end of the rotary kiln and is conveyed by the slope and rotation to the firing, or discharge end of the kiln. In the wet process, exit gas temperature is about 2500C and the moisture in the slurry is evaporated in a heat exchanger, usually a system of hanging chains which are about one-fourth the length of the kiln. Next, in a temperature zone, alkalies vaporize, combustion of any organic compounds takes place and calcium carbonate is calcined to calcium oxide. Clinkering takes place in the burning zone. Presence of iron oxide and alumina as a flux in the raw mix lowers the temperature required to form clinker.

2.5 Portland Cement and Other Cement End-Products

Portland cement is produced by pulverizing clinker consisting essentially of calcium silicates and usually containing one or more forms of calcium sulfate as an interground addition. The oxide composition of the normal Portland cement appears in Table 2.1. These oxides join to form compounds. For practical purposes, Portland cements can be considered as composed of four principal compounds: tricalcium silicate, dicalcium silicate, tricalcium aluminate, and tetracalcium aluminoferrite. These compounds together with their chemical formulas and abbreviations are shown in Table 2.2. While all four compounds jointly compose Portland cement, they still retain their individual strength properties. It follows that dicalcium silicate is a major contributor to the final strength of cement paste, tricalcium silicate contributes importantly to both early and final strengths; tricalcium aluminate is the first of the compounds to hydrate while the contribution to strength of tetracalcium aluminoferrite is insignificant

Aluminates, desirable as they are for the ease in manufacturing, result in an undesirable tricalcium aluminate compound. The latter, as mentioned above, hydrates rapidly. The implication being that cement paste sets too quickly for satisfactory molding to be possible. To prevent a flash set, cement producers add small amounts of gypsum (about 4 to 6% by weight of cement), as gypsum reacts with tricalcium aluminate to form insoluble compounds and thus act as a retarder. A further disadvantage of tricalcium aluminate is that its presence is responsible for lowering the resistance of cement paste to sulfates. Hydration, or the chemical reaction of water and cement, is an exothermic reaction. As a general rule, the faster rate of hydration, the higher the amount of heat liberated. It follows that tricalcium aluminate and silicate contribute importantly to the amount of heat liberated during hydration.

American Society of Testing Materials (ASTM) specification C 150 covers five types of Portland cement, based mostly on the proportions of C3S, C2S and C3A in the cement: (1) Type 1, is a general purpose Portland cement. About 95% of the cement falls in this category. The uses include buildings, pavements and sidewalks, bridges, railway structures, tanks, reservoirs, culverts, water pipe and masonry units. (2) Type 2 is used where precaution against moderate sulfate attack is important and for structures of considerable mass where the amounts of heat liberated during hydration are of concern. Compared to type 1, type 2 cement contains lesser amounts of tricalcium aluminate and silicate (Table 2.3). The result is a decreased amount of heat liberated during hydration and slower rate of strength gain. Also, compared to type 1, type 2 contains a lesser amount of tricalcium aluminate and for this reason has a greater resistance to sulfate attack. (3) Type 3 cement provides high strengths at an early period, usually a week or less. It has higher tricalcium silicate content than type 1 which is desirable as it permits the removal and reuse of expensive forms or reduces the controlled curing period in the winter. (4) Type 4 was developed specially for the Hoover Dam in the U.S.A. as it provides very low heat of hydration (lower than type 2 cement) and as expected acquires its strength at a slower pace. Table 2.3 shows the low amounts of tricalcium aluminate and silicate. (5) Type 5 has the highest resistance to sulfates of the five types and is intended for concrete subjected to severe sulfate action.

ASTM specifications include three additional types of portland cement designated Type 1A, Type 2A, and Type 3A, that are respectively air-entraining cements for the same uses as Types 1, 2, and 3. Air-entraining portland cement is produced in essentially the same way as portland cement, however, they contain small amounts of air-entraining admixtures interground with the cement clinker. When the air-entrained cements are mixed with water, billions of non-interconnected microscopic air bubbles are produced and become entrained in the cement paste. The bubbles relieve the internal pressure created where water freezes in the pores of cement paste and thus improve the freeze-thaw resistance of the cement.

The high cost of energy in the production of clinker has also led the industry to search for suitable additives to "stretch" clinker production. Thus artificial additives such as industrial wastes (blast furnace slag, fly ash, ground waste from fired clay bricks) or natural additives, such as pozzolanas which are volcanic ashes with hydraulic characteristics, have increasingly been used to produce mixed cements of acceptable quality. A pozzolan is a siliceous material which reacts with lime in the presence of moisture at ordinary temperatures. The increasing use of additives (up to 25%, except for blast furnace slag which may be used to over 60%) has introduced a new parameter for deciding on optimal locations for new cement production capacity, which until then was dictated only by considerations of raw material sources, access to transportation infrastructure, location and concentration of cement markets. Finally, cement substitutes, such as rice husk ash cement may become interesting alternative materials.

The major types of modified Portland cement products and specialty cements are described below:

Modified Portland Cement Products:

a) Portland-Blast Furnace Slag Cement: This is essentially an interground mixture of Portland cement clinker and granulated blast furnace slag, or an intimate and uniform blend of Portland cement and fine granulated blast furnace slag in which the amount of the slag constituent is between 25% and 65% of the total weight of blended cement. Type 1S Portland-blast furnace slag cement is for general concrete construction.

b) Portland-Pozzolana Cement: This is a uniform blend produced by intergrinding Portland cement or Portland-blast furnace slag cement and fine pozzolana. Type 1P Portland-pozzolana cement is for use in general concrete construction, and Type P is for use in concrete construction where high strengths at early ages are not required.

c) Pozzolana-Modified Portland Cement: The constituents in this type of cement are the same as those for Portland-pozzolan cement, and the methods of production are the same, however, the amount of pozzolan constituent is less than 15% of the total weight of the blended cement. Type 1(PM) pozzolan-modified Portland cement is for general concrete construction.

d) Slag Cement: This is a finely ground material consisting essentially of an intimate and uniform blend of granulated blast furnace slag and hydrated lime in which the slag constituent is at least 60% of the total weight of blended cement. Type S-slag is for use in combination with Portland cement in making concrete and in combination with hydrated lime in making masonry mortar.

Specialty Cements:

a) Oil-Well Cement: This was developed to seal oil and gas wells under pressure up to 1200 bars and temperature up to 175C. These cements must remain fluid up to four hours and then harden rapidly. Setting time is controlled by reducing C3A to nearly zero or adding to Portland cement some retarder such as starches or cellulose products, sugars, and acids, or salts of acids, containing one or more of the hydroxyl group.

b) Expansive Cement: This tends to increase in volume after setting during the early hardening period, due to the formation of chemical substances such as calcium sulfoaluminate hydrate which cause expansion equal to or greater than shrinkage that would normally occur during the hardening process.

c) Regulated-Set Cement: This has a setting time which can be controlled from a few minutes to thirty minutes or more. Rapid-hardening modified portland cement develops very high early strengths. Promising applications include highway resurfacing and paving patching, underwater patching, manufacturing concrete pipe, blocks, and prestressed precast forms, and use in slip form structures.

d) Aluminous Cement: Sometimes known as calcium aluminate cement or high-alumina cement, this is hydraulic non-Portland cement containing monocalcium aluminate (CaO, A1203 or CA) as the predominant cementitious compound that sets at about the same rate as Portland cement but hardens very rapidly, attaining high strength in 24 hours. Aluminous cements are produced mainly from relatively high-purity bauxite and limestone with very low silica and magnesia content. Special applications of aluminous cement are based on its rapid-hardening qualities, resistance to sulfate action, and refractory properties when used as mortars for furnaces and kilns.

e) White Cement: This is made from iron-free materials of exceptional purity, usually limestone, china clay or kaolin, and silica. Clinker is burned with a reducing flame in the kiln and rapidly quenched in a water spray to keep any iron in the ferrous state to avoid coloration by feric ions. Clinker is ground with high-purity white gypsum using ceramic balls and liners in grinding mills; recently high-chromium alloys have been used for liners and grinding media. White cement conforms to Portland cement specifications for the various types and is used in decorative concrete including terrazzo, highway lane markers, and architectural concrete.

f) Masonry Cement: This is a hydraulic cement for use in mortars for masonry construction containing one or more of the following materials: Portland cement, Portland-pozzolan cement, slag cement, or hydraulic lime usually with hydrated lime, limestone, chalk, calcerous shale, talc, slag, or clay interground for plasticity.

2.6 Environmental Issues

The operations in a cement plant result in pollution affecting the air, water and land resources. Air contamination originates from several sources. The grinding and handling of the raw materials emits dust. The kiln operations and clinker cooling also cause dust, in addition to emitting oxides of sulfur and nitrogen, hydrocarbons, aldehydes and ketones. The cement grinding, handling, packaging and shipping operations also cause dust to be generated. The major source of dust in cement plants is from the kiln.

Water pollution results from water coming in contact with the kiln dusts. The most significant source of water pollution is from the leaching operation which is used for removing the soluble alkalies and recovering the insoluble portions for reuse as raw materials. Another source of water pollution is the wet disposal in the plant of dust in the form of a slurry. The wet scrubbers used to collect kiln dust from effluent gases is also a cause of water pollution.

The supplies of kiln dust, raw materials, clinker, and coal are frequently stored in piles on plant property. Unless proper measures are taken, rainfall runoff can discharge from these piles and carry pollutants into adjacent waters.

Table 2.1

OXIDE COMPOSITION OF NORMAL PORTLAND CEMENT (TYPE I)

Oxide	Range, Percent
Lime, CaO	60-66
Silica, SiO_2	19-25
Alumina, Al_2O_3	3- 8
Iron, Fe_2O_3	1- 5
Magnesia, MgO	0- 5
Sulfur Trioxide, SO_3	1- 3

Source: Reference 17

Table 2.2

PRINCIPAL COMPOUNDS OF PORTLAND CEMENT

Name	Chemical Composition	Abbreviation
Tricalcium silicate	$3CaO \cdot SiO_2$	C_3S
Dicalcium silicate	$2CaO \cdot SiO_2$	C_2S
Tricalcium aluminate	$3CaO \cdot Al_2O_3$	C_3A
Tetracalcium aluminoferrite	$4CaO \cdot Al_2O_3 \cdot Fe_2O_3$	C_4AF

Source: Reference 17

Table 2.3

- REPRESENTATIVE AVERAGE COMPOUND COMPOSITION FOR FIVE TYPES OF PORTLAND CEMENT

Type of Cement	General Description	Potential Compound Composition, Percent			
		C_3S	C_2S	C_3A	C_4AF
I	General purpose	49	25	12	8
II	Modified general purpose	46	29	6	12
III	High early strength	56	15	12	8
IV	Low heat	30	46	5	13
V	Sulfate resistant	43	36	4	12

Source: Reference 17

3.0 STATUS OF TECHNOLOGY AND EQUIPMENT IN LARGE-SCALE PLANTS

This chapter describes the steps in the manufacture of cement in large-scale rotary kiln plants, the major technologies developed for each stage and the equipment employed in each stage of the production process. Most of the equipment is manufactured by the following leading suppliers of cement machinery for the cement industry: F.L. Smidth of Denmark, Polysius Neubeckum and Humboldt Wedag of West Germany, Fuller Company and Allis Chalmers of the U.S.A., Fives Caile Babcock of France and Ishikawajima-Harima Heavy Industries (IHI) of Japan.

3.1 What is Large Scale?

Large-scale cement plants range anywhere from 300 tons per day (about 95,000 tons per year) to as large as 4,500 tons per day (about 1.4 million tons per year). Kilns as large as 8,000 tons per day (2.5 million tons per year) are in operation and up to 10,000 tons per day (over 3 million tons per year) are contemplated. The normal size of a large cement plant being built around the world is around 3000 tons per day (about 1 million tons per year). The large cement plants employ the rotary kiln for both efficiency and economy.

The following are the most frequently used types of rotary kilns: (a) straight rotary kiln; (b) rotary kiln with enlarged burning zone; (c) rotary kiln with enlarged calcining zone; (d) rotary kiln with enlarged burning and calcining zone; (e) rotary kiln with enlarged drying, calcining, and burning zone (wet-process kiln); (f) rotary kiln with enlarged drying or preheating zone (long dry process or wet process kiln). The aim of the zone enlargement is the extension of the material's residence time in the particular kiln zone.

The current status of technology and equipment used in various stages of the cement industry in both the developed and developing countries is herewith described.

3.2 Quarrying and Crushing

Raw materials used for the manufacture of Portland cement can be derived from almost any source containing the mineral elements of which cement is composed. However, the bulk of the material comes from quarried limestone. Limestone deposits vary from soft, water-dispersible chalks and marls to the hardest of marbles. Much of the limestone used is hard to moderately hard, and must be mined or quarried, using explosives to break up the deposits. The secondary materials, clay or shale, can vary from soft and sticky materials to hard and laminated materials.

The actual operation of the quarry as shown in Figure 3.1 consists of: (a) removal of overburden; and (b) drilling and blasting. The types of equipment used for removing the overburden are bulldozers, draglines, scrapers and various types of motor shovels, depending on the nature and depth of the overburden.

Cement raw material blasted in the quarry requires size reduction before further processing. Size reduction is performed in crushers and grinding mills. The equipment which breaks up the rock containing the raw materials into small pieces, small enough to be fed into the raw meal grinding machine, has remained basically the same for many years. Normally primary and secondary crushers are used, though for wet materials these are replaced by a circuit consisting of wash mills and crushers. A variety of processes and equipment are available for selection of the right kind of size reduction machinery. Machinery for size reduction in the coarse range (crushers) by application of compression are: (a) jaw crushers; (b) gyratory or cone crushers; and (c) roll crushers. Crushers for size reduction by impact are: (a) hammer crushers or hammer mills (single or double impeller type) and (b) impact crushers. The selection of the proper feed openings of gyratory and jaw crushers depends on sizes of the rocks as well as upon the bucket volume of the quarry excavator.

In the cement industry, the jaw crusher is in general use; this is due to its relatively simple design and also to the circumstance that this crusher is manufactured in large units. The jaw crusher serves mainly as a primary crusher (see Figure 3.2). The size reduction of the crusher feed is performed between two crusher jaws; one of them is stationary, and the other is moved by toggle pressure. Various jaw crushers with different design feature have been developed; of these two remain the most popular, namely the double-toggle jaw crusher (also called Blake-crusher) and the single-toggle crusher; both are shown in Figure 3.3.

Gyratory crushers (also known as cone crushers) crush the material between the cone shaped stationary crushing ring and a crushing cone; the cone performs a gyratory motion about a vertical shaft , the lower end of which is positioned in an eccentric. These crushers are manufactured in two types: (a) Gates crushers and (b) Symons crushers. The cement industry employs Gates (Gyratory) crushers mainly as primary crushers. Compared to the jaw crusher, the Gates crusher, with the same sizes of feed opening and discharge slot, has two or three times higher capacity. The Symons (or cone) crushers are mainly used for secondary crushing.

Cone crushers are based upon the passage of material between two rotating rolls which crush the material by compression. The particle size of the crushed material depends on the distance of both rolls from each other. Depending on the kind of crusher feed, the surface of the crushing rolls can be smooth, ribbed or toothed. Subject to the hardness of the crusher feed, the ribs can be arranged along or across the axis of the rolls.

Hammer crushers are widely used in the cement industry. They are used for size reduction of hard to medium hard limestone, and sometimes for marl crushing. Hammer mills work with reduction ratios of 1:40; depending on the crusher feed, this ratio can increase to 1:60. Sometimes the high reduction ratio of hammer crushers does away with the need for the installation of multi-stage crushing plants. Generally two types of hammer crushers are manufactured: single shaft and double shaft hammer crushers. Figure 3.4 shows the two types of hammer mills.

Crushing by impact is a dynamic operation and the breakage or size reduction follows along natural cleavage lines, i.e., where cohesion is low. Crushing by impact is, thus, applicable only for brittle rocks, since plastic material does not shatter when impacted. Size reduction by the impact crusher ensues in three stages: (a) main size reduction carried out by striking , i.e., by impact of the impeller bars to the crusher feed; (b) impact of the feed against the breaker blades; and (c) by crashing the material chunks against one another. Humboldt-Wedag manufactures three types of impact crushers, namely: (a) the coarse impact crusher; (b) the fine size impact crusher; and (c) the hard rock impact crusher. The crusher manufactured by F.L. Smidth, Copenhagen, Denmark, and called EV-Crusher, is a combined impact and hammer crusher.

3.3 Raw Material Handling and Storage (including preblending)

The field of raw material blending and storage is large and is influenced by many diverse factors. This begins with the quarry and the consistency of the raw materials. In most cases, there is not one consistent cement-making component. As a result, the cement making process requires a combination of various raw materials which have to be blended together.

There are several basic systems available to obtain the blending required. The predominant system used in most existing plants is to handle the various components separately in storage and feed these to the grinding mill without prior blending. The mix is controlled by adjusting the feeders before the grinding by sampling the ground material. This type of system generally requires a more extensive blending system after the grinding operation. The alternative to the above process is to completely blend the various materials in a stockpile prior to the grinding operation. This reduces the amount of homogenizing to be done after the grinding.

Preblending systems can range from the two limiting configurations shown in Figure 3.5. The integral batch preblending consists of stacking all the various raw materials so that the overall composition of the resulting pile is that of the raw mix. The pile is reclaimed and sent to the raw mill in such a way that homogenization of the raw materials is achieved. The chemical composition of a pile being stacked is monitored by a feed-forward control. The opposing configuration is that of continuous preblending. No stacking and reclaiming is involved. Instead, the various raw mix component materials are fed from bins directly and simultaneously to the raw mill. The correct raw material proportions are monitored by chemical analysis of the mill product and interactive feedback control to the bin weighfeeders. The concept of batch preblending solves the problem of filtering medium-term chemical variations in the raw materials that are not handled effectively by the feedback control and homogenization silos.

3.4 Raw Material Grinding

The purpose of grinding the raw materials is to produce a fine particle-sized material to feed the kiln that will allow proper burning or clinkerization to take place. The choice of the size reduction or grinding equipment and the process is governed primarily by the physical characteristics of the raw materials and by hardness and moisture content in particular. If the raw materials have a naturally high water content, the wet process is generally used and during the grinding water is added to produce a pumpable slurry (Figure 3.6). If the dry process is to be used (Figure 3.7), no water is added, and as most raw materials contain moistures ranging from 3% to 18%, drying of the materials either before or during the grinding operation has to take place. Waste heat from the kiln and cooler is often used to dry the raw materials.

Since various raw materials are usually combined to produce a suitable mixture for making cement, in all probability the various raw materials will have different grinding characteristics. This will result in differential grinding within the grinding system. In most cases it is necessary to grind the entire raw mix to a point where the hardest fraction is reduced to a suitable size for the burning process. This hardest portion of the raw mix is usually the silica, which poses the greatest problem in the burning process. However, the separate grinding of the raw materials is not possible if the silica is an integral part of the limestone. One solution that is used is to use a rod mill before the ball mill, since the rod mill tends to grind the larger sizes, which are normally the hardest fractions.

There are several different types of grinding mills now used for the wet or dry grinding of cement raw materials. The following are the basic types: (a) Wet overflow rod mill; (b) wet overflow ball mill; (c) wet or dry diaphragm ball mill; (d) airswept mill; (e) double rotator ball mill; (f) roller mill; and (g) autogenous mill.

The most common mill for slurry grinding is the single or double compartment ball mill, used in either closed circuit or open circuit. In the open circuit design, the fineness is controlled by the feed rate to the mill and the material is kept in the mill for a long enough time to be ground to the proper fineness. The closed circuit system (Figure 3.8) can be of several designs but essentially it is the passing of the slurry through some classifying system with the coarse fraction returning to the mill.

Most raw materials used in a dry process contain moisture. There are three basic methods used for drying raw materials: (a) predrying before the mill; (b) combining drying and grinding within the mill; and (c) drying within the air separator. The equipment used in predrying systems includes, but is not necessarily limited to the following: (a) rotary dryer; (b) crusher dryer; (c) flash dryer; and (d) fluid bed dryer. The equipment for drying and grinding simultaneously within the mill, can generally be classed as follows: (a) drying compartment; (b) air-swept mills; and (c) semi-air-swept mills.

The most common system for grinding raw materials is the diaphragm discharge ball mill (Figure 3.9), whether a single or multicompartment unit. The unit can be fitted with a drying compartment to provide a greater degree of drying in the mill. In this particular type of dry-grinding installation, the amount of air drawn through the mill is kept low because the material is discharged from the mill by mechanical means. In the air-swept mill, the raw material enters with the air through the feed trunnion and is predried in the drying chamber. Because the complete material transport is pneumatic, large amounts of air are required, which makes possible the use of low quantities of low temperature gases.

The double rotator incorporates the advantages of both the airswept mill and the diaphragm mill. It enables high air throughput similar to the airswept mill, which allows drying of a high initial moisture content. The raw material is fed, together with hot gas, into the drying section of the mill. After the material is dried, it is conveyed through the division head into the coarse-grinding section of the mill. After the material is ground, it exits through the periphery of the mill shell. The material is then mechanically transported to the air separator. The oversize from the separator is fed back through the other end of the mill into the fine grinding section. A further advantage of the separation between the coarse and fine-grinding section is the optimum sizing of the ball charge.

Since roller mills are air-swept and can handle large volumes of air, they are particularly suitable for simultaneous drying and grinding by the use of hot waste gases from rotary kilns or suspension preheaters and the clinker coolers. If no waste gases are available, the hot air for drying can be produced in auxiliary air heaters with automatic temperature control. As shown in Figure 3.10, the material to be ground is fed into the mill by an airlock type feeder. It falls onto the grinding table (shown in Figure 3.11) and is thrown outward and under the grinding rollers by centrifugal force. Ground material moves outward from the roller path, spills over the edge of the table, and is carried upward by high velocity air passing up through louvers or ports around the periphery of the table. The classifier at the top of the mill separates the coarse oversize particles from the carrier air. The oversize particles fall back onto the grinding table, and the material of desired size is carried by the airstream to cyclones which separate out 90 to 95% of the material. The airstream continues on to a dust collector which separates the remainder of the material from the air. In Europe, electrostatic precipitators are used exclusively for roller mill dust collection whereas glass fabric filters are commonly used in the United States. A number of European roller mill systems utilize a precipitator for both material separation and dust collection and are not equipped with cyclones.

As compared with ball mills, in roller mills the ground material is rapidly withdrawn from the grinding path thus reducing the chances of overgrinding. In addition roller mills can accept somewhat larger feed size than ball mills. However, three important factors are considered potential constraints to the adoption of roller mill technology. The first is the nature of raw materials. Soft, chalky limestones and marls are very inefficiently ground in a roller mill, and raw feeds containing more than 3% quartz greatly increase maintenance requirements owing to the abrasion of working surfaces. Secondly, a roller mill used with a Suspension Preheater kiln cannot handle raw materials containing more than 7% to 8% moisture, because insufficient heat is available in preheater exit gases to dry wetter feeds. A third constraint is the potential for entrapment of alkalies, sulfur, and chlorides in the roller mill. Roller mills are operated with throughput capacities of more than 500 tons per hour of cement raw mix (Loesche-mill, Polysius double roller mill, Pfeiffer-MPS-mill, SKET/ZAB-roller mill).

3.5 Homogenization of the Raw Mix

In the past, fluctuations in the calcium carbonate content of limestone were kept to a minimum by selective quarrying, and also because relatively low quantities of raw materials were processed in cement plants. With increasing production capacity of the cement plants, selective quarrying is no longer very effective; instead prehomogenization is mostly applied to the main components of cement raw material. The argillaceous component of the raw material is mostly homogeneous, although some plants need to homogenize it also. Silica sand and iron ore are mostly homogeneous, and do not require prehomogenization.

Prehomogenization can be divided into two groups: (a) combined prehomogenization of the raw material components and (b) segregated prehomogenization of the particular raw material components.

Combined prehomogenization requires components of balanced chemical composition. The proportioning of the components is done before stacking the stockpile. Irregular particle size composition of the components, however, can cause partial segregation, resulting in temporary chemical deviation of the raw mix from the set point. This method does not yield such high quality results when compared to prehomogenization of the particular components. Segregated prehomogenization of the raw materials is the most widely used method of preblending in the cement industry. The particular prehomogenized components, after proportioning them as they come from the feed bins and weigh feeders, are fed into the raw grinding mill. The chemical analysis of the raw mix leaving the mill, supplies the information as to what corrective measures should be taken to bring the raw mix into conformance with the established requirements.

The following longitudinal stockpiling methods of blending beds are employed: (a) roof-type stockpiles (Chevron method); (b) line-type stacking (Windrow method); (c) areal stockpiling; (d) axial stockpiling; (e) continuous stockpiling; and (f) alternate stockpiling. Roof type stockpiling is the most widely employed blending bed. To avoid the disadvantage of coarse particle accumulation or particle size segregation, the Windrow method is sometimes selected. The stockpiling of a circular blending bed is, also, mostly performed by the Chevron and Windrow methods.

The following equipment is usually used for retrieval of the blended raw materials from the stockpiles stockpiles: (a) reclaiming scraper or (b) a reclaiming bucket wheel. Depending on the type of design, the scraper can reclaim the blending bed from the front end, or by travelling along and adjacent to the longitudinal axis of the stockpile (Figure 3.12). Belt conveyors then convey the reclaimed material to the mill feed bins. The bridge mounted bucket wheel is designed to simultaneously accomplish a revolving and a transverse movement. Figure 3.13 shows the reclaiming method employing the bucket wheel.

In the past the wet process was the preferred method for production of high quality cement because homogenization of the slurry resulted in a thorough mixture of the raw materials. Now pneumatics has enabled the cement industry to pneumatically homogenize the dry cement raw mix. The various raw mix homogenization methods are: (a) the Fuller Airmerge system; (b) Polysius Homogenization system; (c) Moller homogenizing system; (d) the IBAU Central Chamber Blending system and (e)Peters mixing chamber silo process.

The Fuller Airmerge system (also called the quadrant blending method). Two air compressors supply the aeration and blending air. The volume of the blending air directed into the blending quadrant is 75%, and the air directed into the the three aeration quadrants is 25% of the total air. Thus an extremely well aerated light density column of material is created above the blending quadrant. The denser material over the aeration quadrants continuously combines with the lighter density material of the blending column, and is displaced upward, thus creating an active vertical circulation of material. By cycling the air supply to each of the four quadrants in turn and at a predetermined length of time, a nearly homogenous cement raw mix is produced. This is diagrammatically shown in Figure 3.14. Under special raw mix quality conditions it might be more advantageous to supply pulsated rather than continuous blending air. Pulsated air produces a greater mobility than continuous air in the raw mix with the same amount of air. Pulsation also results in a broader and more uniform dispersion of the air throughout the material.

The Polysius system shown in Figure 3.15 is divided into nine aeration fields, each of which can be supplied with a different quality of air. Like the Fuller system, it basically consists of sectors which are simultaneously aerated and then not aerated with blending air.

The Moller system has three processes: (a) a shearing stream process which is used when there are large input variations in the calcium carbonate content of the raw mix; (b) an homogenizer with upper floor silos is used when the raw mix leaving the raw mill shows only small quality variations; and (c) a throughput homogenizer is used when the cement raw mix has narrow input variations.

In the IBAU blending system the blending silo is simultaneously used for a continuous blending process as well as for raw mix storage as shown in Figure 3.16. The mixing chamber process is a continuous process, blending the raw mix simultaneously during silo feeding and discharge, or only when the material is discharged from the silo. The preblended material entering the mixing chamber is subjected to an intensive, alternated aeration, fluidizing the material layers, and thus effecting an active blending as is shown in Figure 3.16.

Peters mixing chamber silos (Figure 3.17) are constructed as one story silos. The particular design permits material discharge, at a controlled rate, through only one lateral discharge socket located in the silo wall, irrespective of the silo diameter. Material withdrawal from the expansion prechamber is also possible. The Peters continuously operating homogenizing silo reduces high and long time variations in the raw material composition.

3.6 Clinker Production

Clinker is produced in rotary kilns in large-scale cement plants. The kiln is the most important piece of equipment in the manufacture of cement. It is the largest capital expenditure, the greatest source of fuel consumption and the main area of dust emission. A rotary kiln consists of a steel tube lined with refractory bricks, an insulation layer between the shell and lining, front and back housings, a supporting structure and a driving mechanism. It has a length of between 30 and 230 meters or more and a diameter from 2 to 7.5 meters. The ground, proportioned and homogenized raw materials enter the kiln at its upper feed end, the firing system is installed at the lower or discharge end. In the rotary kiln, as the feed flows slowly towards the lower end, it is exposed to increasing temperatures. During passage through the kiln, the raw materials are heated, dried, calcined, and finally heated to the point of incipient fusion at about 2900F, a temperature at which a new mineralogical substance called clinker is produced. Clinker production is one of the most important functions of a cement plant as the quality of the finished cement largely depends upon proper burning conditions in the kiln. The kiln department in a typical large-scale plant is shown in Figure 3.18.

In terms of process technology, the physical condition of the feed material is the basis for the following four processes: (a)wet process; (b) semi-wet process; (c) dry process; and (d) semi-dry process. Each of them are described below.

3.6.1 Wet Process

In the most widely used wet process system, a mixture of 32 to 48% water and finely ground and blended feed is fed to the kiln as shown in

Figure 3.19. Shortly after entering the kiln, the slurry encounters a chain system, which is a series of long strands, garlands, or curtains of steel chains fastened to the kiln shell. The rotary movement of the kiln causes these chains to immerse in the slurry and then to receive heat from the hot combustion gases generated in the burning zone. The chains thus transfer the heat to the slurry, which causes the slurry temperature to rise gradually. The garland type chains and the slope of the kiln convey the slurry down the axis of the kiln.

As water evaporates, the material gradually is converted to plastic nodules, which the chains convey further. Slightly beyond the feed end chain system, the water is removed, and the dry raw feed progresses through the preheating, calcining and burning zones. The preheating zone raises the temperature and drives off combined water in the raw materials. The calcining zone decarbonates the calcium and magnesium carbonates, and the burning zone causes the clinker-forming chemical reactions to occur. The fresh clinker then travels through the cooling zone of the rotary kiln and drops into a clinker cooler. A substantial portion of the heated air is then used for combustion of the fuel in the burning zone, while the cool clinker is eventually removed from the cooler ready for finish grinding or intermediate storage. The kiln dust generated in the process, and caught in the pollution control equipemnt, may be reintroduced into the kiln in a number of alternate ways. It may be "insuflated" with fuel through the kiln burner pipe; it may be added through the use of dust "scoops", or it may be added to the slurry at the feed end of the kiln either with or without intermediate leaching treatment.

The following rotary kiln burning processes are applied in the wet process: (a) the long wet process rotary kiln with internal heat exchangers such as chains, segments or other arrangements; (b) the short wet process rotary kiln without internal heat exchangers, working in conjunction with a separate heat exchanger for partial drying of the slurry (these heat exchangers are known as slurry dryers or concentrators or calcinators); (c) the medium long wet process rotary kiln with preliminary dewatering of the slurry by suction or pressure filters; and (d) the short wet process rotary kiln without internal installations with mechanical preliminary dewatering of the slurry (the resulting filter cake is then processed into nodules which are fed into a preheater e.g., a shaft preheater or to a heat exchanger grate).

3.6.1.1 Semi-Wet Process

This process (shown in Figure 3.20) seeks to obtain the advantages of the wet process without the high fuel consumption implied. The raw materials are washed in water to form a slurry, but then filtered to expel the majority of the water content. The resulting cake has a moisture content of 18-20%. The cake is converted into nodules which are then exposed to hot kiln gases in some kind of preheater. This removes some of the remaining water content before the nodules are fed into the kiln. This process theoretically results in considerable fuel saving but has never been widely adopted since the procedure for filtering the slurry to form a cake entails the use of cumbersome batch operated pressure filters, which produce an intractable substance difficult to maneuver and pelletize.

3.6.2 Dry Process

This process is shown in Figure 3.19. In this process the water content of the raw materials ranges from 0% to 7%. Crushed raw materials are either first dried and then ground, or drying and grinding are carried out simultaneously in a drying circuit mill. Individual components are fed into the mill by means of weigh feeders. Raw meal is then conveyed into the system of homogenizing and storage silos where it is pneumatically or mechanically homogenized and its composition is possibly corrected. The raw mix is then routed and fed into the rotary kiln. The development of better dry raw mix air homogenizing systems and dust suppression systems has led to the adoption of long dry rotary kiln with enlarged feeds equipped with internal heat exchangers (Figure 3.21). In the dry process kiln, the chain system retains the heat of the hot kiln gases used to dry the raw mix. For a dry process the following rotary kiln burning processes are applied: (a) the long dry process rotary kiln without internal installations; (b) the long dry process rotary kiln with internal heat exchangers, such as chains and refractory bridges; (c) the short dry process rotary kiln working in conjunction with preheaters such as the suspension preheater; and (d) the dry process rotary kiln with waste heat boiler.

3.6.2.1 Semi-Dry process

In this process, dry raw materials are wetted to a moisture content of 12-14% to form a "cake". This cake is then made into pellets or modules which are fed onto a travelling grate through which the hot gases of the kiln are passed. In this way the pellets entering the kiln are preheated to a large extent, allowing the reduction of the kiln length to about half, giving, with the grate, an overall length of about 70% of the equivalent long kilns. The temperature of the grate exit gases is about 180F and due to the filtering effect of the layer of granules, the dust load of the exit gases is very low. Also, the low temperature as well as the content of water vapor make the exit gases ideally conditioned for electrostatic precipitation. Figure 3.22 shows a Lepol kiln (as such kilns are normally called) with a single gas circuit and with a double gas circuit. When this kiln has a single gas circuit, the rotary kiln exit gases penetrate the bed of nodules downward , from where they are withdrawn by suction and led to the dust collector. Fresh air is supplied through the inlet damper to the drying compartment, to prevent the bursting of the granules due to the high vapor pressure. This results in heat losses and in higher exit gas volume. The double gas circuit is an improvement on the single circuit kiln since it reduces the volume of the exit gases, and fresh air is no longer added.

The Lepol kiln is a significant development in the field of cement production using the semi-dry process. It is widely used in cases where raw materials have special properties such as high alkalinity. The Lepol kiln's advantage is its versatility, since this kiln is also used for burning of crushed rock such as limestone and dolomite gravel and the pyroprocessing of nickel and iron ore pellets.

3.6.2.2 Preheaters

The revolutionary innovation in the dry process was the development of the suspension preheater, which is used in conjunction with a short rotary kiln for processing dry raw meal. In this system the blended dry meal passes through a special piece of equipment called the suspension preheater. This is a tall structure in which are arranged a number of cyclones in vertical series. The gases from the kiln are passed upwards through each cyclone. The raw meal feed is introduced through an air seal into the gases entering the highest cyclone to reduce the dust carried away by the exit gases. The meal caught in the gas screen is introduced to the circuit again by mixing it with the gases entering the next lower stage. As the raw meal proceeds to the lowest part of the system, it encounters progressively hotter gas streams which have been heated in the kiln and conducted directly into the preheater system. The material, as it leaves the last stage and enters the kiln is at a temperature approaching calcination.

Cyclone preheaters are predominantly built as four stage units (Figure 3.23). When modernizing or reconstructing older cement plants or when converting from the wet to the dry process, Two-stage cyclone preheaters are often added to existing rotary kilns to improve heat economy as well as kiln capacity. Because of the length of the rotary kilns, and the two stages of cyclones, the temperature conditions differ from that of a conventional four stage cyclone. Various preheater systems are outlined below:

(a) Polysius Dopol preheater (Figure 3.24): This double stream preheater manufactured by the Polysius Company derives its name from the fact that the exhaust gases are repeatedly divided into two streams to give a high grade of dust separation at a favorable pressure loss. Splitting the gas stream into two lines allows the application of smaller cyclones for the same gas volume with a high degree of separation. The goal of the manufacturers was to achieve very large kiln capacities, without fundamental changes in the design of the system and without the application of several preheater lines working in parallel.

(b) Bahler-Miag raw mix preheater (Figure 3.25): This consists of three double cyclones working in parallel current with one conical preheater shaft as a fourth stage, with counter current heat exchange. Designing the fourth stage as a conical preheater shaft results is a considerable operating advantage as compared to a conventional cyclone preheater. The large cross-section of the countercurrent stage helps in reducing the possibility of caking by raw mixes having large concentration of chlorides, alkalies, and sulfates. In the United States, the Allis Chalmers Company and in Spain the ATEINSA Company manufacture and sell this preheater as licensees.

(c) SKET/ZAB raw mix suspension preheater (Figure 3.26): This consists of three shaft stages as well as two cyclone stages located on the top. This preheater is characterized by its high operating safety in relation to volatile components of the raw mix. The widely spaced shaft stages, especially in the lower part of the preheater, are less sensitive to caking of alkali condesates.

(d) Krupp counter-current suspension preheater (Figure 3.27): This is almost a counter current heat exchanger except for the upper most stage which is constructed as a double cyclone stage supplied with a duct for the ascending gas.; the remainder of the preheater is a cylindrical, self supporting shaft. Nozzle type constrictions divide the shaft into four compartments. The raw mix is fed from between the uppermost preheater compartment and the cyclone stage. From here the raw mix is carried upward by the gas stream, preheated, separated in cyclones and discharged into the upper most preheater compartment. From here the raw mix descends from compartment to compartment into the discharge shaft, from where it finally enters the kiln.

3.6.2.3 Precalciners

One of the problems with the rotary kiln, both wet and dry, is the flushing effect of dry hot, finely ground raw materials being aerated by carbon dioxide on an inclined rotating surface. Some smaller wet kilns and kilns using the semi-dry process and plastic raw materials promote the formation of nodules which eliminate this problem, but in large wet kilns with extended chain systems and rotary kilns with preheaters, flushing is a serious problem causing unsteady operation. The precalcinator, by removing the carbon dioxide outside the rotary kiln, completely eliminates this problem and is the basis for a much steadier operation.

The industrial development of precalcining occured in Japan and West Germany during the 1960's for two different reasons. In Japan, the market created the need for very large production units which are only practical with precalciner technology. Interest in burning low grade fuels in West Germany led to the first precalciner operation there. Precalcining technology also improves kiln brick life, reduces alkali and sulfate buildup, improves kiln stability and reduces NOx emissions.

Precalciner systems have one common basis: the degree of decarbonation of the raw mix entering the rotary kiln is increased by burning a portion of the total fuel requirements in a precalciner vessel which is part of the suspension preheater. Since the rate of heat transfer is vastly superior in the precalciner than in the rotary kiln, the volume of the precalciner is very small in comparison to the rotary kiln volume it replaces. In all precalciner configurations, the raw mix is fed at approximately 700C to the precalciner vessel. The major differences between configurations is the gas flow and the location of burners and the geometry of ducts and vessels.

In countries where the production of low alkali clinker is necessary, a reduction of alkali levels must be effected. As with conventional preheaters, precalciner systems bypass a portion of the kiln exit gases. An efficient alkali bypass requires a high coefficient of volatilization with a low recirculation dust load, i.e., the waste dust is to have as high a concentration of alkali as possible. The bypass in a precalciner system can be more efficient than a conventional preheater in terms of overall fuel efficiency.

The most popular precalciner systems in use today are:

(a) the Ishikawajima-Harima Heavy Industries (IHI) SF-suspension preheater: Although the name is misleading, the main characteristic of this process (Figure 3.28) is that the calcination of the raw mix is performed separately in a so-called "flash calciner". Whereas in a regular suspension preheater, the raw mix is only slightly calcined (about 10-15%), it subsequently requires half the length of the rotary kiln for the calcination, and the other half for burning clinker. IHI introduced the SF process by which the heat transfer process can be economically accomplished by suspending the raw mix particles in the kiln gases before they enter the kiln. The SF process created the flash calciner in which the raw mix is calcined upto 90% before it is fed into the kiln. This reduces the heat consumption in the kiln and also increases the volume output of the kiln. Fuller Company, as a licensee of IHI, supplies SF-flash calciners to various parts of the world. During the fuel oil crisis, Fuller developed a coal dust firing system for the application of the SF-flash calciner.

(b) the Mitsibushi Fluidized Calciner (MFC) suspension preheater: This is shown in Figure 3.29. The MFC suspension preheater consists of a regular raw mix suspension preheater working in conjunction with a fluid bed calciner. The calcining of the raw mix with this process is performed in a separately heated fluid bed reactor located between the suspension preheater and the rotary kiln.

(c) the Reinforced Suspension Preheater (RSP): This is shown in Figure 3.30. The RSP preheater is a modification of the regular suspension preheater and is a joint development of the Onoda Cement Company and Kawasaki Heavy Industries Ltd, both of Japan. It consists of a two-compartment calciner, i.e., a heating shaft with a swirl burner and the calcining shaft arranged about the heating shaft. The suspended raw mix is calcined to about 90-95% before entering the kiln. In the United States, the Allis Chalmers Company manufactures the RSP preheater under license from Onoda Cement Company.

(d) the Polysius precalcining system: This is shown in Figure 3.31. This system is based upon an exclusive license of the Rudolf Rohrbach Company of West Germany and is characterized by a combined passage of combustion gases and air through the rotary kiln's cylinder. It is capable of working in conjunction with any clinker cooler.

(e) F.L. Smidth (FLS) Precalcining with separate raw mix preheater lines: This is shown in Figure 3.32. This system is characterized by a special air duct which conveys hot combustion air from the grate clinker cooler to a separate precalciner. The process control allows for a suitable margin of safety against overheating, even at a precalcining degree of 90-95%. For removal of chlorine, alkalies, and sulfur, a bypass can be easily attached to the system causing only moderate heat losses.

(f) FLS-Precalcining system for low alkali cement: This is shown in Figure 3.33. In this case the precalcining process is performed in one line consisting of the precalciner and the four-stage preheater. This line works independently of the exit gases from the rotary kiln. The kiln exit gases which are not utilized in the preheater are cooled and cleaned in a separate dust collector.

(g) FLS-Integral kiln with precalcining at kiln inlet: This is shown in Figure 3.34. In this process, the kiln exit gases come together with the uncalcined raw mix. When meeting the exit gases, the raw mix begins a whirling movement, thus initiating the calcining process. Before the mixture of exit gas and raw mix arrives at the gas duct at the lowest preheater stage, the temperature of the exit gases decreases to about 1545F. The kiln gases pass the kiln feeding zone, where the precalcining takes place. The raw mix which is separated in the lowest stage of the preheater, enters the kiln through a specially designed pipe. This arrangement prevents the precalcined raw mix from blending with the uncalcined raw mix in the kiln feeding area. To attain a high degree of precalcination, this separation of the two raw mix lines is very important.

(h) the Humboldt-Wedag Pyroclon precalciner: This is shown in Figure 3.35. There are two types of precalciners under this name: Pyroclon "R" (regular) and Pyroclon "S" (special). The choice between the two types of precalciners depends upon the production capacities of the kiln.

(i) the KSV-precalciner of the Kawasaki Heavy Industries: This is shown in Figure 3.36. This precalciner consists of a calcining furnace installed in the lower part of a conventional suspension preheater. This furnace is a combination of a spouter bed and a vortex chamber. In this process almost all the calcination is completed in the preheater working in conjunction with the KSV-precalciner. The KSV process increases the capacity of the rotary kiln 2-2.5 times as compared to the conventional suspension preheater.

3.7 Clinker Cooling

Clinker cooling is an integral part of the pyroprocessing or clinker burning process. Its primary objective is to obtain the maximum heat recuperation from the hot clinker in the form of combustion air or secondary air. Clinker cooling is necessary because hot clinker is difficult to convey and the heat has a negative effect on the grinding process. It also improves the quality of cement. There are four types of clinker coolers: (a) rotary coolers (the cooling drum is located under the rotary kiln); (b) satellite coolers (the cooling drums are attached to the circumference of the rotary kiln's discharge end; (c) grate coolers; and (d) shaft coolers. These types are shown in Figure 3.37.

The rotary cooler is the oldest type of clinker cooler and consists of a revolving cylinder into which the contents of the rotary kiln are emptied. The negative pressure in the rotary kiln induces suction of cold air through the open end of the rotary cooler and the cooling air passes the rotary cooler in cross current to the motion of the clinker. The satellite cooler consists of several, mostly ten or eleven sheet metal cylinders arranged wreath-like along the circumference of the hot kiln end, forming an integral part of the rotary kiln. The satellite coolers revolve with the rotary kiln. Openings in the kiln shell allow the clinker to enter the satellite coolers (cooling occurs cross-currently and the cooling air enters the kiln as combustion air). The motion of clinker in the satellite coolers is mostly parallel to the motion of the clinker in the rotary kiln, however there are satellite coolers which are capable of conveying the clinker in the opposite direction. The F.L. Smidth Unax-satellite cooler and the Humboldt-Wedag satellite cooler are some of the popular types currently in use.

The clinker grate cooler with air quenching effect, which is generally known as the Fuller cooler, was designed to be operated in conjunction with the rotary kiln. This cooler was developed to eliminate the detrimental effect of cement expansion which is caused by the recrystallization of the magnesia. Compared to the rotary cooler, the Fuller cooler requires about 20% less space.

The Fuller cooler is a reciprocating grate cooler and was designed for fast initial cooling to favorably influence clinker properties for high magnesia content. The other grate cooler is the travelling grate cooler developed for use with rotary kilns equipped with grate preheaters. Since a fluidized bed creates the most useful heat transfer conditions, Bade exploited the concept to combine the counter-current cooling process in the shaft cooler with a fluidized bed. Since the cooling in the shaft cooler is performed instantly, the quality of the clinker cooled in this way equals that of a grate cooler.

Almost all firms producing cement machinery now manufacture clinker grate coolers or clinker coolers similar to grate coolers. These are the Folax cooler of F.L. Smidth Company, the Recupol cooler of the Polysius Company, the Krupp grate cooler, the Claudius Peters grate cooler, the Humboldt-Wedag grate cooler and the vibratory cooler of the Allis Chalmers Company.

3.8 Clinker Grinding

The essential purpose of the grinding process (Figure 3.38) is to produce fineness, i.e., to obtain a specific size surface so that hydration can take place and concrete strength develops within a reasonable time. During clinker grinding gypsum is added to produce cement. Clinker can be ground by two different types of grinding circuits: (a) open-circuit grinding; where the mill product is sent to storage silos without sizing or returning the oversize to the mill for further grinding, and (b) closed-circuit grinding; where the mill product is sent to the separator and the oversize returned to the mill at once for further grinding. Greater production is obtained by closed-circuit grinding than in open-circuit grinding.

The most commonly applied closed-grinding system consists of a two-compartment mill and an air classifier. The mill and the air-separator are considered to be an integrated system, in which the mill product is passed on to the air separator where it is divided into a fine fraction (the end product) and a coarse fraction which is returned to the mill inlet. A mill for open-circuit grinding is usually divided into three compartments. The various sized materials pass through these compartments and then are stored; the larger sized materials are returned for further grinding.

3.9 Packing and Dispatching

Cement is dispatched either in sacks (usually 50 kg) or, nowadays to an increasing extent, in bulk by road, rail, or water-borne transport. Cement dispatch in 50 kg sacks is the usual form of packing if the infrastructure for handling and transporting bulk cement is not available or when the volume of shipping is too small to justify the construction of large bulk handling facilities. The proportion of cement dispatched in sacks varies by region. In Europe, the quantity of cement dispatched in sacks is below 10% for some countries (Sweden, Switzerland) and ranges up to 50% in others (Spain, Greece, Italy), while in developing and industrially emerging countries the percentage is above 90%.

Pulverized bulk materials like cement are packed in various types of sacks. Depending on the properties of the material and the required sack filling capacity, the machines employed are either of the in-line or the rotary type, with mechanical or with pneumatic filling systems. The packers manufactured by CAR-Ventomatic (CAR), Haver & Boecker (H&B), and F.L. Smidth (FLS) have established themselves as reliable and efficient in industrial operation. The Claudius Peters packer, a relatively newcomer to the market, has meanwhile undertaken various technical modifications which have improved its dependability.

The packers used for filling cement into sacks are of two types: in-line and rotary packers. In-line packers are manufactured by all the above manufacturers (except FLS) and a four-spout in-line packer can attain an average filling rate of about 1400 sacks per hour. Rotary packers have gained widespread acceptance as a modern form of high capacity sack filling machine. The best rotary packers attain a capacity of 400 sacks per hour and include products like the H&B Roto packer, the CAR Giromat rotary packer, and the FLS Fluxomatic rotary packer. The weighing machines used with most of these packers are becoming electronic rather than the mechanical weighing systems used previously.

In conjunction with the in-line and rotary packers two filling systems are employed within the packers: impeller and pneumatic. Impeller packers, manufactured by H&B and CAR, are predominant in the industry and are used with in-line machines. Leading manufacturers for the pneumatic packers are FLS and H&B. Pneumatic systems are particularly suitable for materials with poor flow properties or with a sticking or caking tendency.

Automatic loading machines for sacks destined for dispatch on or in road vehicles are of various types and makes. The type of automatic equipment depends mainly on whether the vehicles are of the covered or the open type and whether they are loaded from the side, the rear or from the top. Well known manufacturers of automatic loaders are CAR, Beumer, Mollers and Boubiela. The first three firms supply automatic machines for loading from the top. Rear end loaders for roofed or container vehicles are available from Beumer and Boubiela. Beumer also supplies a side-loading system. The CAR system has better adjustability for coping with sacks varying in dimensions, which is especially advantageous when different grades or types of cement have to be dispatched.

3.10 Environmental Control

Particulate matter, commonly called dust, is the primary emission in the manufacture of Portland cement. The following varieties of dust are generated in the operation of a cement plant: (a) raw material dust, i.e., dust from limestone, marl, clay, iron ore, or slag; (b) raw mix dust; (c) coal dust; (d) exit dust from raw material dryers; (e) exit dust from kilns; (f) clinker dust; (g) raw gypsum dust; and (h) cement dust. Dust emissions are a nuisance to the workers of the cement plant, they are a detriment to the environment, and they also constitute a non-negligible loss of material.

For the control of dust, the cement industry employs mechanical collectors, i.e., cyclone collectors and to a lesser degree small size gravity settling chambers, further fabric type dust collectors, gravel bed filters, and finally electrostatic precipitators. When properly designed, installed, operated and maintained, electrostatic precipitators or fiberglass fabric filters preceded by multicyclones will adequately collect the dust from hot kiln gases.

Dust collection in cyclone separators is achieved by centrifugal force. The equipment consists of a cylindrical or slightly tapered upper portion and a funnel shaped lower portion. The dust is discharged through double flap valves or air locks in order to prevent infiltration of superflous air. The air or gases to be treated enter tangentially the upper part of the cyclone, and, after having disposed of a large part of their dust content, leave the cyclone through a central outlet pipe. The tangential entry of the air or gases into the cyclone causes dust to be thrown out by centrifugal action. The particles strike the wall of the casing and slide down to the discharge at the bottom. Cyclones can be operated either with forced draught or with induced draught. A large cyclone can remove dust particles to about 20 micron in size. The dust collection efficiency of a single cyclone is in the order of 90-92%.

Electrostatic dust precipitators consist of a negatively charged wire and a positively charged collecting plate. The dust particles contained in the gas acquire a negative charge from the electrons thrown off by the wire and are attracted by the plate. Moisture content improves the conductivity of dust particles and electrostatic dust precipitators function optimally at 15-30% moisture.

Fabric (or bag) filters are used for collecting the dust form mills. conveying devices, crushing operations and kilns. They are used alone or in conjunction with other types of dust control equipment.

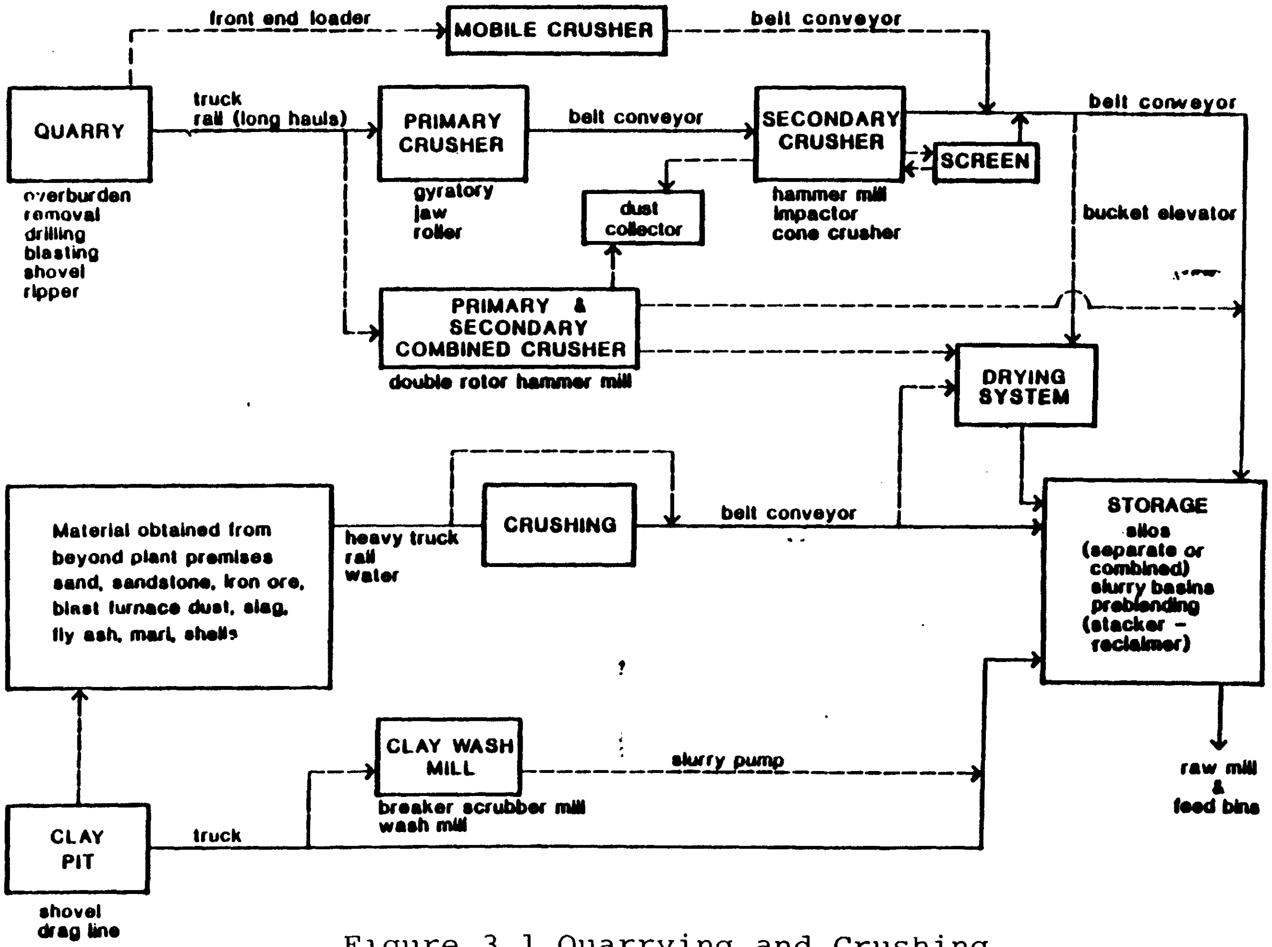
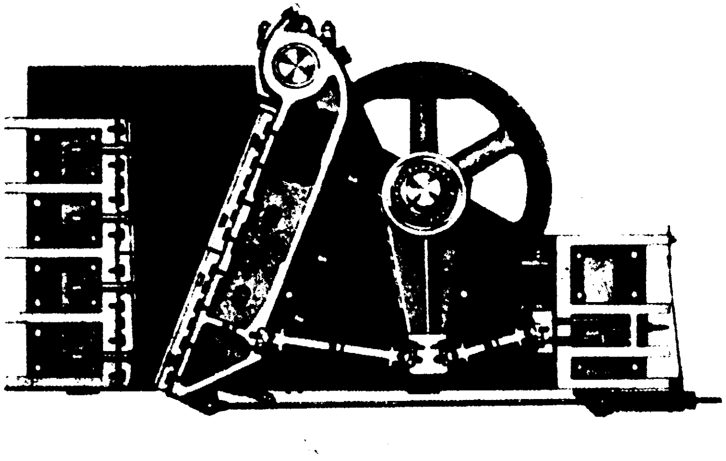
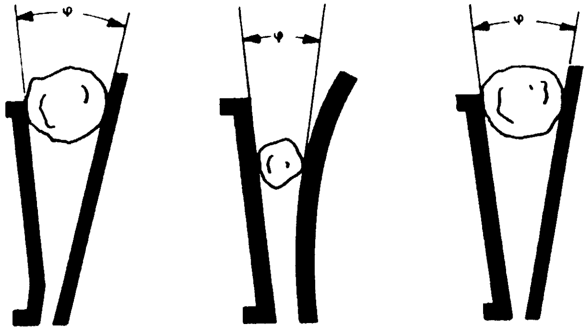


Figure 3.1 Quarrying and Crushing

Source: Lafarge Consultants



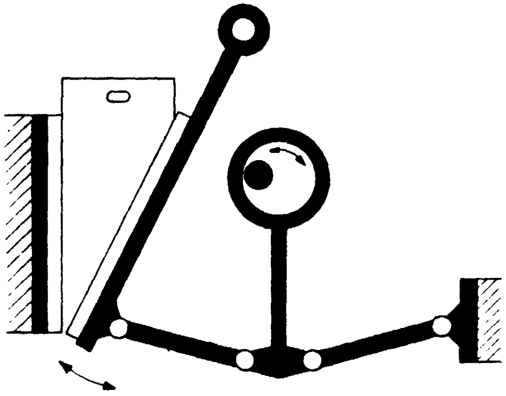
Jaw crusher — Cross-section



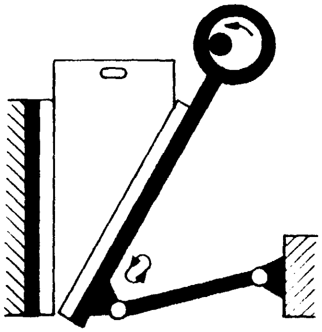
Various modifications of crusher jaws

Figure 3.2 Jaw Crusher

Source: Reference 9



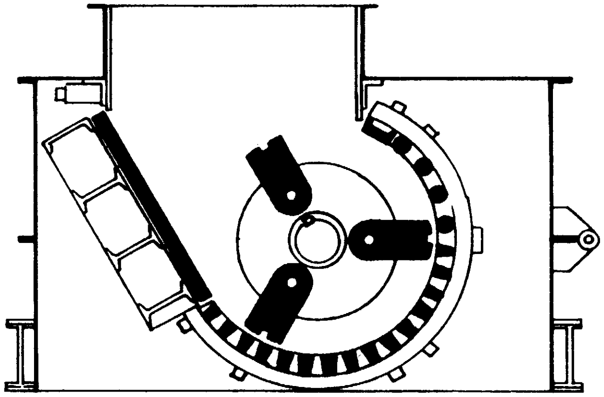
Schematic of the double-toggle jaw crusher



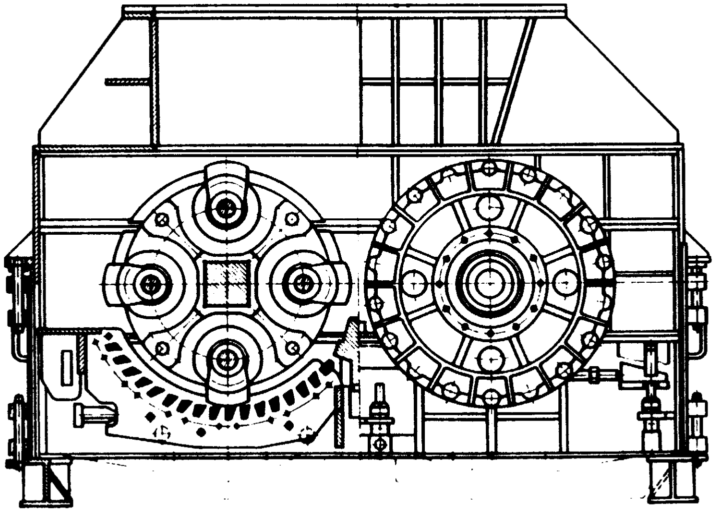
Schematic of the single-toggle jaw crusher

Figure 3.3 Toggle Jaw Crushers

Source: Reference 9

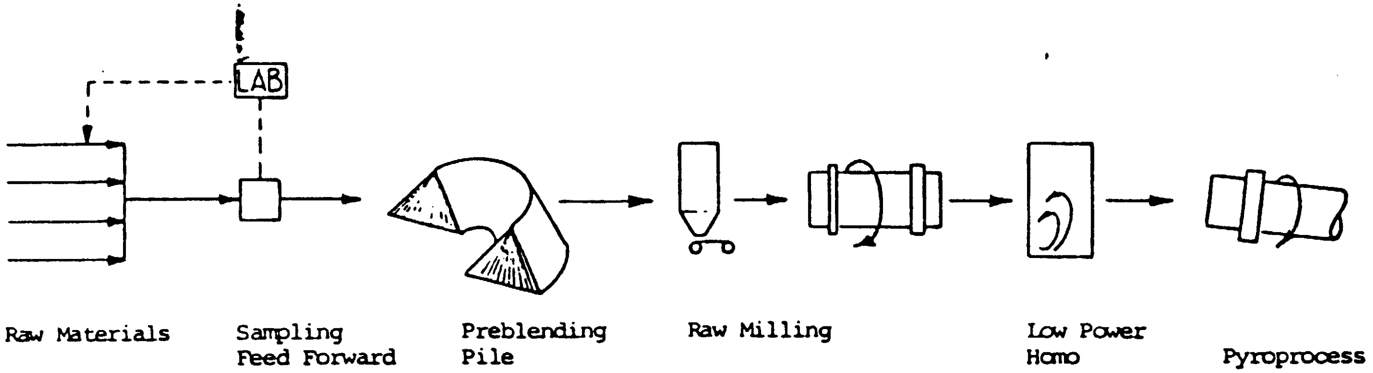


Single rotor hammer crusher

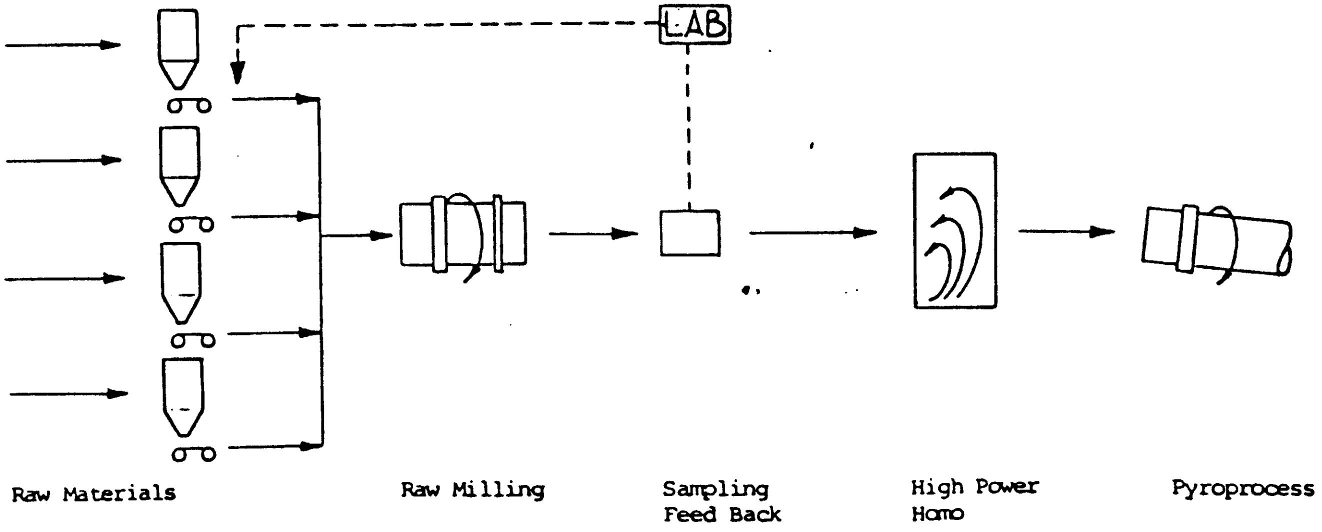


Double rotor hammer crusher

Figure 3.4 Hammer Crushers
Source: Reference 9



INTEGRAL BATCH PREBLENDING SYSTEM



CONTINUOUS PREBLENDING SYSTEM

Figure 3.5 Preblending systems
Source: Lafarge Consultants

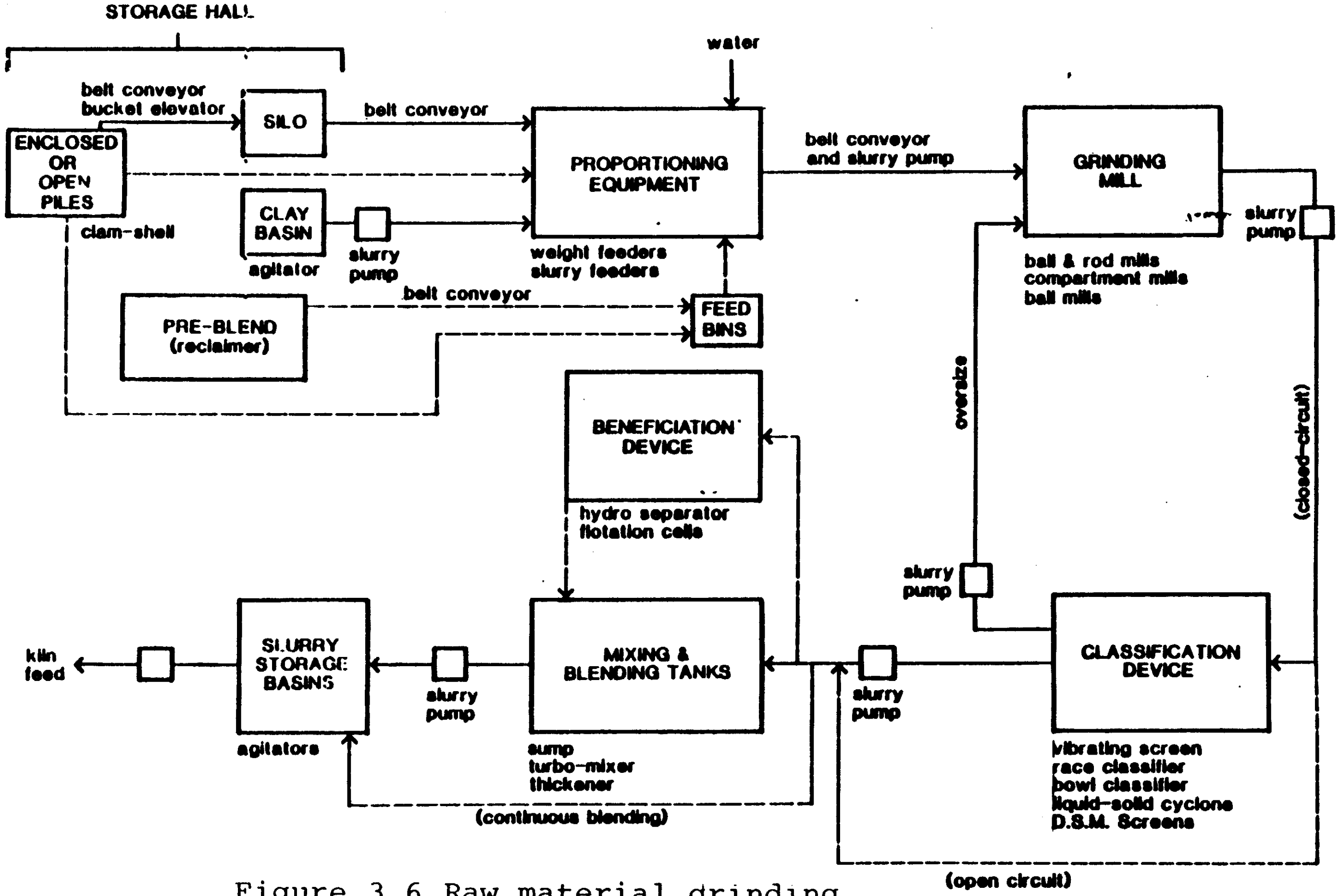


Figure 3.6 Raw material grinding
in the wet process
Source: Lafarge Consultants

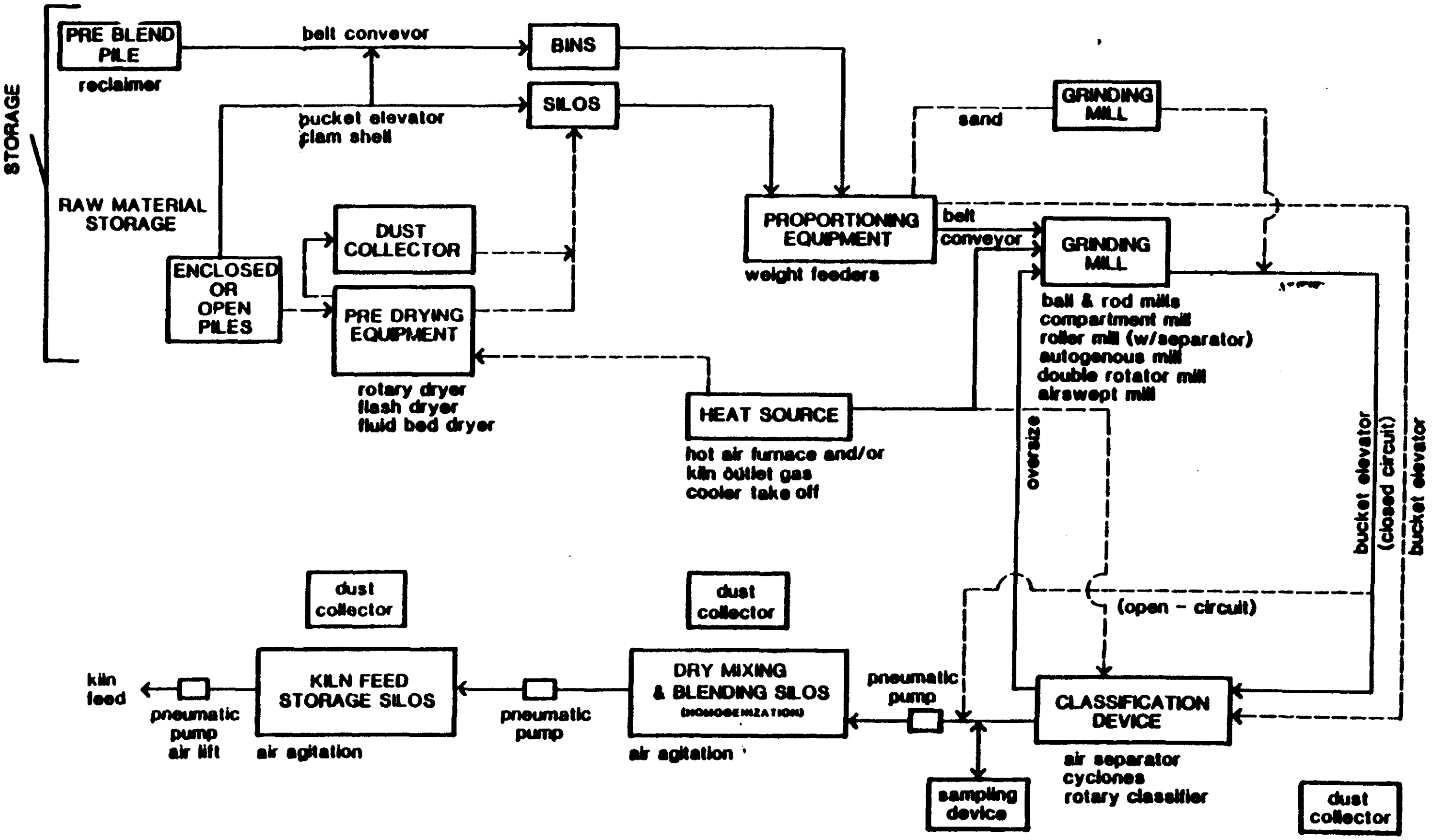


Figure 3.7 Raw material grinding
in the dry process
Source: Lafarge Consultants

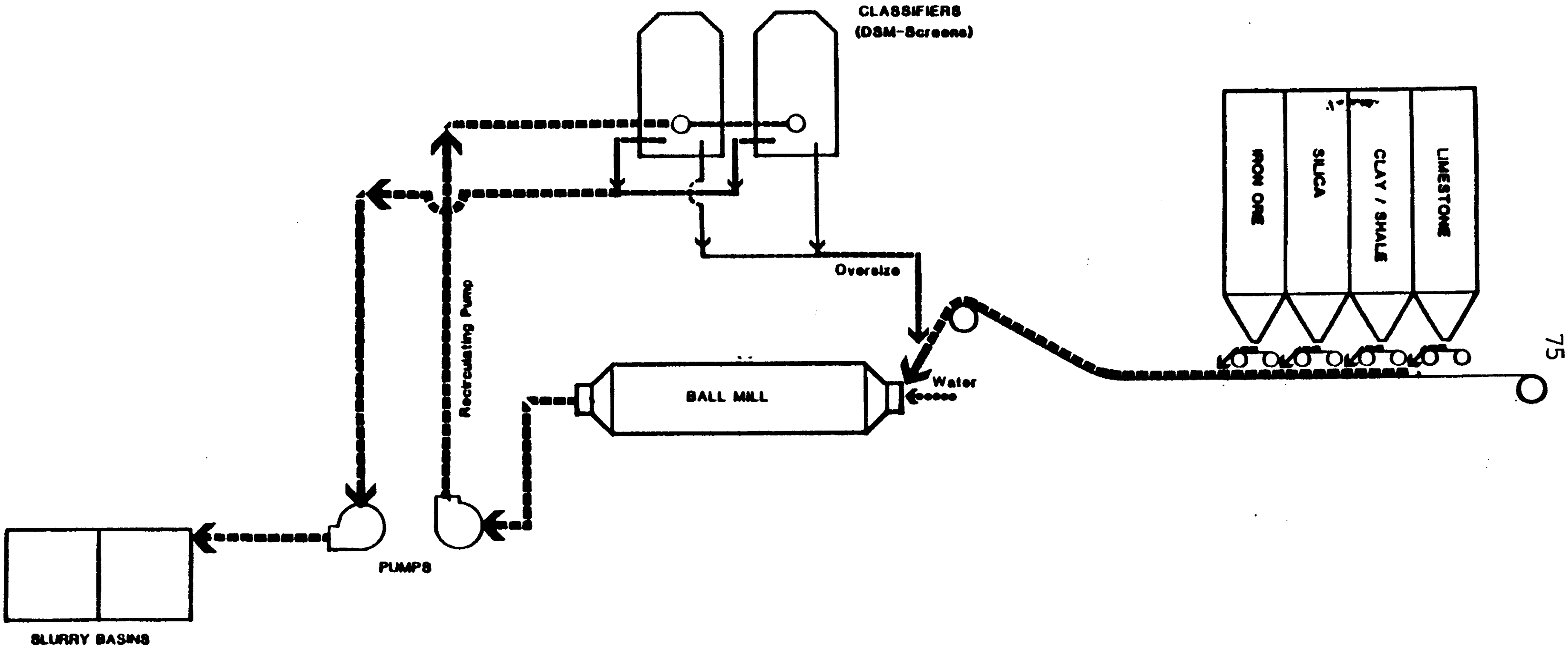


Figure 3.8 Wet process raw material grinding using the ball mill
Source: Lafarge Consultants

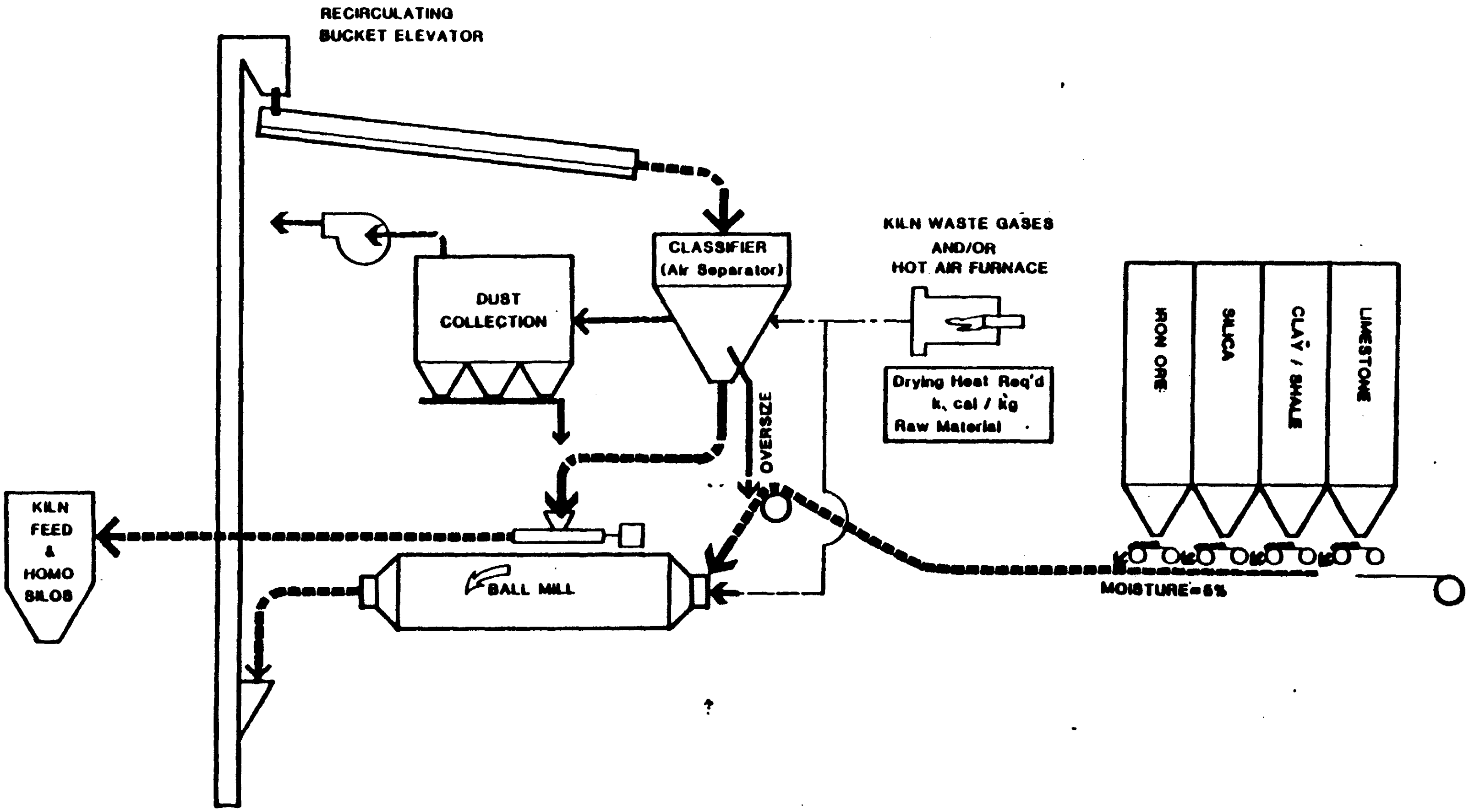


Figure 3.9 Dry process raw material grinding using the ball mill
Source: Lafarge Consultants

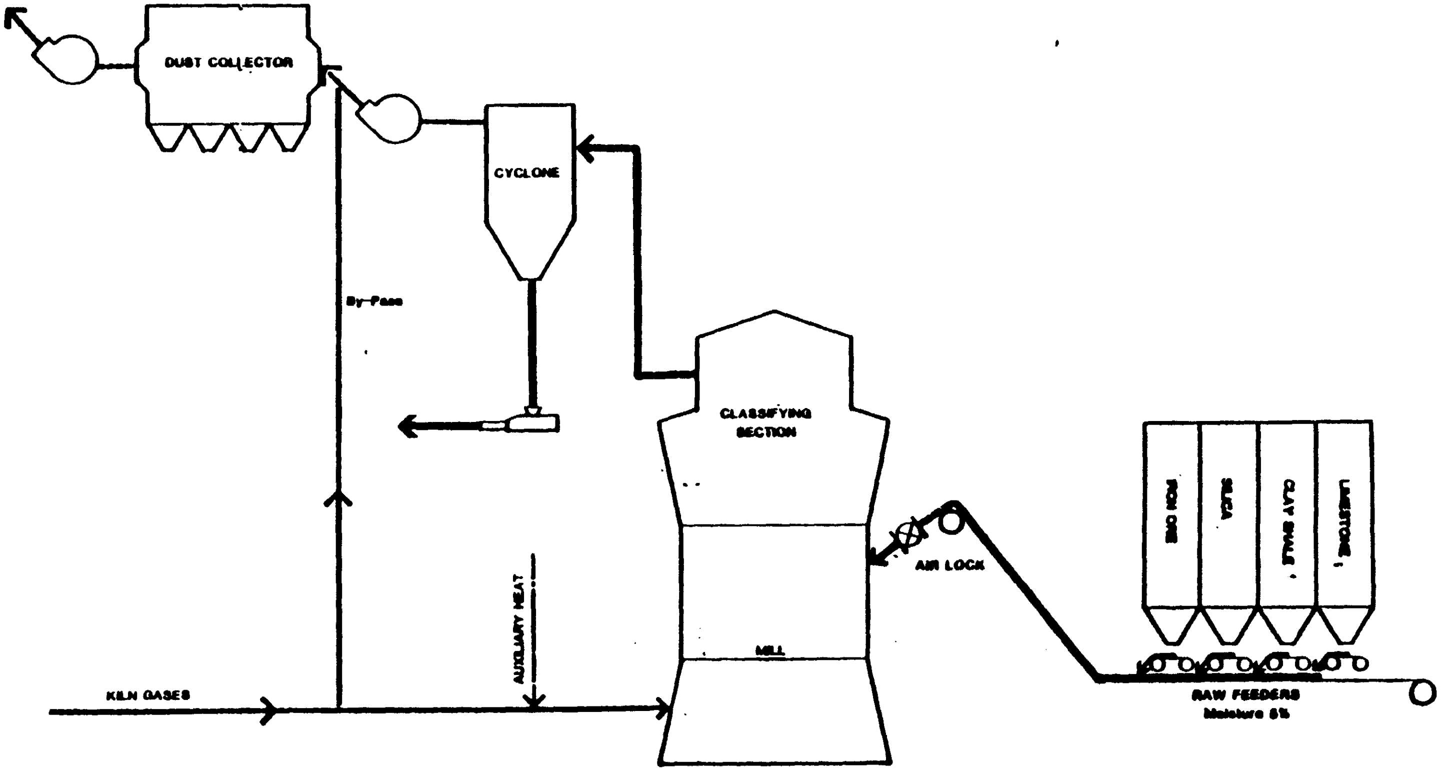


Figure 3.10 Dry process raw material grinding using the roller mill
Source: Lafarge Consultants

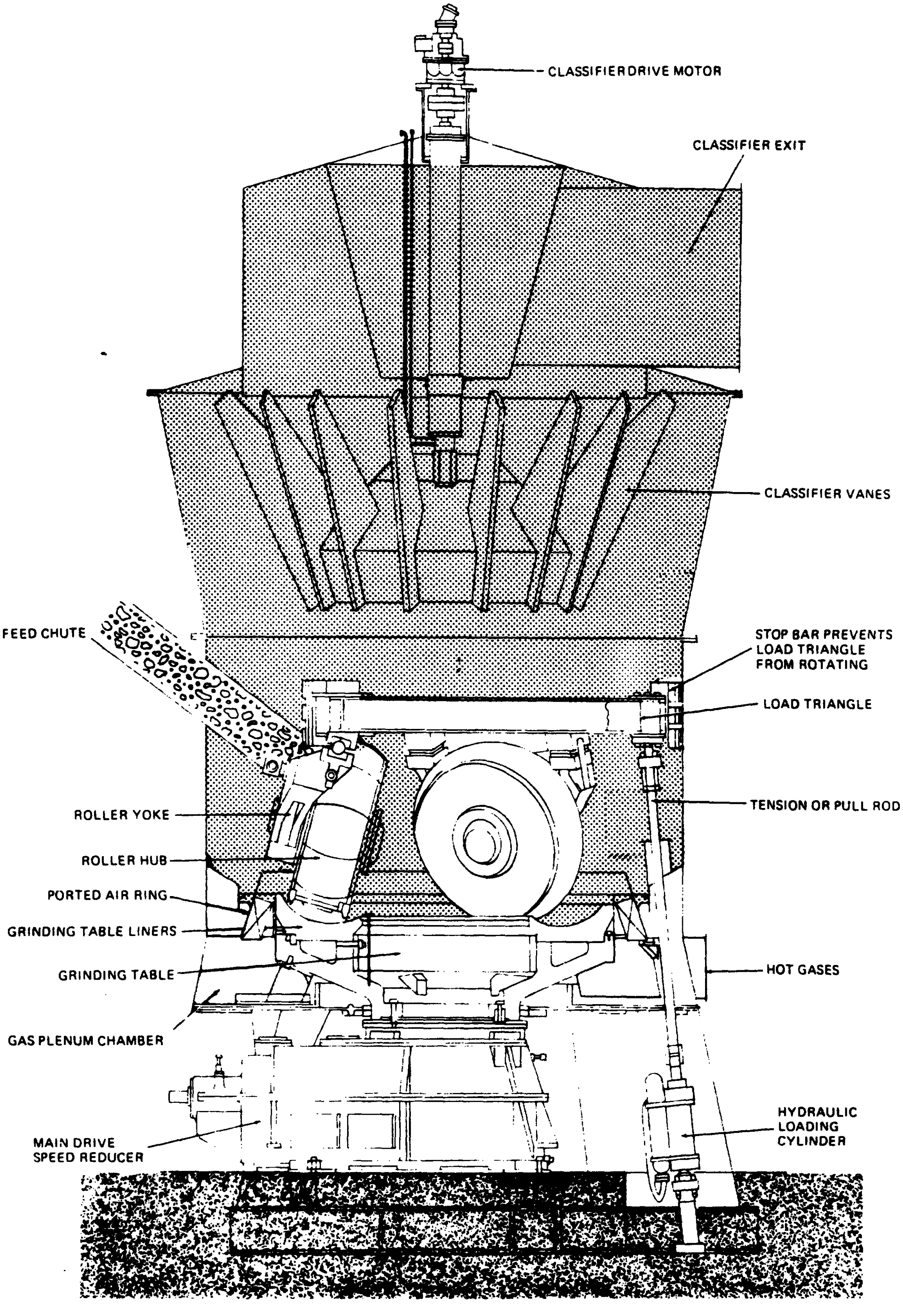
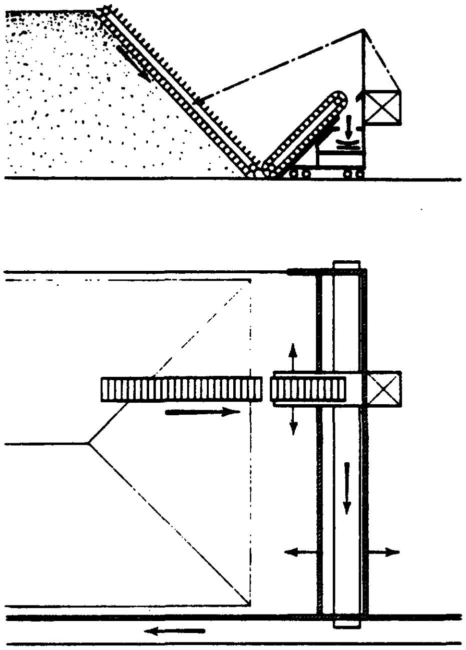
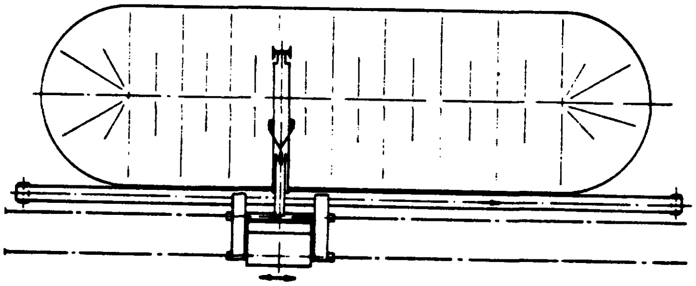


Figure 3.11 Roller Mill
Source: Allis Chalmers Corporation



Scraper reclaimer for front end reclaiming of a blending bed



Scraper reclaimer for alongside reclaiming of a blending bed

Figure 3.12 Reclaiming using the scraper

Source: Reference 9

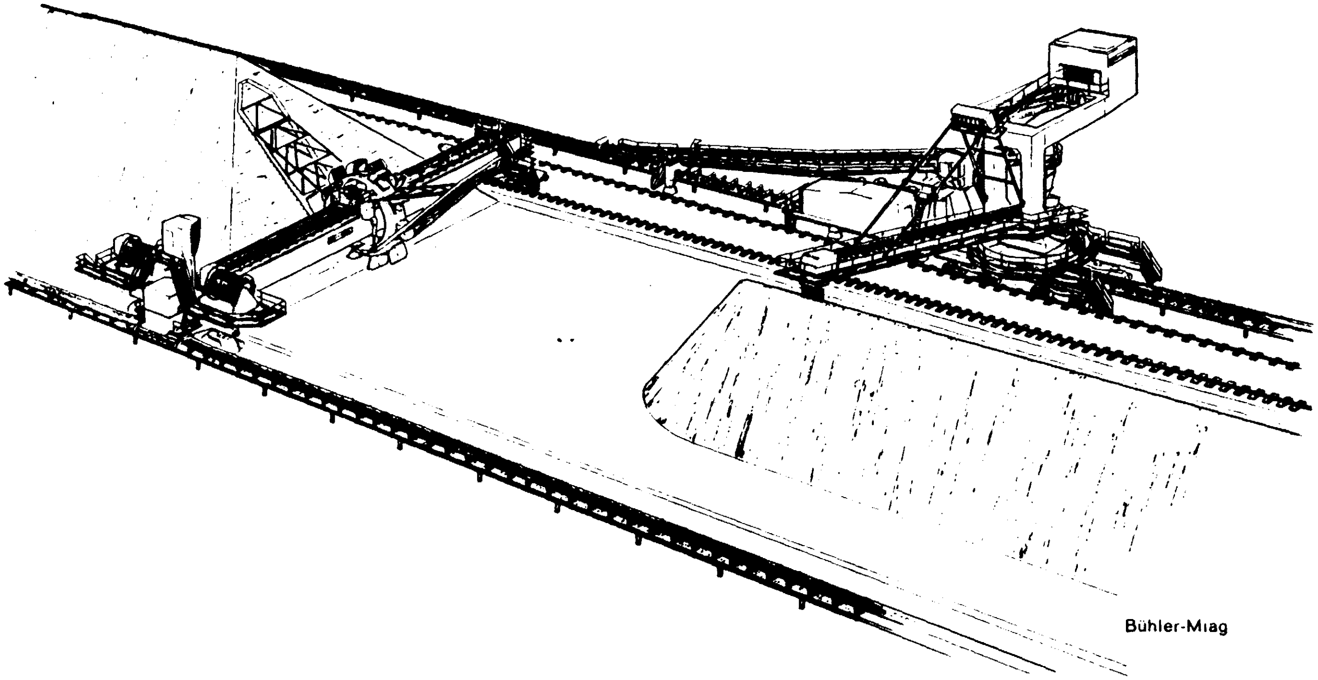


Figure 3.13 **Blending bed reclaiming with a bucket wheel**

Source: Reference 9

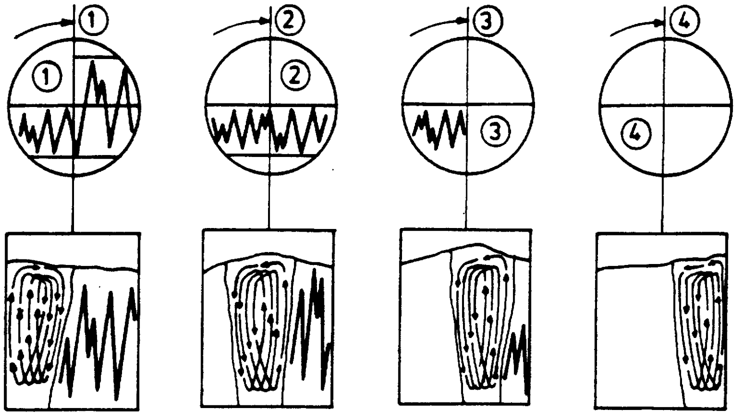


Figure 3.14 Schematic of the quadrant blending system

Source: Reference 9

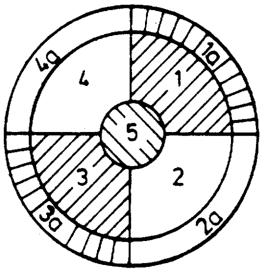
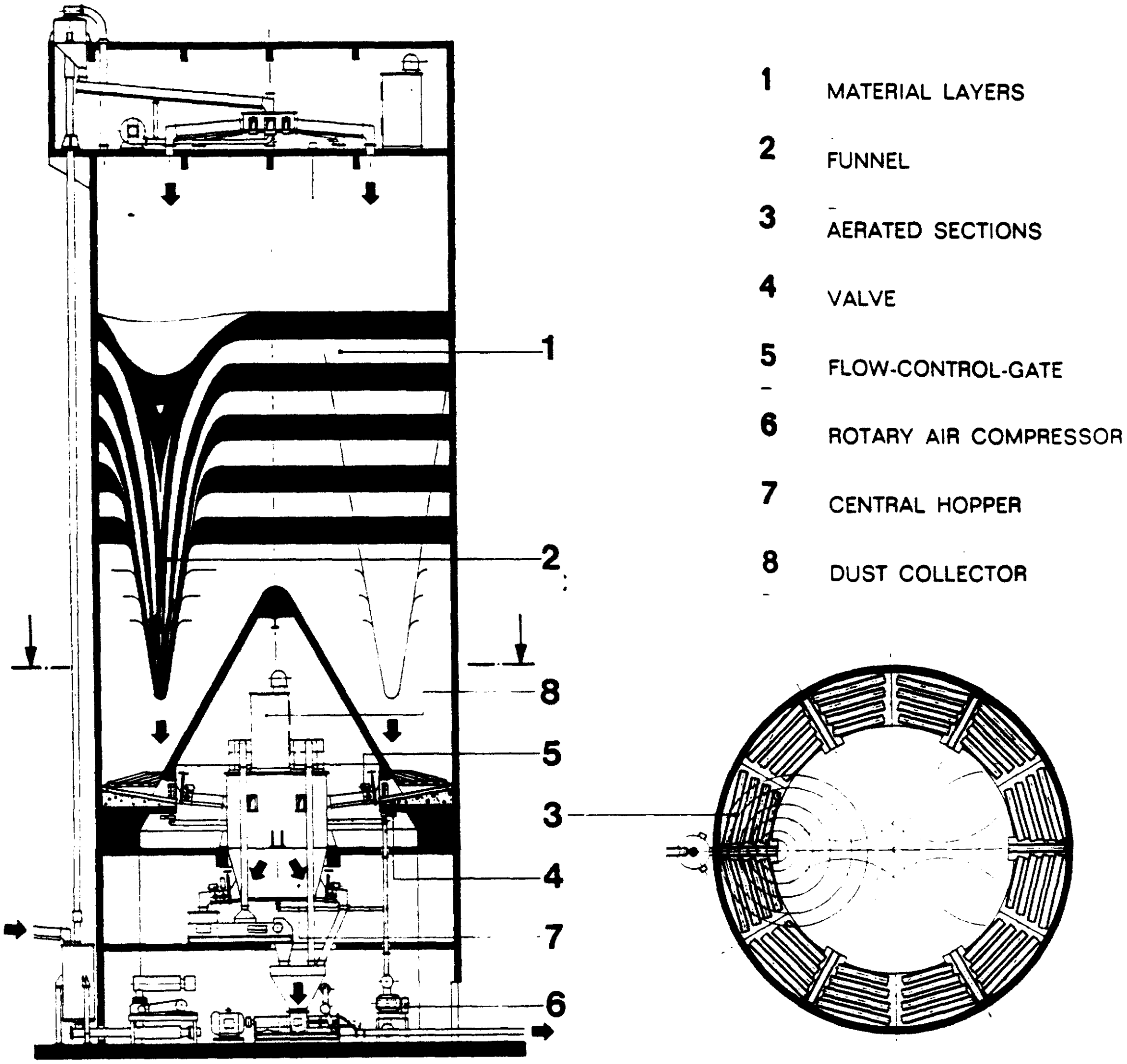


Figure 3.15 Schematic of the Polysius blending system

Source: Reference 9



IBAU Central chamber blending silo

Figure 3.16

Source: Reference 9

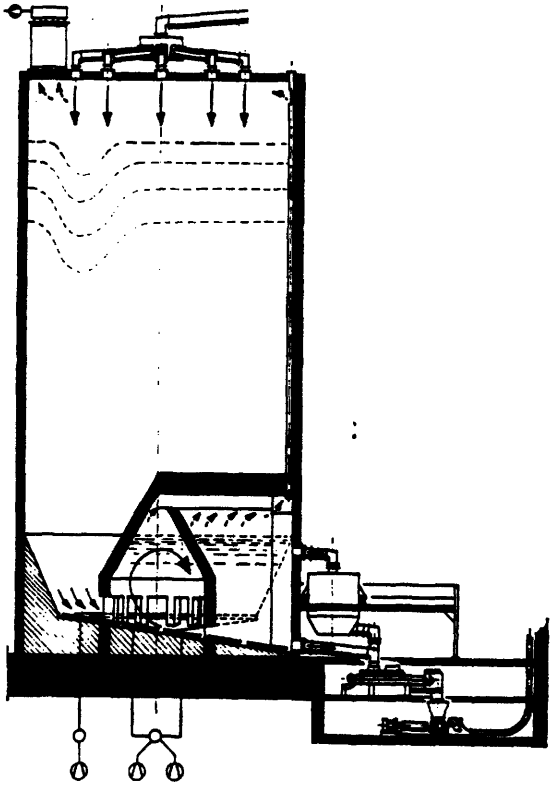


Figure 3.17 Peters mixing chamber silo

Source: Reference 9

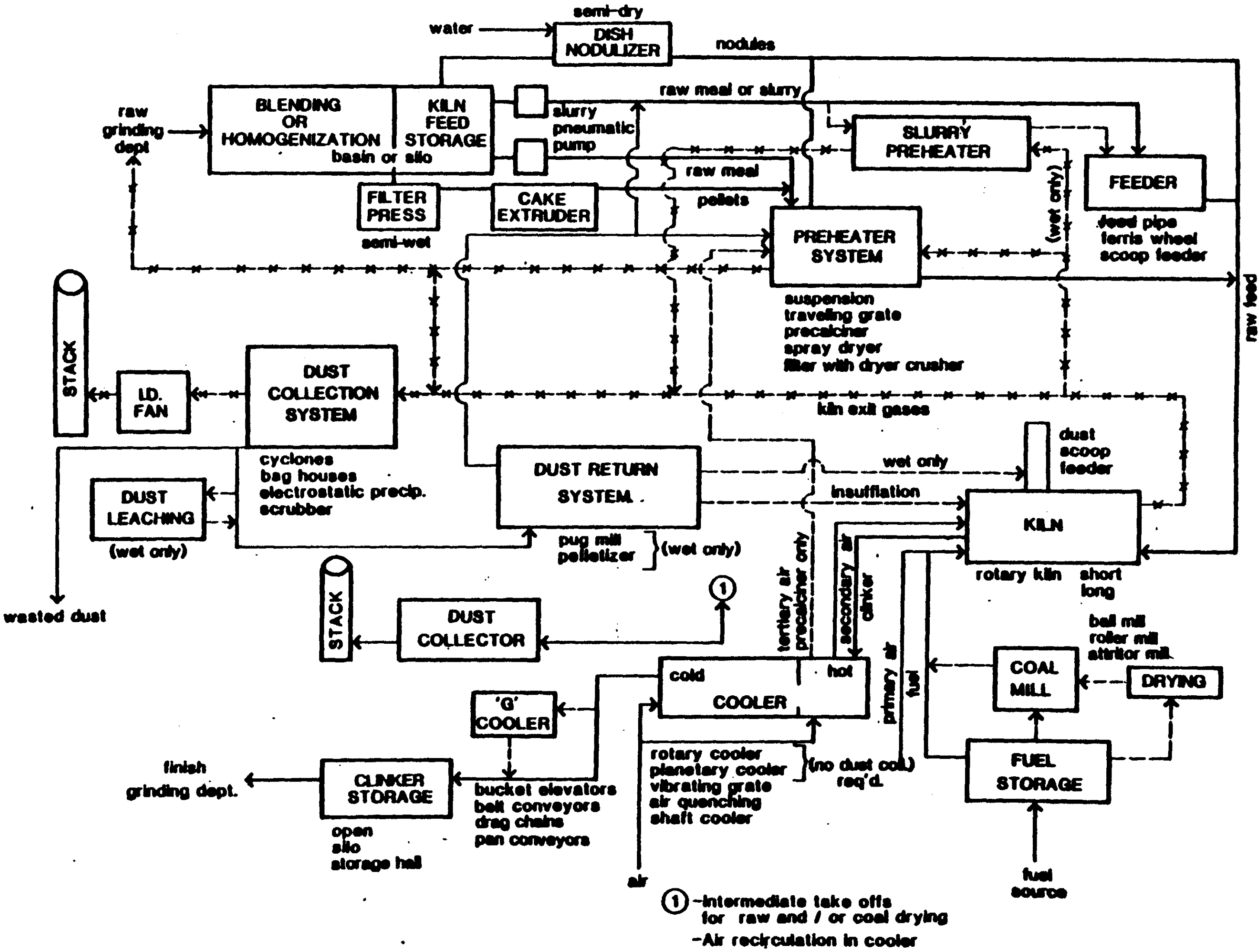


Figure 3.18 KILN DEPARTMENT (PYROPROCESSING)
Source: Lafarge Consultants

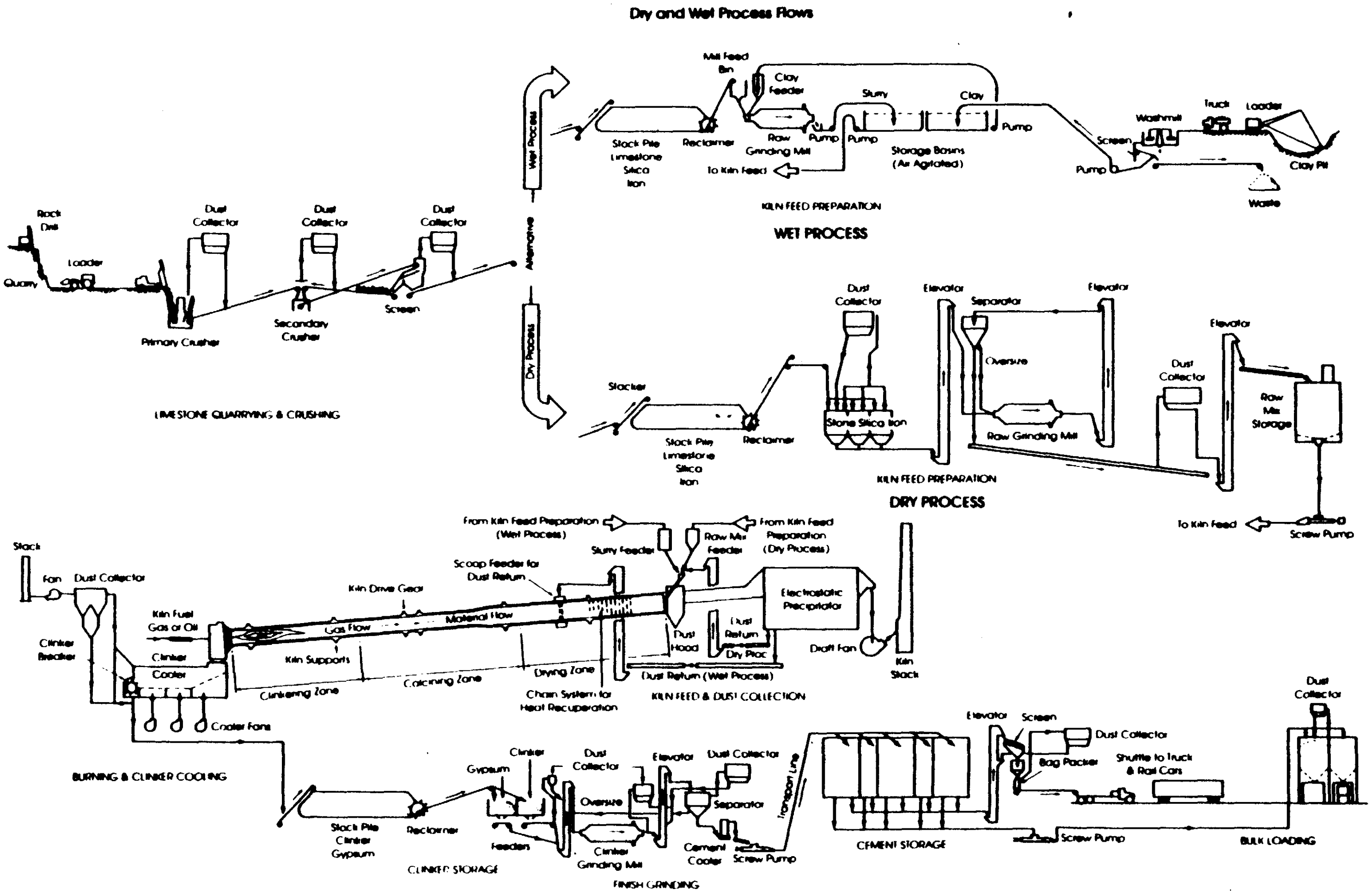


Figure 3.19 Wet and dry processes
Source: Reference 16

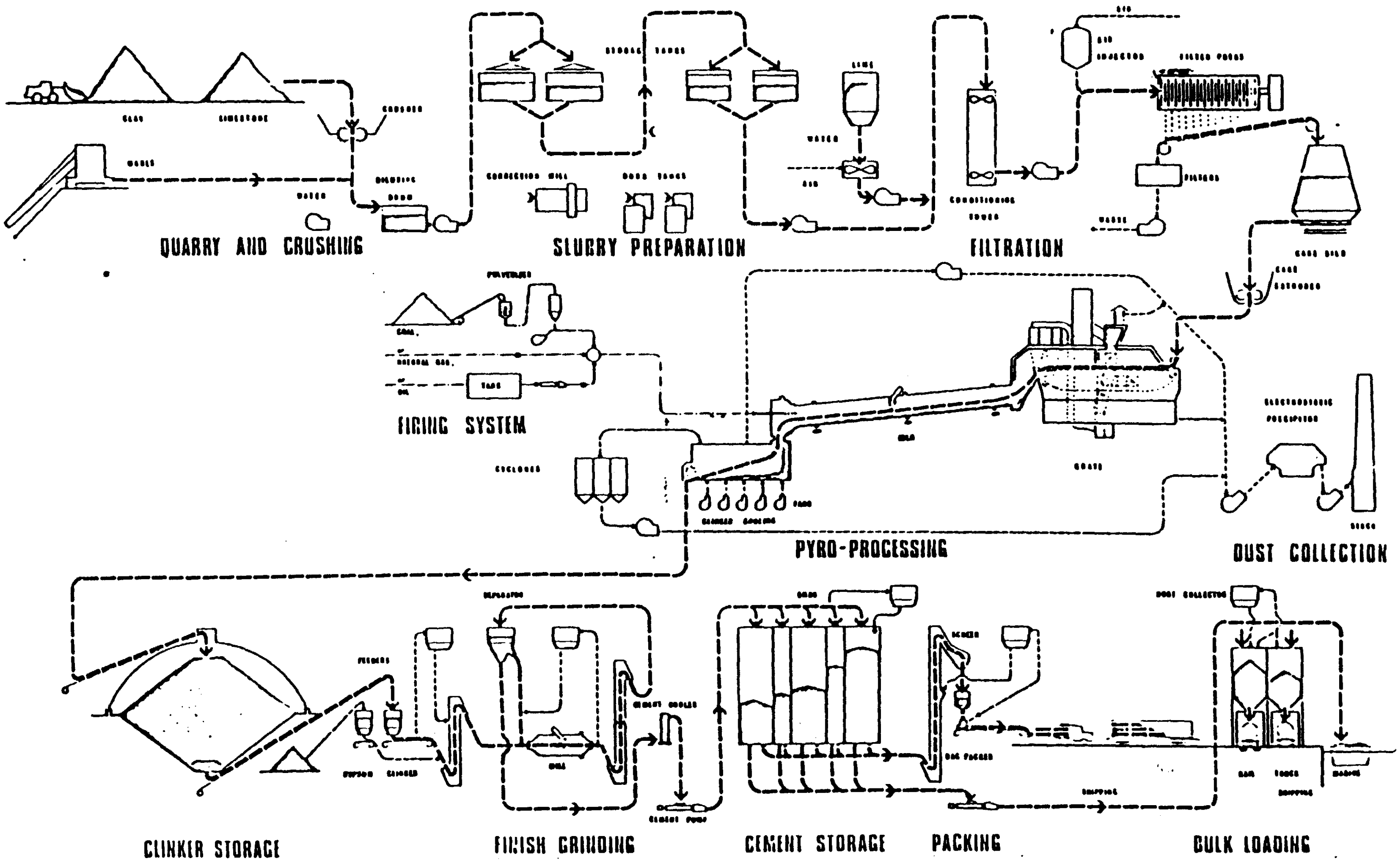


Figure 3.20 Semi wet process flowsheet
Source: Lafarge Consultants

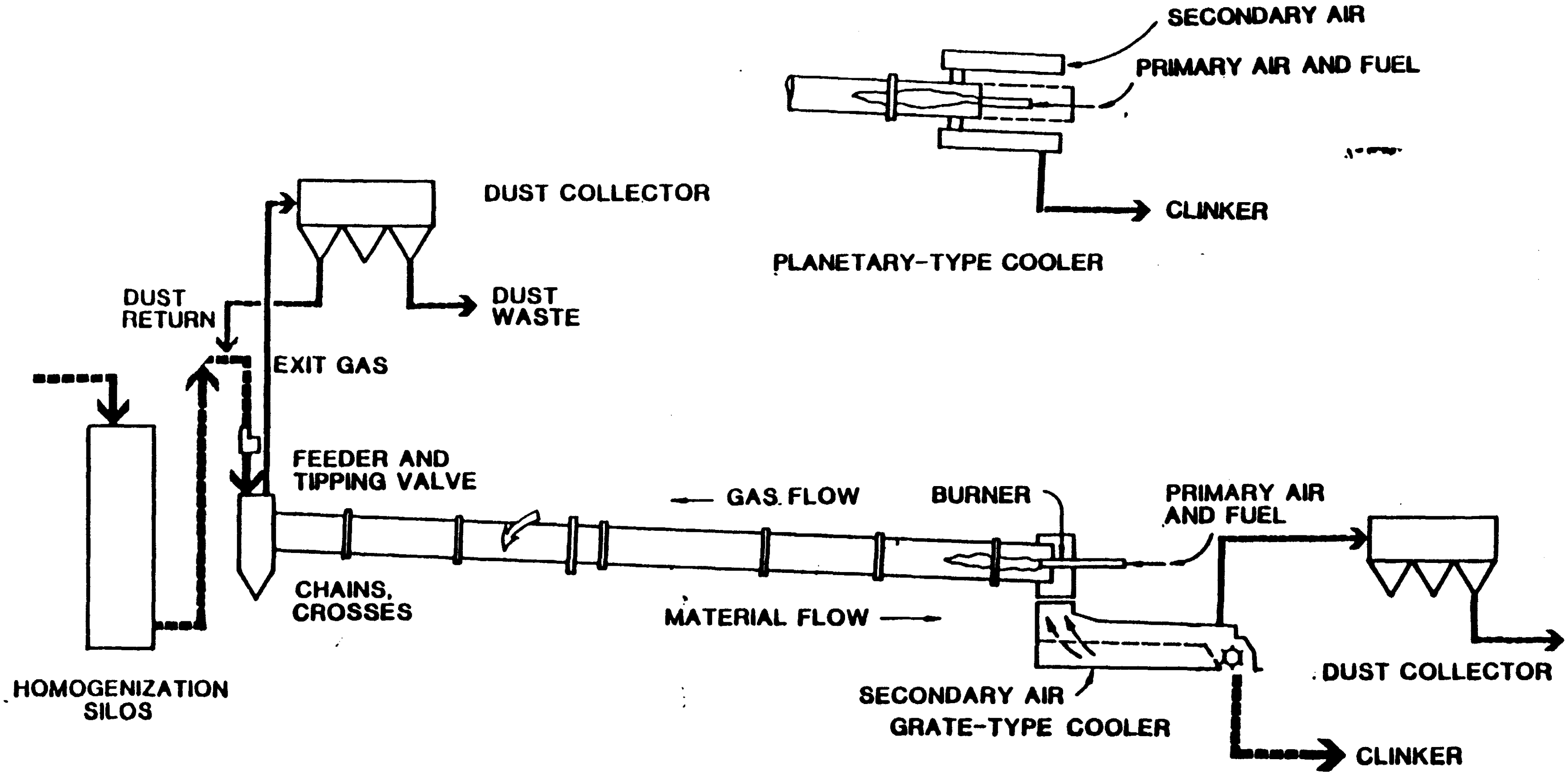
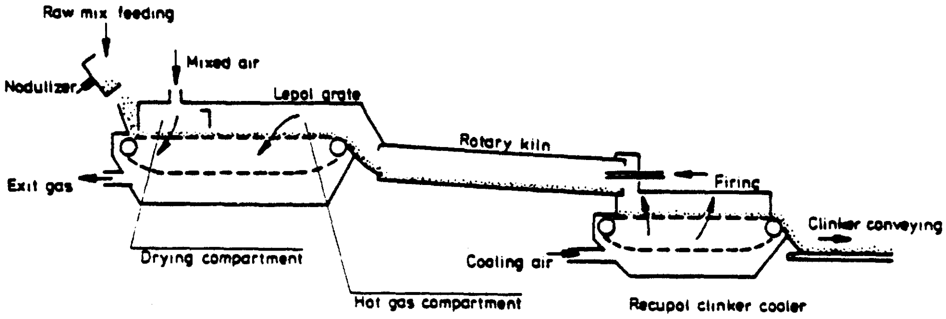
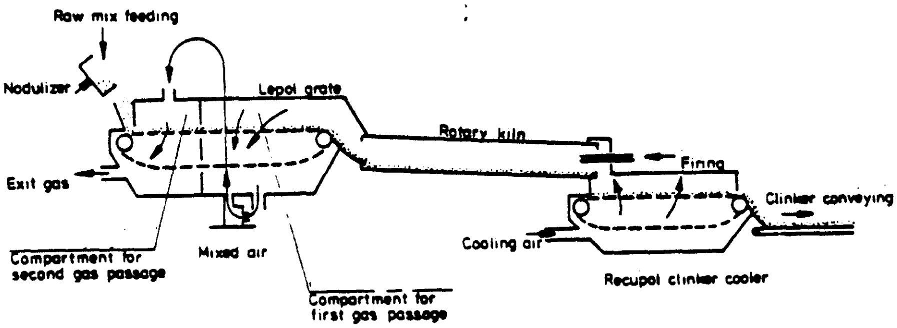


Figure 3.21 Long dry process kiln system
Source: Lafarge Consultants

LONG DRY PROCESS KILN SYSTEM



Lepol kiln with single gas circuit



Lepol kiln with double gas circuit

Figure 3.22 Lepol kilns
Source: Reference 30

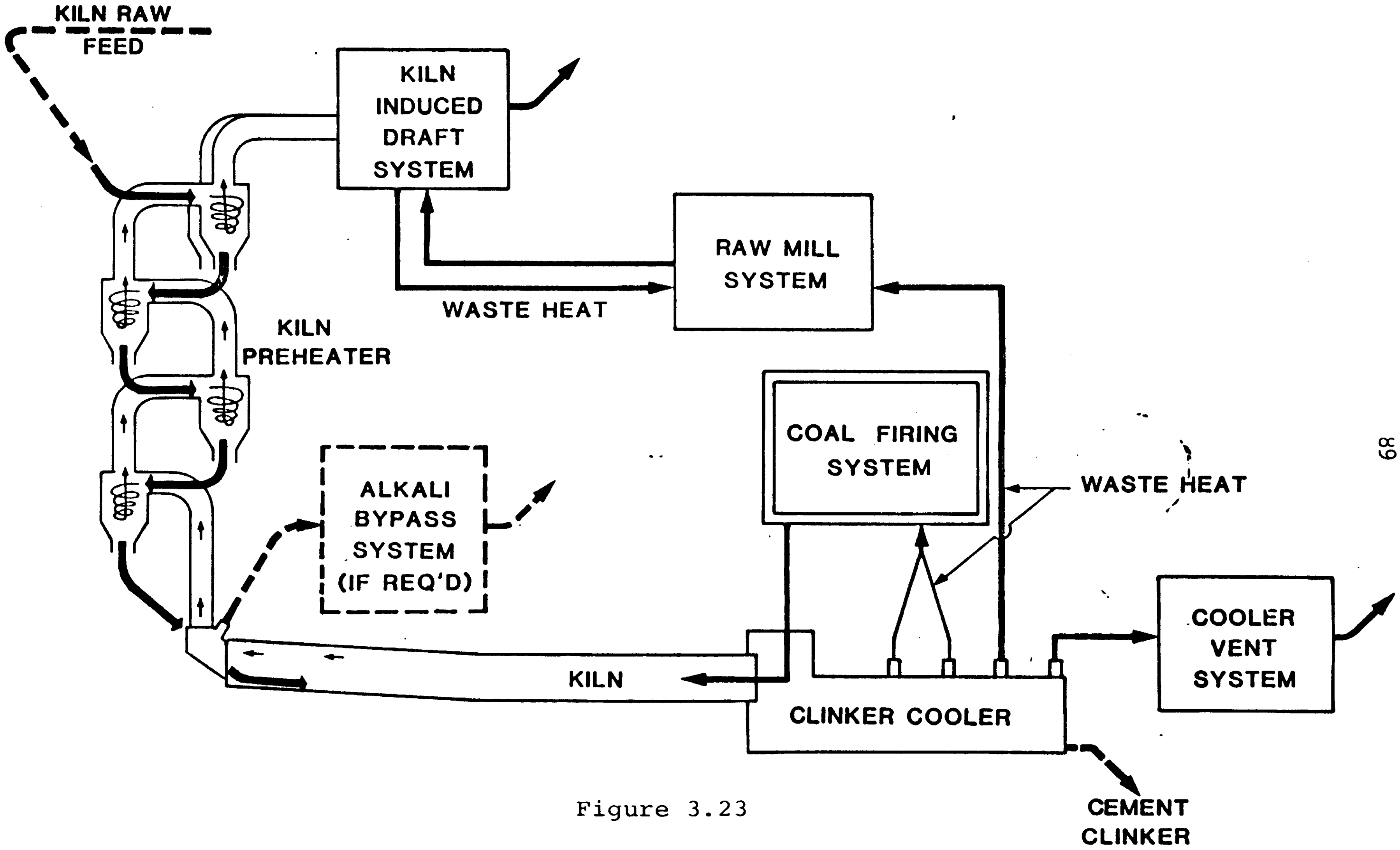
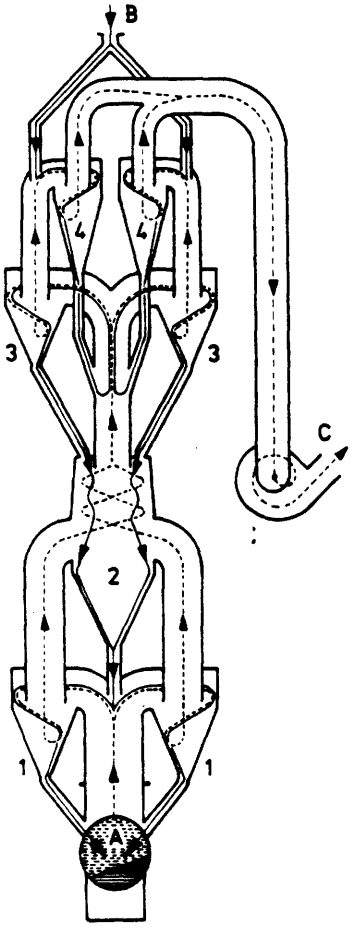


Figure 3.23

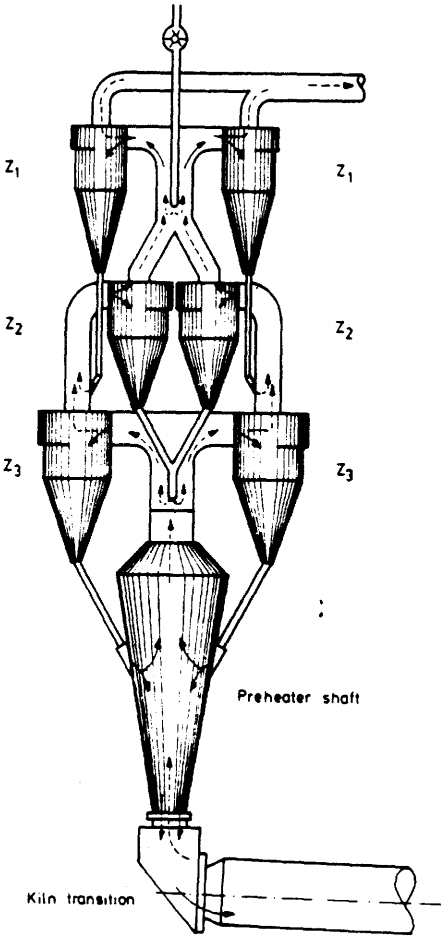
DRY PROCESS
4-STAGE PREHEATER KILN

Source: Lafarge Consultants



Polysius Dopol-Preheater

Figure 3.24
Source: Reference 9



Bühler-Miag raw mix suspension preheater

Figure 3.25
Source: Reference 9

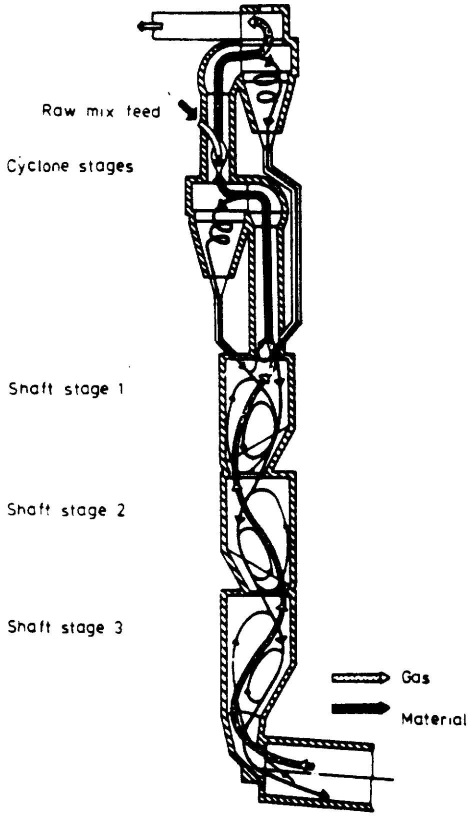


Figure 3.26 ZAB suspension preheater
Source: Reference 9

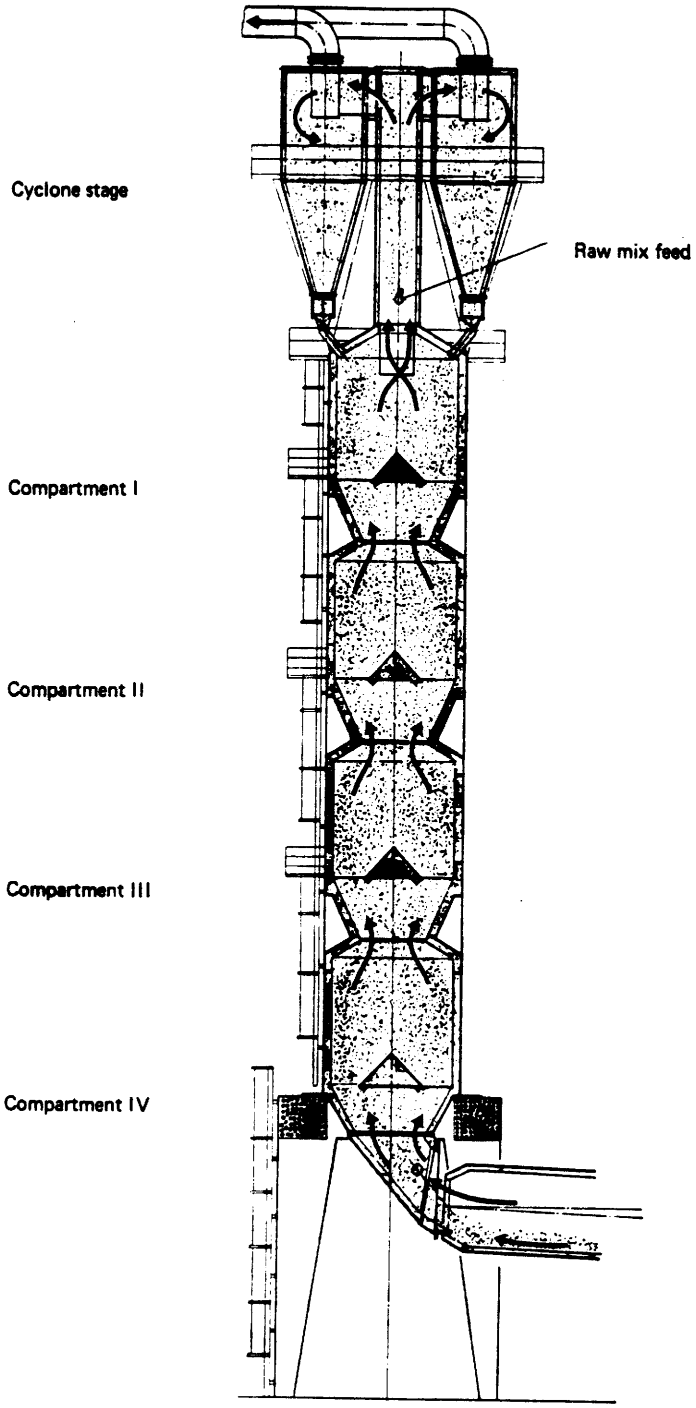


Figure 3.27 Krupp counter current heat exchanger
Source: Reference 9

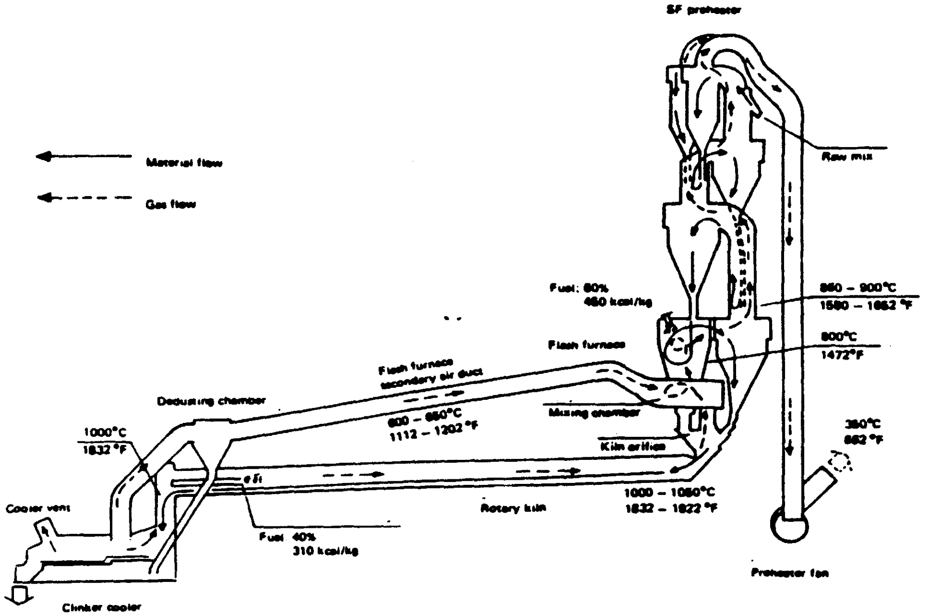


Figure 3.28 IHI SF heat exchanger
Source: Reference 30

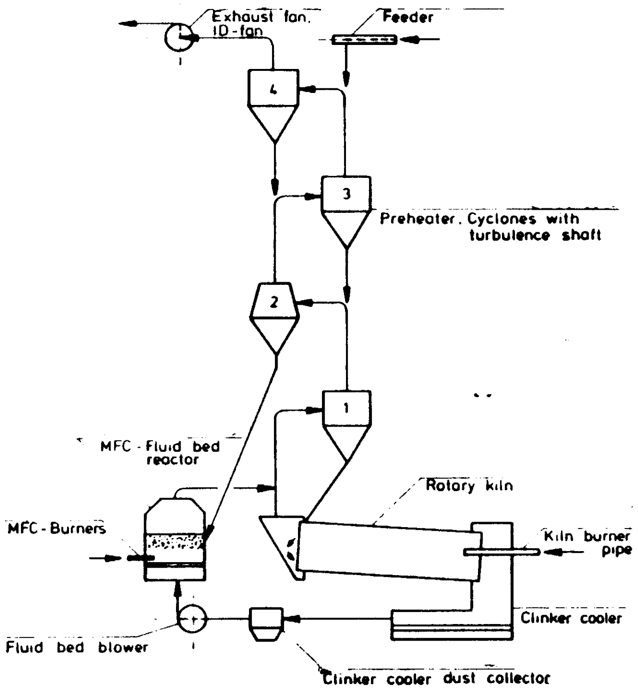


Figure 3.29 MFC preheater with fluid bed reactor
Source: Reference 9

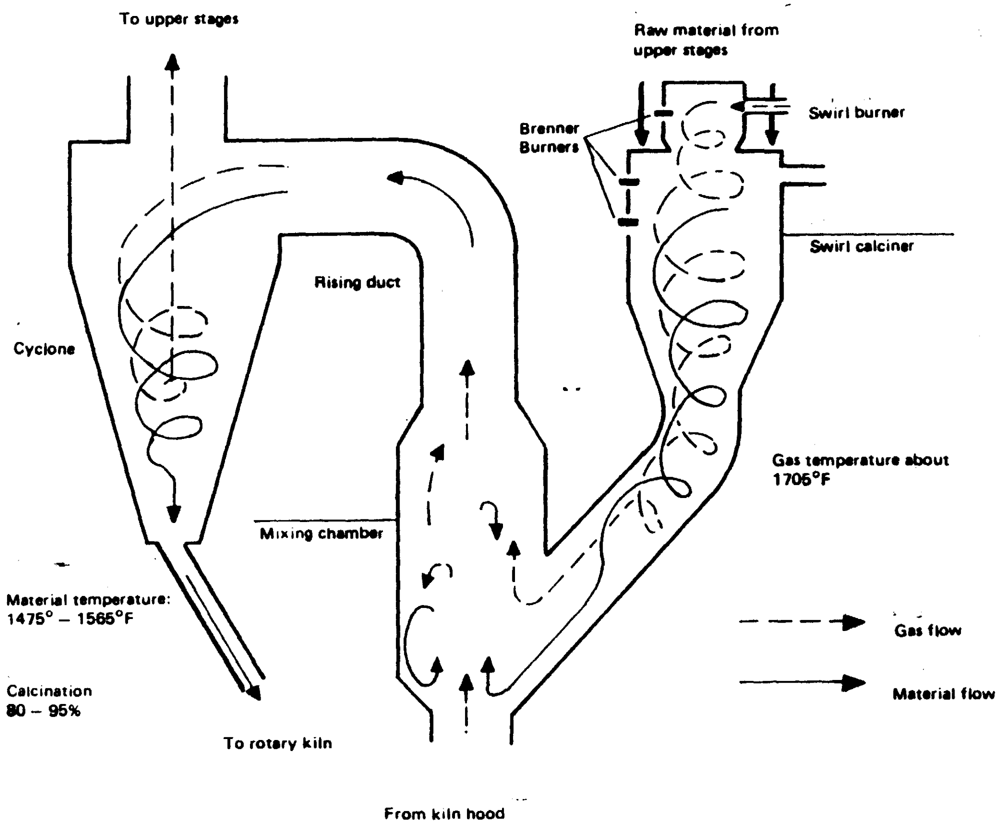


Figure 3.30 RSP-preheater
Source: Reference 9

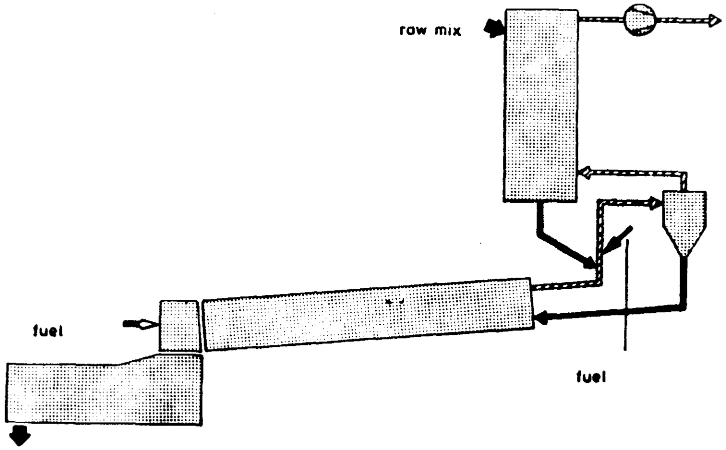


Figure 3.31 Polysius-Rohrbach precalcining process
Source: Reference 9

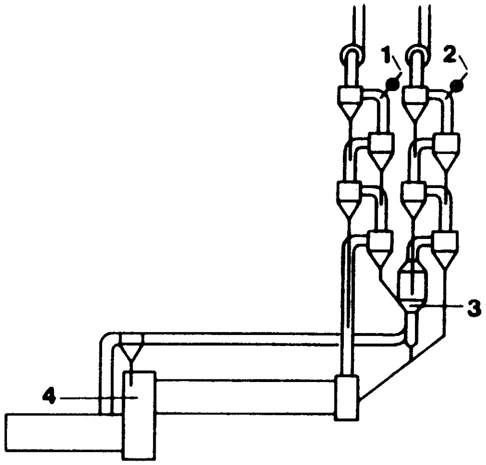
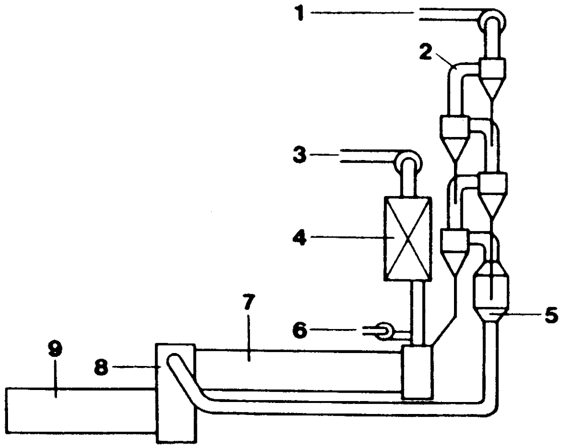


Figure 3.32 FLS-Precalciner system with separate raw mix preheater

Source: Reference 9



Notation:

1 Exit gas from precalciner
2 Raw mix feed
3 Exit gas from rotary kiln
4 Dust collector
5 Fuel to precalciner
6 Cooling air
7 Rotary kiln
8 Kiln burner
9 Clinker cooler

Reference 3.33 **FLS-Precalciner for low alkali cement**
Source: Reference 9

Notation:

1 Raw mix from the fourth cyclone stage
2 Raw mix from the third cyclone stage

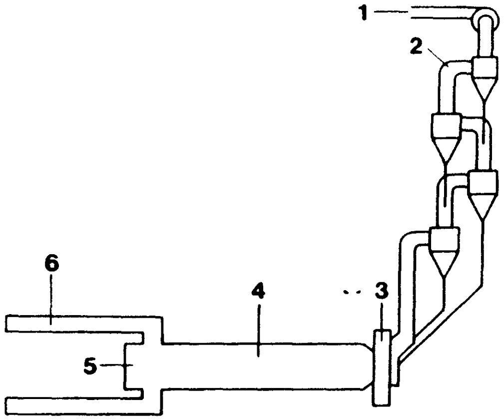


Figure 3.34 FLS-Integral kiln with precalcining system

Notation:

1 Exit gas
2 Raw mix feed
3 Cylindrical section with scoops
4 Rotary kiln
5 Kiln burner
6 Planetary coolers

Source: Reference 9

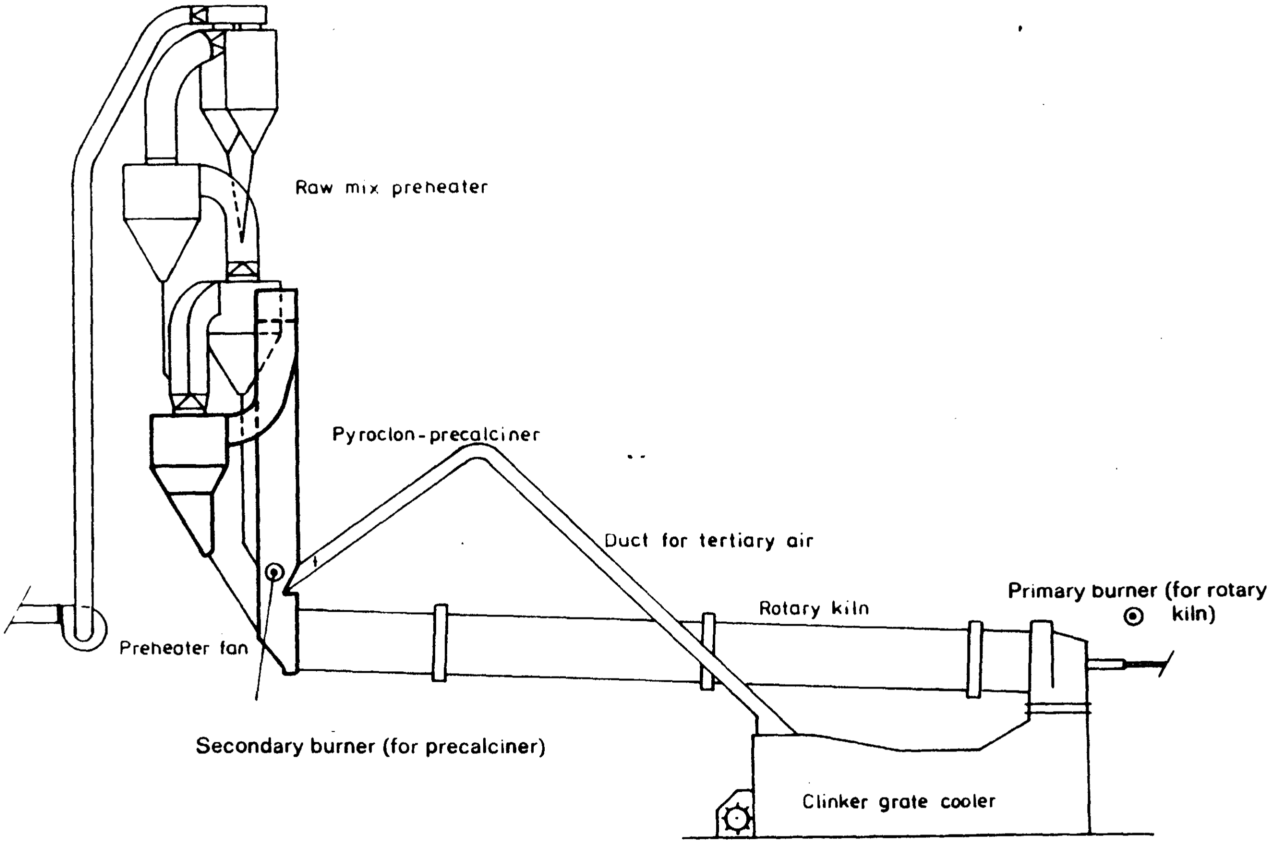


Figure 3.35 **Rotary kiln-preheater plant with Pyroclon-precalciner system Humboldt-Wedag**

Source: Reference 9

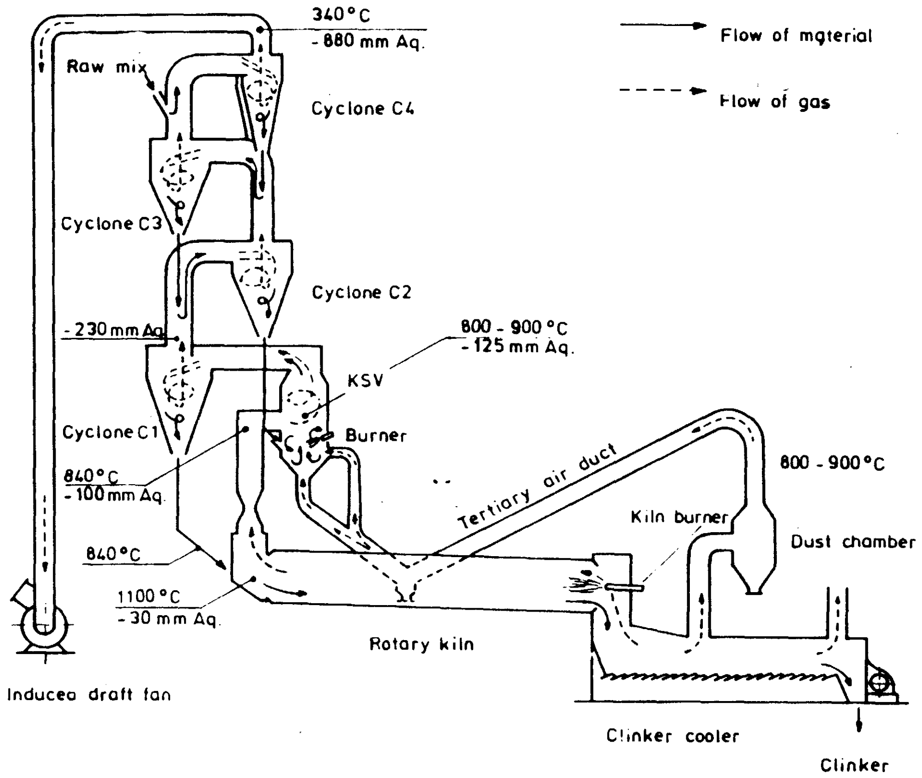
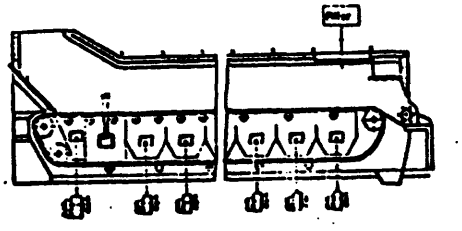
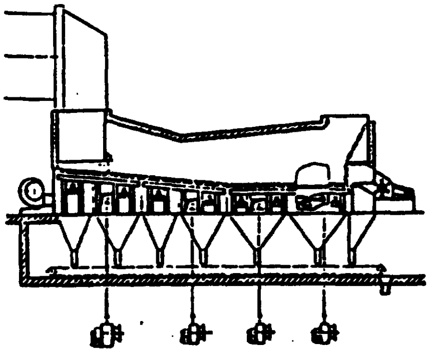


Figure 3.36 Flow chart of a preheater working in conjunction with a KSV-precalciner

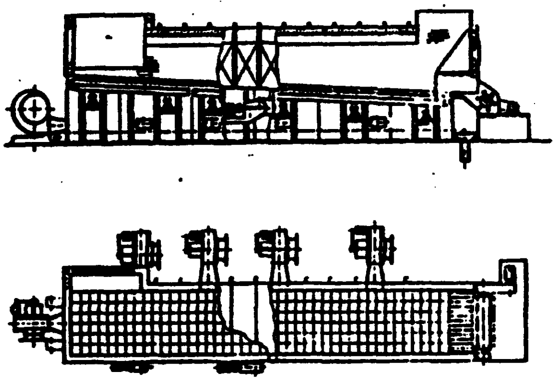
Source: Reference 9



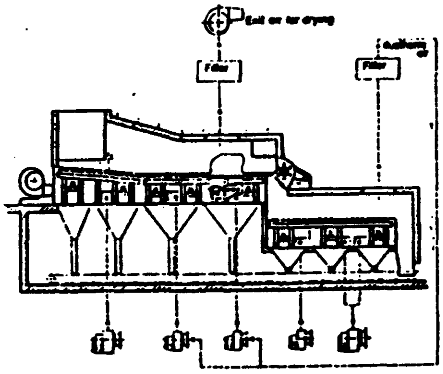
Travelling-grate-cooler



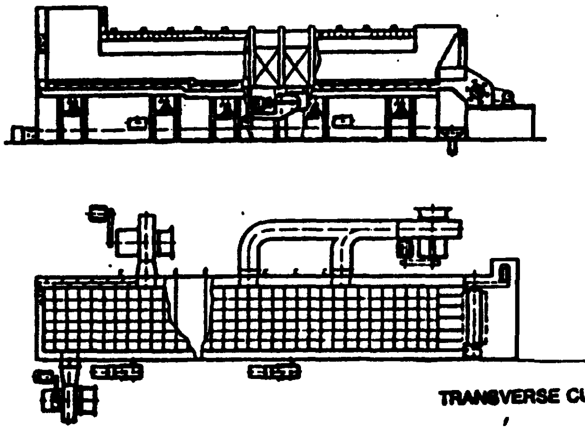
Combi-grate-cooler



Sloping-grate-cooler

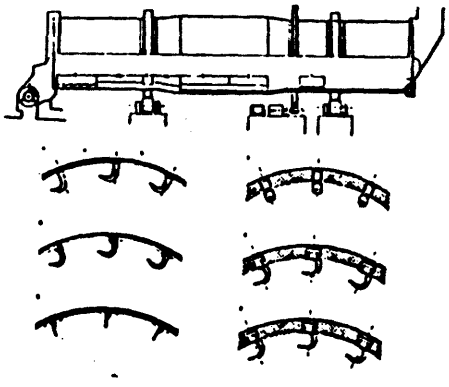


Duostage-grate-cooler with ducthorm air



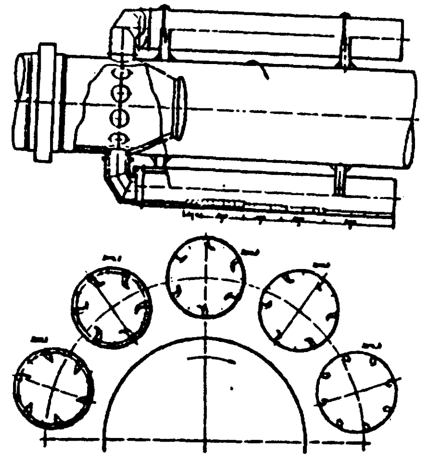
Horizontal-grate-cooler

Figure 3.37 Types of clinker coolers
Source: Lafarge Consultants

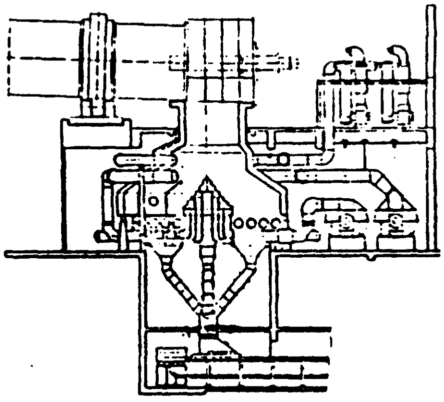


Rotary-cooler

COUNTER CURRENT



Satellite-cooler



Shaft-cooler

Figure 3.37 contd.

TYPES OF CLINKER COOLERS

Source: Lafarge Consultants

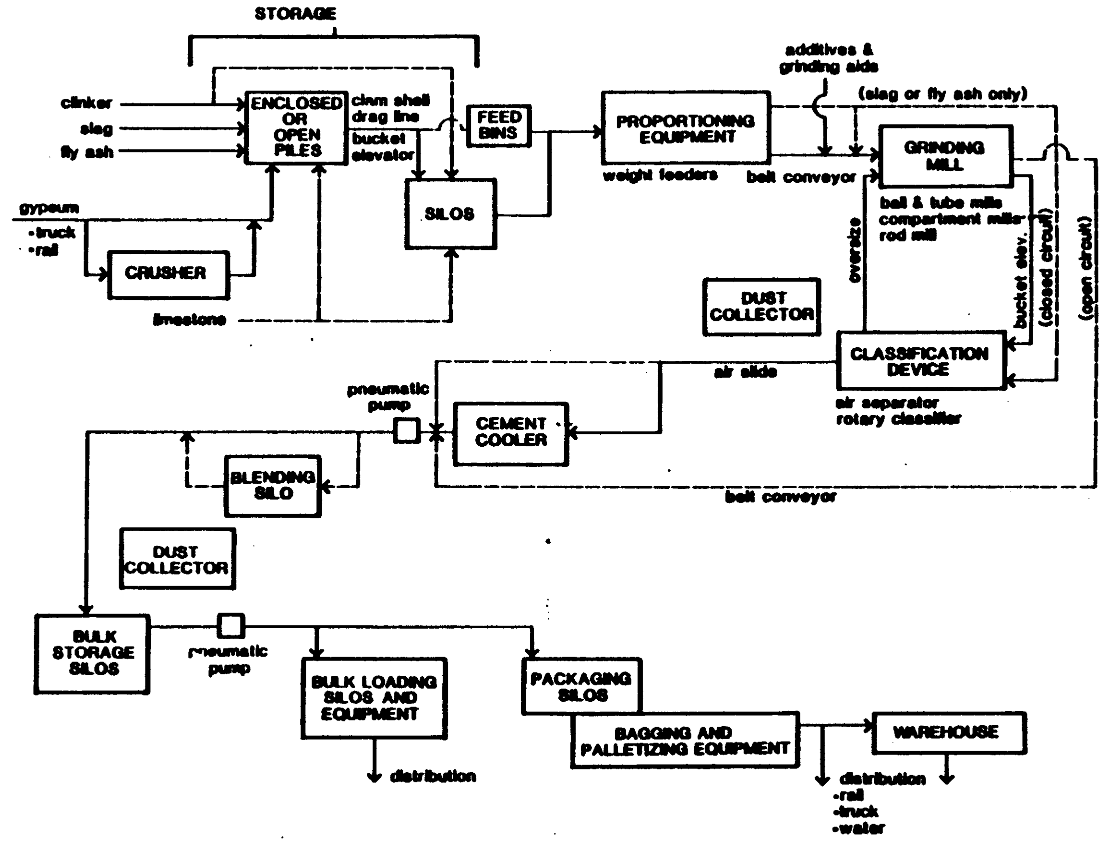


Figure 3.38 **CLINKER GRINDING AND CEMENT SHIPPING**
Source: Lafarge Consultants

4.0 STATUS OF TECHNOLOGY AND EQUIPMENT IN SMALL-SCALE PLANTS

This chapter describes the leading technological packages available for manufacturing cement on a small-scale in kilns, the most important of which is the vertical shaft kiln. Not all of the technological options available have been exploited commercially for long periods of time, nevertheless, they reflect the kinds of choices that are available for small-scale manufacturing under various circumstances.

4.1 What is Small-Scale?

Small-scale cement plants range in output from 2 tons per day to about 200-300 tons per day. Vertical shaft kilns are usually employed in small plants and the viable capacity of such kilns is between 20 tons per day and 300 tons per day (6,000 and 90,000 tons per year). Although rotary kilns have been employed for outputs as low as 150 tons per day, they are best utilized in larger plants.

Production of portland cement in the small-scale plants has been attempted in several parts of the world. The small scale production of cement based on the vertical shaft kiln has been successfully used in India, China, West Germany, Italy, Spain, Brazil, Greece, Australia, Kenya, France, Nepal, Poland, Yugoslavia and Austria (Table 4.1). Of all the countries, China has demonstrated the application of small-scale cement in a remarkable manner as almost 66% of China's total cement output at present is through small-scale plants. China has about 3400 small scale units spread all over the country and information indicates that 70 percent of the cement production through small-scale plants in China goes to agricultural and 30 percent to local industry. The distribution of cement production in small plants in China is indicated in Table 4.2.

4.2 Survey of Available Technologies

The various known technologies of small-scale cement plants differ mainly in the pyroprocessing (burning process) systems employed. The most widely known forms are: (a) Vertical shaft kiln; (b) Small rotary kiln; (c) Fuller-Pyzel fluidized bed process; (d) Reba flame firing sintering grate process; and (e) Lurgi sintering bed process. Each of the technologies are described below. A comparison of the different small-scale technologies is shown in Table 4.3

4.2.1 Vertical Shaft Kiln (VSK)

The vertical kiln (Figure 4.1) was the first type of kiln used in the production of cement. Vertical kilns are constructed with clear internal diameters of 6-9 feet and shaft heights of 24-30 feet for outputs ranging from anywhere from a few tons per day to 200 tons per day. Figure 4.2 shows the flowsheet for a VSK cement plant. The raw meal cannot be fed to the vertical kiln in the form of a powder. Instead it is mixed with the fuel in the correct proportions, a suitable quantity of water is added and the mixture is then agglomerated into round-shaped bodies called nodules. It is the nodules that are then fed into the kiln. The feed operation requires the crushing of limestone, proportioning of raw materials, grinding in a mill, homogenizing and nodulizing in a pan type nodulizer. The successful operation of a shaft kiln depends upon the size of nodules, their uniformity, porosity, and thermal stability. The nodulizer consists of an inclined disk or pan rotating about its axis. Raw meal is charged into the nodulizer by means of a screw conveyor and water is sprayed. A rotating scraper continuously cleans the raw meal deposited from the bottom and the collar of the drum. The nodules slide down the chute and are charged in the vertical shaft kiln.

The vertical shaft kiln in which the nodules are converted into clinker consists of a cylindrical shell with a conical top and a refractory brick lining. The various zones of reaction starting from the top of the kiln are the drying zone, the calcining zone, the sintering zone, and the cooling zone. The whole kiln charge composed of unburnt nodules and clinker rests on a flat grate rotating slowly at the bottom of the kiln and mounted on the main shaft. the grate is driven with the help of a variable speed motor to control the discharge rate of the clinker. The clinker is finally taken out of the kiln bottom with the help of mechanically or hydraulically operated discharge gates.

The most popular methods to prepare the raw materials and the fuel before they are fed into the vertical shaft kiln are described below.

4.2.1.1 Raw Materials and Fuel Preparation

The black meal and the slurry fuel processes are used to prepare the raw materials and the fuel for a vertical shaft kiln and are differentiated below. Since the raw meal is fed in the form of pellets, the processing is limited to raw materials with adequate pelletizing characteristics. All solid fuels of carbonaceous nature are suitable for the vertical shaft kiln process, while gas or liquid fuels cannot be used. The preferred fuel is coal containing small number of volatile matter. Coals containing no more than 20% volatiles are preferred, as well as charcoal, metallurgical coke or charred lignite, or brown coal. The ash content is of minor importance, as the ash is finely distributed and becomes part of the raw meal, however, excess ash has an adverse effect on the homogeneity of the burning process.

Pellets made up of raw materials and fuel should have high strength characteristics (breakup of the pellets with excessive dust formation could clog the kiln) and sufficient porosity for uniform burning. Good plasticity of raw materials and fuel mix is required to obtain the required pellet characteristics. A mix containing ground limestone and a non-plastic component like ash metallurgical slags, or shales has poor nodulizability. The moisture content of the nodules determines their quality and fuel consumption. Nodules with low moisture are likely to easily integrate, while high moisture content increases the fuel consumption for drying and evaporation.

The production of high strength nodules is indispensable for a shaft kiln or any kiln working on the semi-dry process. The pan type nodulizer (pelletizer) for the production of nodules for shaft kiln was introduced at the Gippsland Cement plant in Australia by Steven Gottlieb. It is due to this development that vertical shaft kilns can produce high quality clinker.

The pan pelletizer works independent of the fueling process used whether it be normal, black meal or coal slurry. The final nodules produced are uniformally shaped and sized, and are produced for direct feeding into the shaft kiln. The uniformly sized pellets improve gas flow and heat transfer in the kiln.

(a) White Meal (Conventional) Process:

The conventional process is the most simple where the fuel e.g. petrol coke in sizes of 1.5-2.5mm is fed directly to the nodulizer together with the raw meal. For the white meal process, solid fuel is crushed to a grain size of approximately 5mm and mixed with the dry raw mix under a water spray in a mixer. After pelletizing this mixture, the pellets are fed into the shaft kiln. In this process all types of raw mills can be used for raw meal preparation. The white meal process produces slag-like clinker comprising molten parts which is relatively hard to grind.

(b) Black Meal Process:

The black meal process developed by Dr Spohn in West Germany in the 1950s is one of the most advanced technologies available in Vertical shaft kilns today. In the black meal process, the solid fuel and all raw mix compounds are interground in the raw mill. The roller mill is the most suitable for raw grinding. The pellets are formed out of the dry black meal by using water spray on an inclined pelletizing table.

(c) Gottlieb Fuel (Coal) Slurry Process:

A variation of the Black Meal Process as proposed by Steven Gottlieb is the Coal slurry process. The main difference is in the method of feed preparation. This method requires the raw meal to be ground "white" i.e., without fuel. The fuel (coal with volatile matter upto 16-18%) is ground separately in a wet ball mill to make slurry with about 50% moisture content. The white meal and the coal slurry are separately stored in hoppers over the nodulizer platform and are pumped at controlled rates (through flow meters) into a double paddle mixer to mix the feed continuously. The feed is discharged into the standard nodulizer where a little water is added to give final shape to the nodules. These nodules are charged and burnt in the vertical shaft kiln in the same manner as in the case of the Black Meal process.

The main advantage claimed by this process is that by wetting of the coal particles before nodulizing, the retention time for the volatile component of the fuel is increased thereby allowing a higher volatile content in the coal compared to the Black meal process.

(d) Partial Black Meal (or Semi-White) process:

This process is a variation of the conventional black meal process and incorporates the mixing of crushed coal with pre-ground raw materials immediately before feeding into the kiln, rather than at the grinding stage. This technique is based on intermixing rather than the intergrinding of fuel with the raw materials. This variation provides the option of making ongoing adjustments in the raw mix design when the raw material is of variable quality. The ability to compensate for variations in the calcium carbonate content of the calcerous material by altering the fuel feed wherever necessary, considerably eases the task of maintaining quality of output. In situations where mining is likely to be labor-intensive and unsophisticated, this flexibility represents a considerable advance.

4.2.1.2 Kiln design packages:

(a) Loesche

The Loesche Company of West Germany is one of the few (if not the only one) manufacturers of small-scale cement plant equipment in the industrialized countries. Loesche has continued to supply turn-key vertical shaft kiln plants to both the developed and the developing countries. The Loesche small-scale cement plants are based on the interground (black meal) fuel process. The Loesche kiln (Figure 4.3a) is fed nodules or pellets by a disc type nodulizer. The Loesche kiln is a stationery kiln and the only moving part is the grate which revolves about four times in one hour. The Loesche vertical kiln technology does not require a separate fuel pulverizing or drying plant as solid fuel and raw materials are ground and dried together in the vertical Loesche roller mill (Figure 4.3b). Since compact vertical shaft kiln plants produce a more porous clinker, the Loesche roller mill is used in conjunction with very precise air separators to produce quality cement. The Loesche mill is an air-swept mill incorporating its pulse-jet-filter. The mill is free of product dust within two minutes after stopping the feed to the mill and this allows it to be used for grinding the raw materials also.

(b) Indian technologies:

In India, for the purpose of government policy and institutional finance, a small-scale plant is defined as one with a capacity of 200 tons per day or less. There are four organizations claiming to have developed the technology for small-scale plants. These are: (i) The Cement Research Institute of India (CRI); (ii) Appropriate Technology Development Association (ATDA); (iii) the Jorhat Regional Research Laboratory (RRL); and (iv) D.P. Saboo - a Jodhpur based technologist-entrepreneur. They are all offering modified designs of Vertical Shaft kilns in combination with material handling, grinding, packing and pollution control systems of varying degrees of sophistication and capacity. None of these combinations and designs are radically different from those in use in Europe and China.

Therefore, it is the specific design package in use which can be attributed to a particular claimant rather than a title to a radically new technology. The dissemination strategy adopted by the developers of these designs have incorporated a varying degree of involvement on their part. Each of these designs is described (depending on available information) below:

(i) Cement Research Institute of India (CRI) design:

CRI has emerged as a major licensor of small-plant technology in India. CRI's dissemination strategy has been to license machinery manufacturers with an established production capability to supply plant based on CRI's design. As many as 14 manufacturers have been licensed and are located in all the main regions of the country. As CRI's main innovation is in kiln design, each manufacturer is effectively left to put together the "peripherals" on their own. Movers Private Limited, originally a materials handling machinery manufacturer, has undertaken considerable innovation and introduced increasingly sophiticated materials handling and instrumentation to become the market leader for the CRI design. CRI provides support to its "exclusive" licensees in the form of feasibility studies, identification and surveys of raw material deposits and training of personnel. Under CRI licensees, only Movers will be discussed in detail.

A typical Movers plant consists of the following sections: (1) Crushing; (2) Raw mill; (3) Blending and storage; (4) Kiln; (5) Cement mill; (6) Packing and (7) Electrical and instrumentation. A layout plan and a list of the equipment for a 50 tpd CRI-VSK plant is shown in Figure 4.4. The general arrangement of a CRI-VSK kiln is shown in Figure 4.5.

Typically in a CRI-VSK cement plant, limestone of size not exceeding 250mm is transported in dumpers and unloaded into the service hopper. The required quantity of this limestone is withdrawn from the service hopper by means of a reciprocating feeder and fed to a jaw crusher which is the primary crusher. The Jaw crusher reduces the size of the limestone from 250mm to 70mm. Crushed limestone from the Jaw crusher is fed to a reversible impactor and the crushed material is fed to the hoppers and the storage yard by means of an inclined belt conveyor. Other raw materials like clay, coke breeze and additives (if required) are stored in similar hoppers and storage yards.

The required quantity of each of the above materials is withdrawn from the respective hopper/storage yard by means of electromagnetic vibrating feeders and fed to the horizontal belt conveyor below. This conveyor transfers the various raw materials to an inclined belt conveyor which in turn feeds the raw mill. The raw mill is either a vertical roller mill or a closed circuit airswept ball mill. Here the mixture is ground to a fineness of 10% retention on 170 mesh sieve and the material is elevated to the blending silos, by an air lift, where material is thoroughly blended by the Quadrant Air merge system. After analysis of the total carbonate content of the raw meal, it is stored in raw meal silos. From the raw meal silos, material is elevated to the top of the kiln building to the nodulizer hopper by an air lift. From the nodulizer hopper, raw meal is fed to the pan nodulizer by a variable speed screw feeder and about 13% moisture is added to the raw meal in the nodulizer from a water tank located above.

Nodules of 8-12mm diameter are formed in the nodulizer and fed at a constant rate to the vertical shaft kiln where the processes of drying, calcining, sintering, and burning take place in different zones. The highest temperature is in the burning zone of the kiln and is as high as 1250C. Clinker is formed in the vertical shaft kiln and is extracted by means of a rotary grate equipped with cutter segments through a triple discharge gate of material block tube. The extracted clinker is crushed again in a jaw crusher and elevated to a "mole hill" type stock pile system by means of a bucket elevator or pan conveyor. The storage capacity is approximately ten days production of clinker. Gypsum is stored alongside the clinker in another "mole hill".

100 parts of clinker and 5 parts of gypsum are withdrawn from the respective "mole hills" by means of electromagnetic vibrating feeders and fed to a horizontal belt conveyor below. From this conveyor, the material is transferred to an inclined belt conveyor which, in turn, feeds the cement mill which is essentially a three compartment open circuit, compound tube mill. In the cement mill, the mixture of clinker and gypsum is ground to a fineness of 2250-3000 cm2/gm Blaine's specific surface. The cement is then elevated to a cement silo by an air lift. Cement is withdrawn from the silos and packed in jute bags using a semi-automatic packing machine.

(ii) Appropriate Technology Development Association (ATDA):

The ATDA technology and design for small-scale cement plants is taken from a plant currently employing the technique. The plant is located at Mohanlalganj near Lucknow in the Indian province of Uttar Pradesh. The Mohanlalganj plant has proved that Portland Cement can be produced with marl as the basic raw material, in a vertical shaft kiln using the intermixing technology, i.e., raw materials and fuel are ground separately and mixed just before the nodulizer. The plant layout and equipment are shown in Figure 4.6.

The raw materials (and their chemical compositions) used in the Mohanlalganj plant are as follows:

Raw Materials	Marl	Kankar	Limestone	Blue dust
Silica Oxide	8-10%	32-35%	6-8%	-
Calcium Carbonate	75-85%	50-63%	86-93%	-
Aluminum Oxide	2.5-3.5%	3-8%	up to 2%	-
Ferric Oxide	0.8-2.2%	3-4.5%	-	90%
Magnesium Carbonate	up to 4%	up to 4%	-	-
Water	8-20%	-	-	-

Gypsum: Calcium sulfate (72-78%), Silica Oxide (8-12%), and Ferric and Aluminum oxides (up to 2%).

Fuel	Coke Breeze	SLV Coal	Steam Coal
Net Calorific Value (kcal/kg)	4344	4565-5470	6000
Ash content	30-34%	21-23%	18-20%
Volatile matter	3-4%	11-14%	30% .

The following raw meal composition has been in use at Mohanlalganj: Calcium Oxide (68.9%), Silica Oxide (20.2%), Aluminum Oxide (7.23%), Ferric Oxide (3.35). The fuel is 12.5% of the raw meal weight. The fuel used is a 50/50 mixture of coke breeze and SLV coal, with a combined ash content of 30%.

The capacities of the different machines are based upon a kiln capacity of 20 tons per day, and that for the production of one kilogram of clinker, 1.58 kilograms of dry raw meal are needed. The raw material crushing is done using a jaw crusher followed by a hammer mill. The rotary drier is heated by a direct grate type air heater built on to the drier. Due to the variations in the drier feed, the drier discharge quantity also varies considerably. The bucket elevator can be very sensitive to the peaks in the flow of material. There are five raw material storage silos and the proportioning system is comprised of a weigh-beam type scale and hand operated flap feeders. The Raw meal mill is made up of a cube mixer followed by an air swept ball mill with double cone classifier. Two pneumatic homogenizers operated by compressed air supplied by Rootes blowers comprise the homogenization section. The homogenized raw meal is fed to the kiln by pneumatic conveyors. The fuel preparation consists of a double-roller crusher, fed by a shovel and a screen. Fuel intermixing is used before the raw meal is fed into a rotating pan nodulizer.

The vertical shaft kiln has a half-rotary cylindrical grate and has a variable speed hydraulic drive. The cement grinding section is similar to the raw meal unit, i.e., has an air swept mill with a double cone classifier. Dust collectors on the hammer mill, clinker mill, bucket elevators and screw conveyors are part of the dust control equipment in the plant.

(iii) Jorhat Regional Research Laboratory:

This laboratory is located in the province of Assam and has emphasized research on micro-scale production in cement plants, i.e., vertical shaft kiln capacities on the order of one to five tons per day. The RRL kilns, which are based upon the CRI-VSK design, have been tested to a laboratory scale and patents for their commercial exploitation have been handed over to the National Research Development Corporation (NDRC) of India. The work done at the laboratory and by the NDRC has been restricted to kiln design rather than the development of a technology package. The laboratory appears to have adopted a low profile in the marketing of its plants, although a few have been sold and are on order in India.

(iv) Saboo:

The Saboo design for small-scale cement production (20-30 tons per day) is based upon a refinement of a prototype kiln developed from literature emanating from the Jorhat Research Laboratory. However, the entrepreneur Saboo has conducted considerable research and development work in putting an entire process including materials handling, grinding mills, pollution control and quality control systems. Saboo has a machine fabrication unit and offers a completely redesigned technological package suited to the needs of relatively small investors with restricted access to technical skills and repair workshops. The design is particularly sensitive to minimizing the maintenance requirements of diverse rural-based entrepreneurs.

(c) Miscellaneous designs:

Small-scale cement plants have recently invoked considerable interest and various cement experts and consulting companies around the western world have suggested packages for entrepreneurs and governmental institutions to invest in. Some of the more notable designs have been put forward by the Austrian Engineering Company Limited (Austroplan), Gorrensen's Pty. Ltd. (Australia), and Buro Fur Systemtechnik (West Germany). A schematic for Gorrensen's plant is shown in Figure 4.7. The plant suggested by Harro Taubman of Buro Fur Systemtechnik, which is representative of the latest designs available, is discussed in more detail below.

(i) Buro Fur Systemtechnik:

This consulting company has suggested a design for a 60,000 to 70,000 tons per year (approximately 200 tons per day) plant. The objective of this design is to supply a plant to meet urban cement needs on the basis of locally available raw materials in the developing countries.

The central operation unit of this plant is a vertical shaft kiln which employs solid fuels such as petrol-coke, coke breeze, anthracite, lvm-coal and charcoal. Limestone, marl, clay, and other raw materials like iron oxide and silica are crushed and ground to a grain size representing a 10 to 12% residue on a 4900 mesh screen. The fuel is ground separately to a similar fineness. Both products are stored separately and fed by weighfeeders into a paddlemixer for premixing, and then formed into pellets on a dish pelletizer. The pellets are fed into the kiln where they are burnt and transformed into cement clinker. The clinker is discharged out of the kiln by using a rotating or oscillating roller or plate grate and air-tight discharge gates. The clinker is stored and then ground with gypsum and other components (such as pozzolana, blast furnace slag) as needed. The cement is stored in silos and bagged or shipped loose by trucks. A schematic flow sheet is shown in Figure 4.8.

Schematics and list of equipment for each stage in the plant is given in Figures 4.9, 4.10, 4.11, 4.12 and 4.13. They are in turn the quarry operation, the raw meal grinding unit, grinding mill for the fuel, clinker burning plant, and the cement mill. The ground cement is transported pneumatically into the cement storage silos from where it is filled in bags or shipped by trucks.

(d) Kiln grate designs

Kiln grate design is critical in the performance of a vertical shaft kiln. Three major design configurations are: (a) Cone grate with rotating cone and fixed grate(Lurgi); (b) Rotating grate with extended "rippers" (Gottlieb); and (c) CRI (Cement Research Institute of India) rotating centerpiece. All have one design feature in common, i.e., the rotating portion of the grate moves at one revolution per hour. The cone type grate is most suitable for the black meal clinker. Since the clinker produced from a black meal process is rather small in size, it tends to leak through the grate. The cone type grate is good in preventing such leakage.

4.2.2 Small Rotary Kiln

Rotary kilns are traditionally used for large scale manufacture of cement but they can also be adopted for use in small scale plants. The most common forms of rotary kiln arrangements are: (a) short rotary kiln with suspension preheater (SP-kiln, dry process); and (b) short rotary kiln with grate preheater (semi-dry or semi-wet process).

The SP-kiln is recommended for mini-cement plants when the fuel situation favors the use of gaseous, liquid, solid or mixed fuels of high, medium or low calorific values. In addition low grade fuels and combustible waste materials can be fired into the kiln. The alkali reduction capacity of SP kilns is very poor when compared to rotary kilns with grate preheaters. More than 90% of the initial alkali content of the raw feed is retained in the clinker. Generally with the dry process, the homogenization of dry raw meal is more difficult, therefore dry process kiln operation is sometimes less stable due to fluctuating raw mix properties.

For the SP-kiln process (Figure 4.14), the kiln feed and fuel preparation requires crushing and grinding initially. Blended and homogenized raw meal is then fed to the suspension preheater of counter current type, where it is preheated and partially calcined by the kiln hot gases passing in counter current. Raw meal enters the kiln at a temperature of 450-500C. Pulverized coal mixed with primary air is fired from the lower end of the rotary kiln through coal burners. Secondary air is supplied through clinker coolers to make up for the combustion air. Various chemical reactions (calcination, sintering, cooling) take place as the temperature goes upto 1440C. Hot gases having transferred the heat to the raw materials escape in counter flow. Clinker is discharged into clinker coolers which may be rotary or moving grate type. Clinker is then transported to the storage yard where it is crushed with gypsum.

The short rotary kiln with grate preheater is viable for medium to large plant sizes mostly. The requirement for pure raw materials is not as critical as it is for SP-kilns. The degree of homogenization of the raw mix is not as high, however, for pelletizing, additional process water is used. The semi-dry process offers good possibilities of alkali reduction and is thus suited for the production of low alkali cement.

4.2.3 Fuller-Pyzel Fluidized Bed Process

This process was invented by Robert Pyzel and has been developed by Fuller Company in the United States. The plant consists of a fluidized bed kiln. A fluid bed consists typically of a vertical enclosure containing a horizontal perforated distributor grid. A plenum grid beneath the grid assures proper distribution of the gas phase into the bed of solid particles supported by the gas above the grid. The action within the bed has been compared to a boiling liquid. Fluid beds have been used where control and uniformity of temperature and large scale continuous operation are required.

The fluid bed cement kiln shown in Figure 4.15 consists of a cylindrical metal shell with refractory lining. A specially designed grid separates the plenum chamber from the kiln. Preheated air, which serves both as combustion air and the fluidizing medium, flows from the plenum to the kiln through the grid. Raw meal consisting of finely ground feed mixture is pneumatically conveyed to the fluidized bed along with fuel and preheated air. The temperature of the fluidized bed is maintained at approximately 1315C by introducing the fuel directly into the fluidized bed. Coarse clinker particles are formed on the fluid bed and when finely ground raw mix is blown in pneumatically, raw cement phases are formed on the hot surface of the already present clinker particles, thus continuously increasing the size of the clinker. The burnt clinker leaves the fluidized bed through an overflow and is cooled to 95C in a grate or shaft cooler. All particles below 2.5mm are separated from the main clinker stream by means of a sieve and fed back into the reactor as seed clinker. The size of the clinker particle varies within a very narrow range and since the amount of clinker that overflows the kiln is constant, the usual problems of variable kiln discharge and irregular clinker sizes are avoided. Hot air from the clinker cooler can be used in several ways to improve the energy economy of the process. The hot kiln gases are subject to a series of heat recovery steps through air-preheating and steam generation, which lower their temperature sufficiently so that a baghouse can be used for particulate emissions control without further cooling. In the heat recovery section, air is preheated and the remaining heat of the kiln gases is used to generate high pressure superheated steam. This steam is utilized in a steam turbine system either for direct mechanical drives or to generate electric power for clinker section, air compressor, exhaust fan, cooler air fan, etc. The steam turbine system returns condensate which is deaerated to provide boiler feed water for steam generation. The process, it is claimed, can be made completely self-sufficient.

The specific advantages of the Pyzel process have been claimed where there is: (a) a high alkali problem because of raw material processing in the kilns; (b) strict environmental protection regulations regarding oxides, sulfur, and nitrogen from exit gases; (c) a disposal problem of kiln dust with high alkali problem; and there is a need to use a variety of fuels like gas, oil, coal, anthracite, and coke.

As the fluid bed is a stationary device, the operating and maintenance problems associated with a rotary kiln are avoided because the brick lining is not subject to the dynamic stresses of the rotary kiln.

The Pyzel process is offered by the Scientific Design Company, NY, U.S.A. and is reported to have emerged from extensive pilot studies. The technology is still not commercially available.

4.2.4 Reba Flame Firing Sintering Grate Process

The Reba box-type kiln developed by the British-German Ready Mixed Concrete Company is illustrated in Figure 4.16. In this process, raw materials are fed as pellets and the fuel is injected and burned separately as with the rotary kiln. The principle of the Reba kiln is that material in the form of pellets is calcined and sintered on an inclined stationary grate by passing the combustion gases through the bed of material that is transported by gravity and by special push cars. These are situated under the bed of material and the inclined grate. In this process, the feed operation requires the crushing of limestone, storage in bins, proportioning of raw materials, grinding in a roller mill, and homogenization of raw meal. The nodules produced from the raw meal in the pelletizer are dried in the preheating shaft and heated in the calcination zone to about 1100C. The partially dried nodules thereafter descend on to a set of inclined grates (three sections) in the sintering zone. The granulated material is then sintered at about 1450C. At the end of each section a push car mounted on a trolley pushes the nodules forward by a reciprocating motion. The nodules, as they descend from the top of the inclined grate, are subjected to high temperature gases which are produced in a furnace fired with oil. The flow of gases is in an opposite direction to the flow of material and thus air used to cool the clinker heats up and is used as secondary air together with primary air when burning fuel. Sintering takes place at the lowest grate from where the clinker enters into a shaft cooler. This cooler is provided with baffles so as to increase the exposure of clinker to cooling air fed from the bottom. The three grate sections are provided with cooling water circulation tubes attached to the underside of the grate members.

The Reba process has not been operated on solid fuel (coal) and as such no operational data is available. It is oil or gas fired and is suitable for clinker burning as well as lime and similar materials. The Reba process, like the vertical shaft kiln, can only use raw materials with adequate nodulization characteristics since it is fed with raw meal pellets.

4.2.5 Lurgi Sintering Bed Process

This process, which is shown in Figure 4.17, requires the crushing of limestone to 15mm size in a mill, storage of crushed materials in bins, proportioning of raw materials and grinding in a roller mill before it is homogenized and nodulized. The coal is also screened and crushed before the raw meal and the crushed coal are fed into a drum type nodulizer. The nodulizer is also fed with 15% burnt clinker and water. The nodules of raw mix are conveyed by a belt conveyor to a moving sinter bed made of cast iron. A 75mm thick layer of clinker is first spread over this bed and then fresh nodules fall over the clinker. The sinter bed passes through various zones and light diesel oil is fired over the bed. The nodules undergo various reactions as they pass the various zones and the resulting clinker is discharged through a rotating type breaker over an open pan horizontal conveyor to undergo cooling. The clinker is carried through a bucket elevator and then through a series of screens to the clinker yard where it is ground with gypsum in a grinding mill.

The Lurgi process requires fuel of low ash content and low volatility. Fuel oil and gas is also required as additional burning aids.

Table 4.1

GLOBAL SURVEY OF VERTICAL SHAFT KILNS IN OPERATION

COUNTRY	NUMBER OF LOCATIONS	NUMBER OF ACTIVE KILNS	TOTAL ANNUAL CAPACITY (*tonnes* 10^3)
Kenya	1	6	500
India	6	7	56
Iran	1	2	na
Australia	1	2	110
Belgium	1	4	110*
France	4	24	na
Germany, West	4	31	na
Brazil	1	1	80
Austria	1	2	250
Greece	1	2	na
Italy	8	14	na
Nepal	1	1	48
Poland	1	6	200*
Spain	7	26	na
Yugoslavia	4	22	na

na=not available

* Clinker capacity

Source: Reference 6

Table 4.2

ESTIMATED PRODUCTION IN MINI CEMENT PLANTS IN CHINA

YEAR	BIG PLANT PRODUCTION (*million tonnes*)	MINI PLANTS		MINI PLANTS PRODUCTION		TOTAL PRODUCTION (*million tonnes*)
		Total Number	*Average Size (tonnes per annum)*	*Total (million tonnes)*	*% of Total Production*	
1949						0·7
1957			..			6·9
1965	9·9	200	25599	5·1	34	15·0
1969				7·9		
1970	15·5			10·4	40	25·9
1971	16·9	1800	7400	13·3	44	30·2
1972	19·2	2400	7400	17·7	48	36·9
1973	19·9	2800	7100	19·9	50	39·8
1974					>50	41·8
1975	21·6	>2800	>10100	28·3	57	49·6
1979	24·0	~3400		46·00	66	70·0
1980	24·5	3400	>40000	49·0	66	73·5

Source: Reference 6

Table 4.3

COMPARISON OF DIFFERENT TECHNOLOGIES FOR MINI CEMENT PLANTS

Sl. No	Description	VSK	Rotary Kiln	Lurgi Sinter bed	Reba Process	Fluidized Bed
1	2	3	4	5	6	7
1.	Limitation of Size (in terms of capacity)	Upto 200 tpd, 20-30 tpd units by CRI already running in India. 50 tpd CRIVSK under installation	Generally above 150 tpd. 200-300 tpd unit under installation	30 to 1200 tpd	100 to 400 tpd (experimental unit in Germany)	100 to 500 tpd (experimental unit in USA) 20 to 25 tpd (experimental units in Japan)
2.	Number of Plants Installed & Actually Working	2393 (China) 260 (World) Including India	19 (India) (less than 200 tpd)	60 tpd (India)	NA	NA
3.	Raw Materials Quality Limitation	The raw materials should have good nodulizability apart from satisfying other characteristics required for cement grade	Requirement to satisfy physical & chemical characteristics	The raw materials should have good nodulizability apart from satisfying other characteristics required		The raw materials should have good nodulizability apart from satisfying other characteristics required
4.	Fuel	Low volatile fuel such as coke breeze, or Jhama coal or/ charfines etc. Fuel has to be interground with raw mix. Limiting VM 12%	Medium to high volatile coal with preferably not more than 25% ash	Low volatile fuel like coke breeze or low volatile coal plus diesel oil	Oil or gas	Low grade solid fuels such as high ash coals
5.	Heat Input Kcal/kg Clinker	900 to 1100	900-1100	claimed 1200 but actual consumption reported upto 2404	claimed 730	1050 to 1400 with heat recovery
6.	Instrumentation	very simple	Simple	Simple	Complex	Complex
7.	Maintenance	Low	High	Very high	Claimed low but details not available specially in the context of so many moving parts.	Low as furnace is stationary
8.	MERITS					
	a) Control on Clinker quality	Good	Good	Good	Claimed to be Good	Good
	b) Thermal Efficiency	Very Good	Good	Poor	Good	Good
	c) Dust Problem	Less	More	More	Less	Less
9.	DEMERITS	a) Agglomeration of clinker & channeling requires careful control of raw materials. b) Choice of raw materials for good nodulizability c) No control of fuel at the burning stage.	a) Ring formation requires careful control of raw materials & burning b) High maintenance and investment cost. Red spot & Fire brick spalling are usual c) Complex / heavy construction & foundations d) Delivery time is more e) Experience with suspension preheater in such small capacity is rather limited f) Requirement of costly infrastructural facilities g) Requirement of relatively skilled manpower	a) High maintenance & operational cost b) very high fuel consumption c) Commercial plants not available.	a) Technology not yet proven commeracially. b) Experience with Indian coals not available c) Commercial plants not available	a) i) Technology not yet proven commercially. ii) Small quantities of alkali are found in the cement raw material due to internal circulation. Therefore exhaust gas is to be let out periodically so as to remove alkalies from the system iii) While there appears to be no accumulation in the form of cement raw material adhering to the fluidised bed itself, this used to be found to a small extent on the cover and on the inner sides of the furnace (preheater), which must be occasionally removed by poking b) Experience with Indian coals not available c) Commercial plants not available

Source: Reference 5

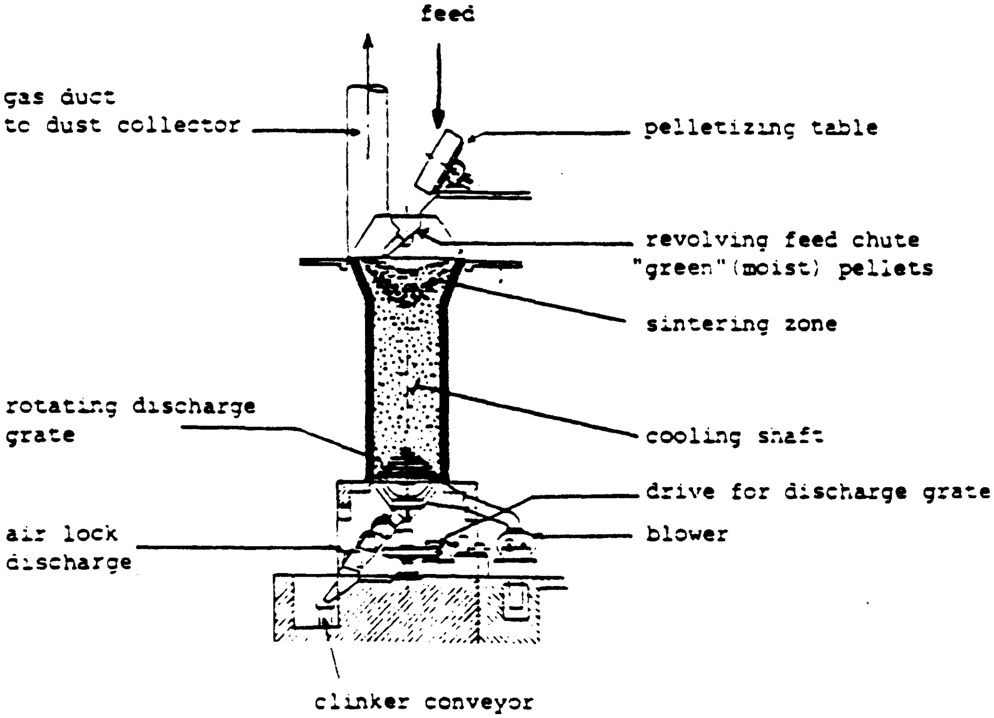


Figure 4.1 Vertical shaft kiln

Source: Reference 51

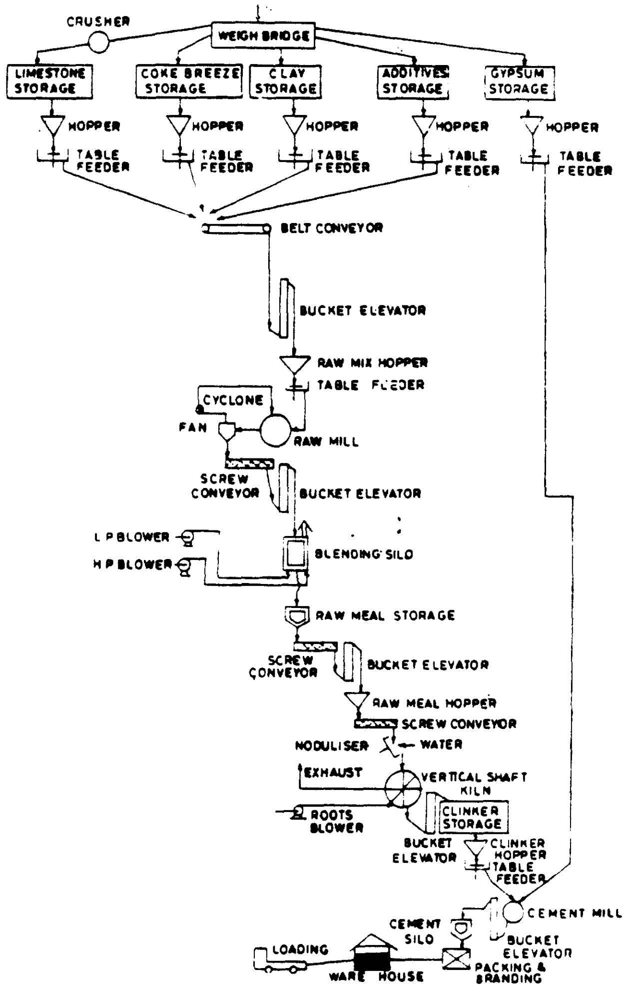


Figure 4.2 Flow sheet of a VSK cement plant

Source: Reference 5

22 - Blackmeal Conveyor

23 - Blackmeal Proportioning Belt

24 - Nodulizer

26 - Vertical Kiln

27 - Step Grate with Main Shaft

28 - Main Gear

29 - Kiln Blower

30 - Discharge Gate - Air Lock

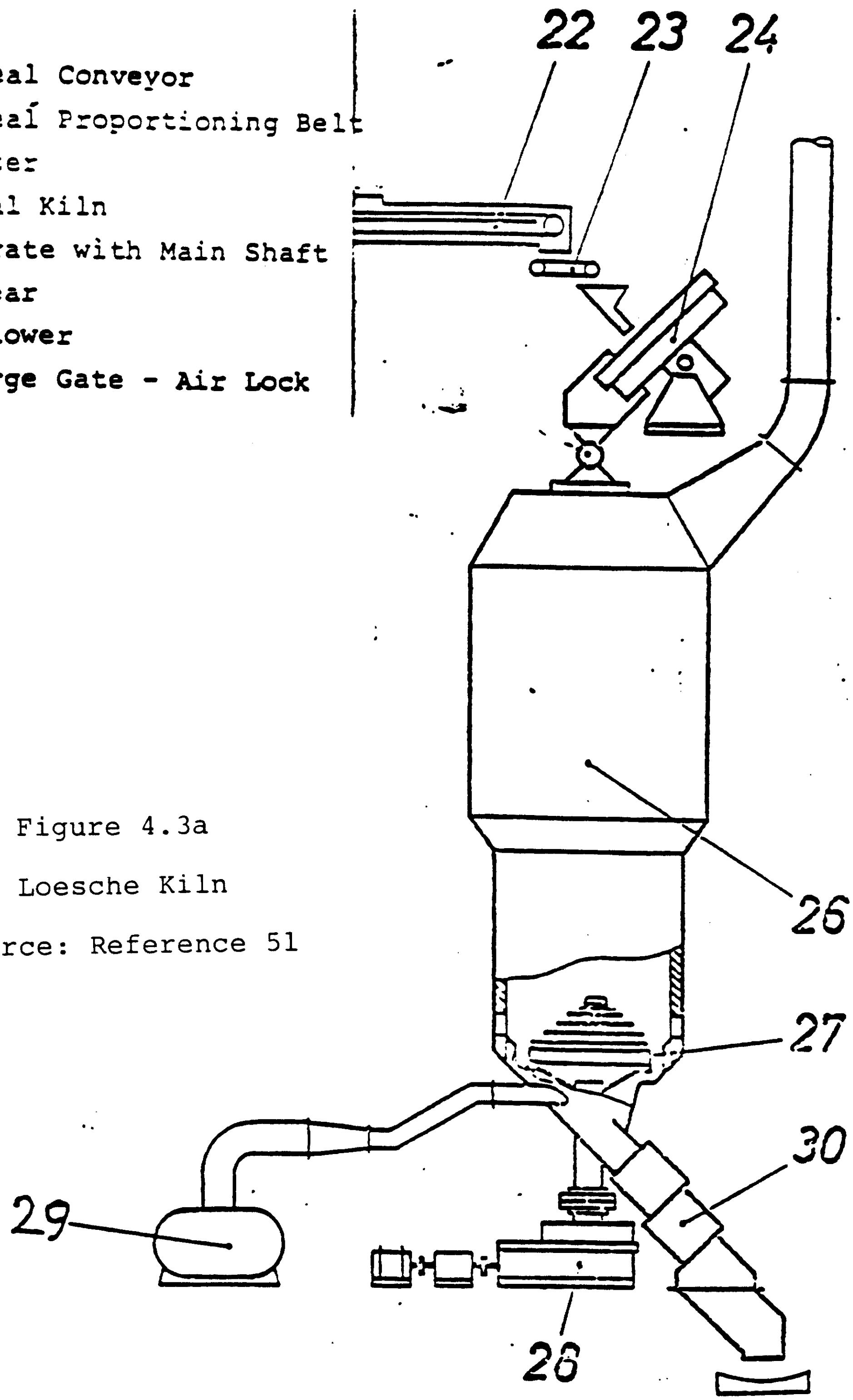


Figure 4.3a

Loesche Kiln

Source: Reference 51

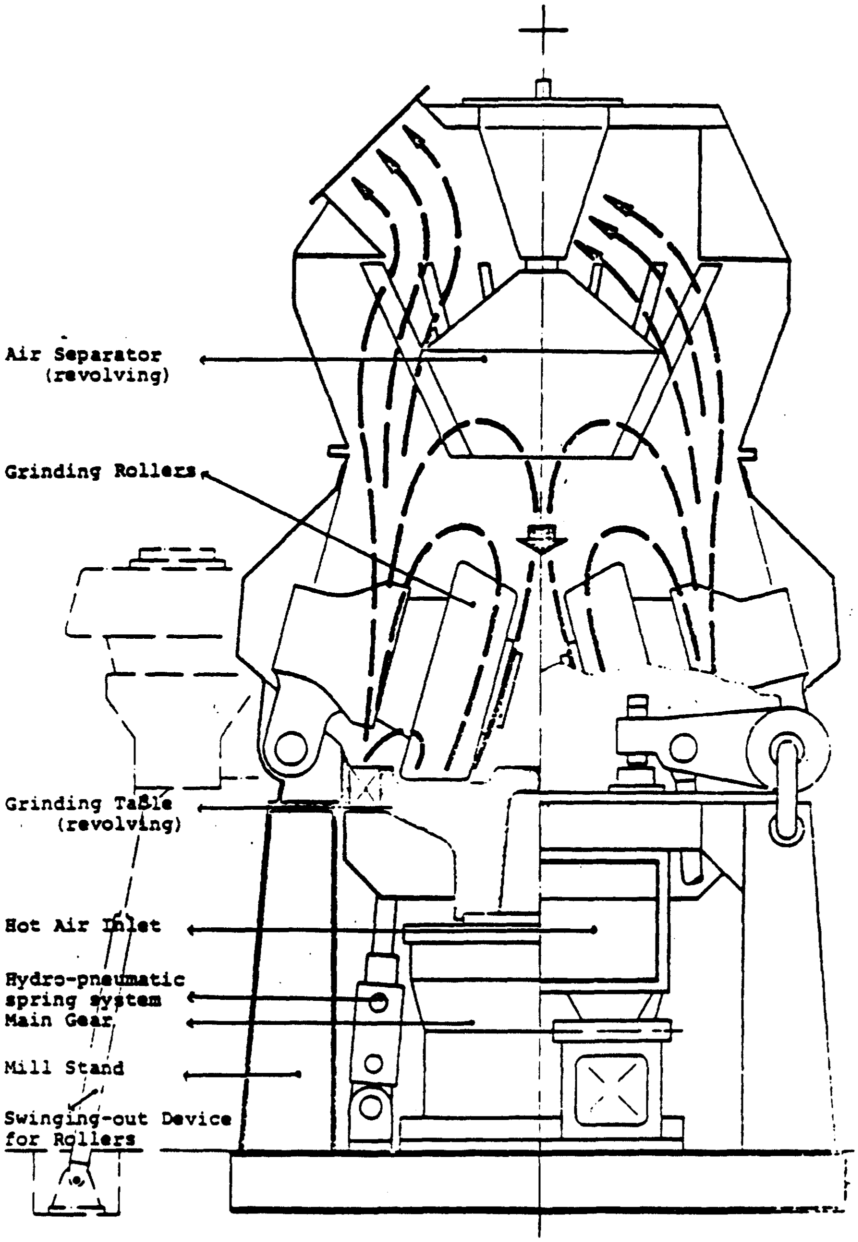
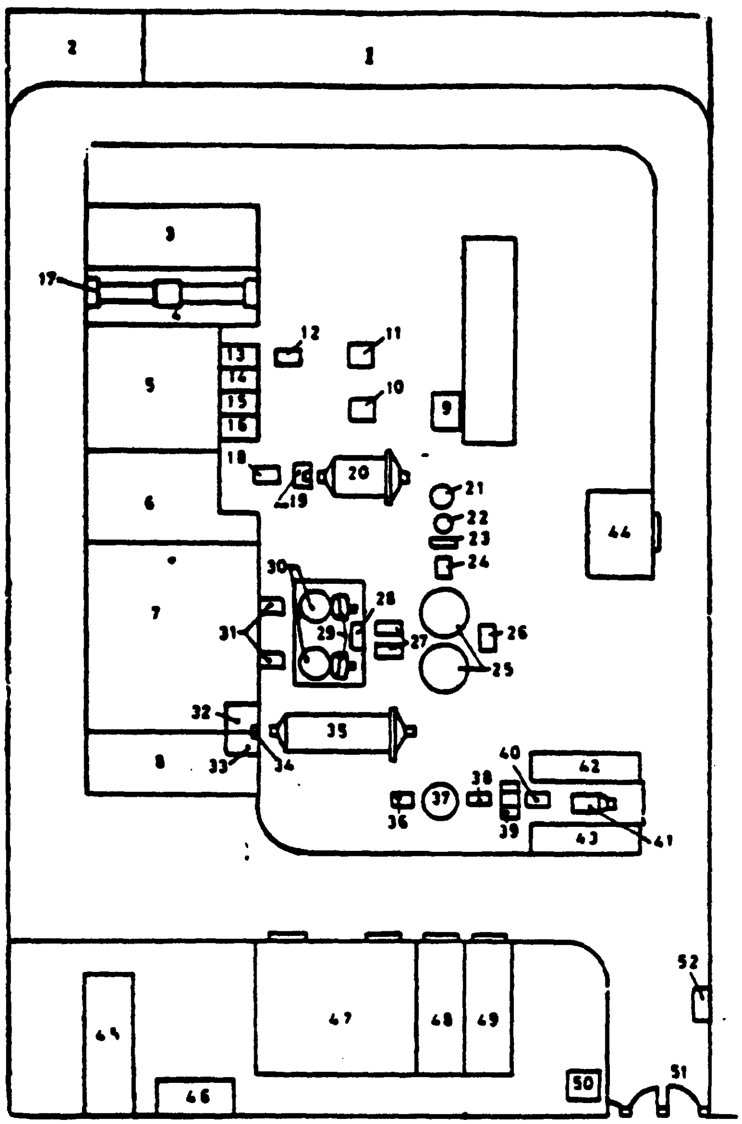


Figure 4.3b Loesche Roller Mill

Source: Reference 51



1. Limestone Store
2. Clay Store
3. Clay Store
4. Additives Store
5. Crushed Limestone Store
6. Coke Breeze Store
7. Clinker Store
8. Gypsum Store
9. Limestone Hopper
10. Primary Limestone Crusher
11. Secondary Limestone Crusher
12. Bucket Elevator
13. Limestone Hopper
14. Coke Breeze Hopper
15. Additive Hopper
16. Clay Hopper
17. EOT Crane
18. Bucket Elevator
19. Rotary Table Feeder
20. Raw Mill
21. Mechanical Separator
22. Cyclones
23. Dust Collector
24. Raw Meal Bucket Elevator
25. Blending & Storage Silos
26. Bag Filter with Con. Shaking Mech
27. Nodulizer Feed Elevator
28. Nodulizer Feed Hoppers
29. Nodulizers
30. Vertical Shaft Kilns
31. Clinker Elevators
32. Clinker Store Hopper
33. Gypsum Storage Hopper
34. Rotary Feeders
35. Cement Mill
36. Bucket Elevator
37. Cement Silo
38. Centrifugal Type Elevator
39. Buffer Tanks
40. Packing Machine
41. Vehicle Loading
42. Packed Cement Platform
43. Gunny Bag Store
44. Electric Sub-station
45. Canteen & Rest Hall
46. Packing Space
47. Office Building
48. Stores
49. Workshop
50. Gate House
51. Main Gate
52. Weighbridge

Figure 4.4 Layout of a CRI-VSK plant

Source: Reference 6

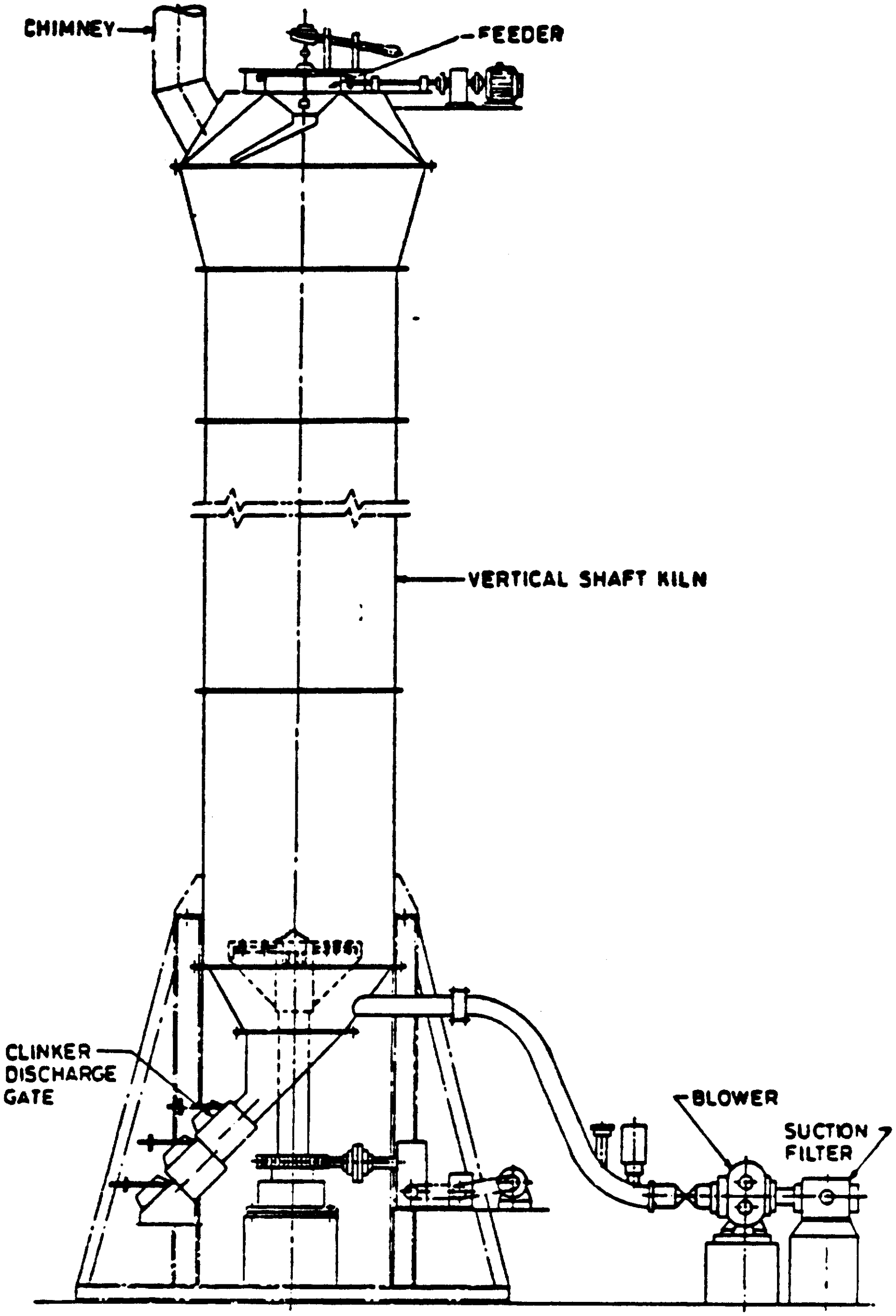


Figure 4.5 *General arrangement of CRI vertical shaft kiln*

Source: Reference 6

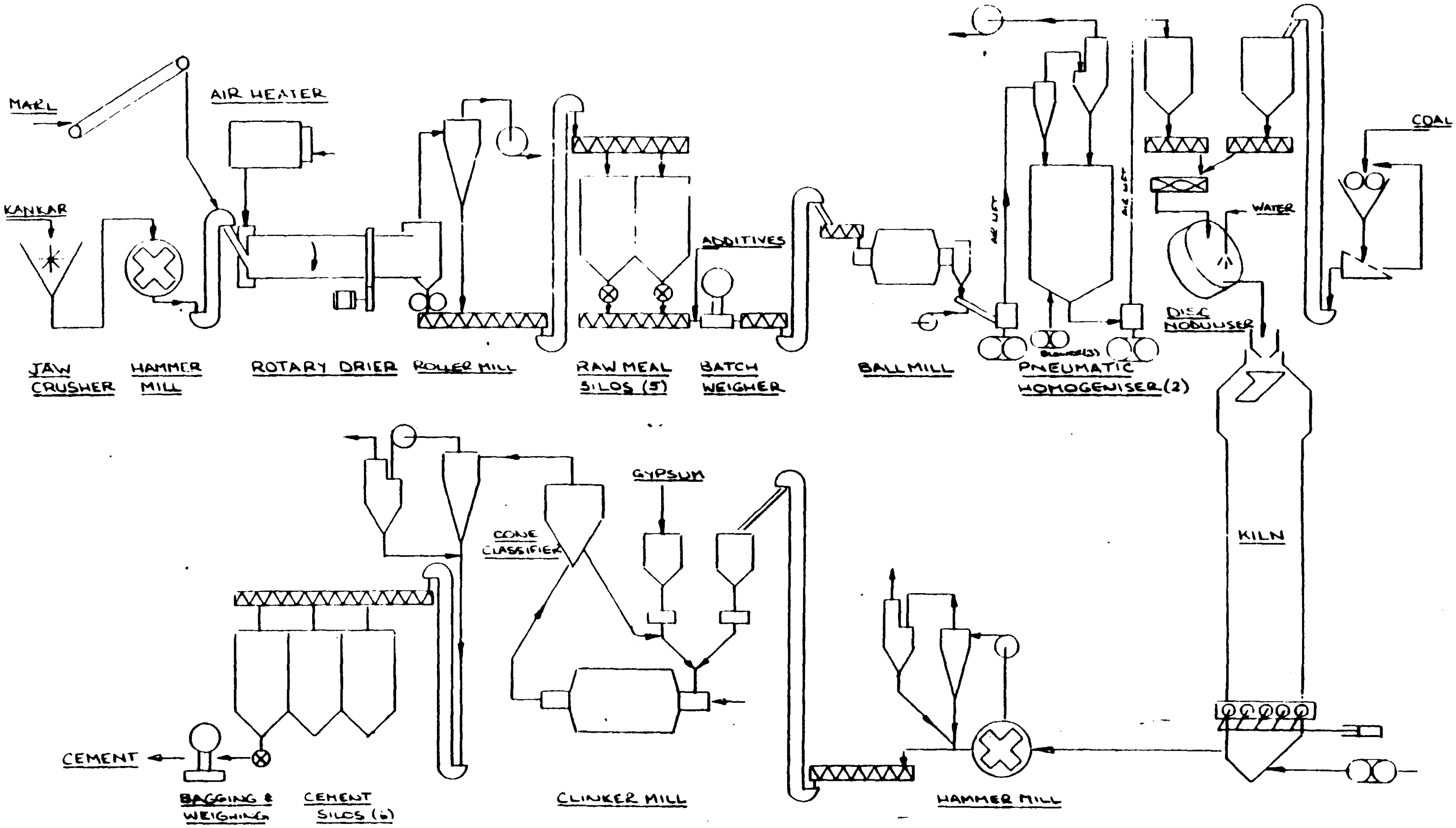
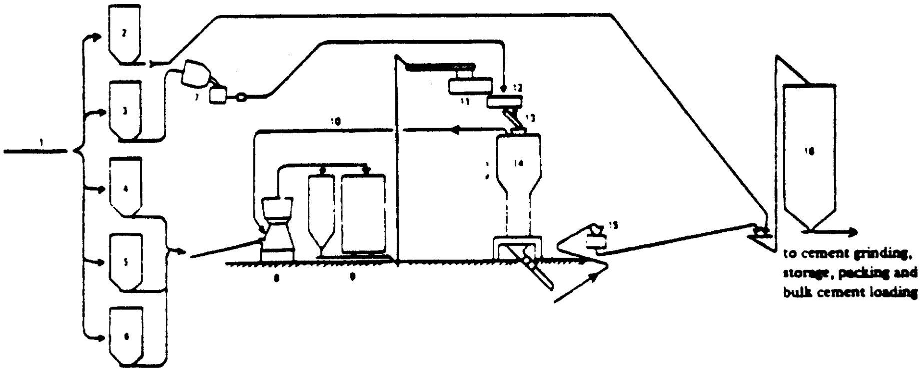


Figure 4.6 ATDA plant layout

Source Reference 46



1. Raw material crushed to minus 1" with movable breaker-plate equipped hammermill, coal minus 1" size, gypsum minus 1" size, all enter plant here.
2. Crushed gypsum hopper
3. Crushed coal or coke hopper
4. Limestone "high" hopper
5. Limestone "low" hopper
6. Clay or shale hopper (optional)
7. Coal slurry mill and pump
8. Raw mill with automatic sampler and analyser
9. Cyclone and electrostatic dust collecter for raw mill dust loaden gases, including flue gas from kiln
10. Kiln flue, gas line
11. Raw Meal proportioning feeder
12. Blending conveyor for raw meal and coal slurry
13. Pelletizer and rotating pellet feeder
14. Vertical kiln with rotary grate, blower and alternating discharge gates, externally insulated around the hot zone
15. Clinker crusher
16. Clinker and gypsum silo

Figure 4.7 Flow sheet of the Gottlieb VSK

Source: Reference 21

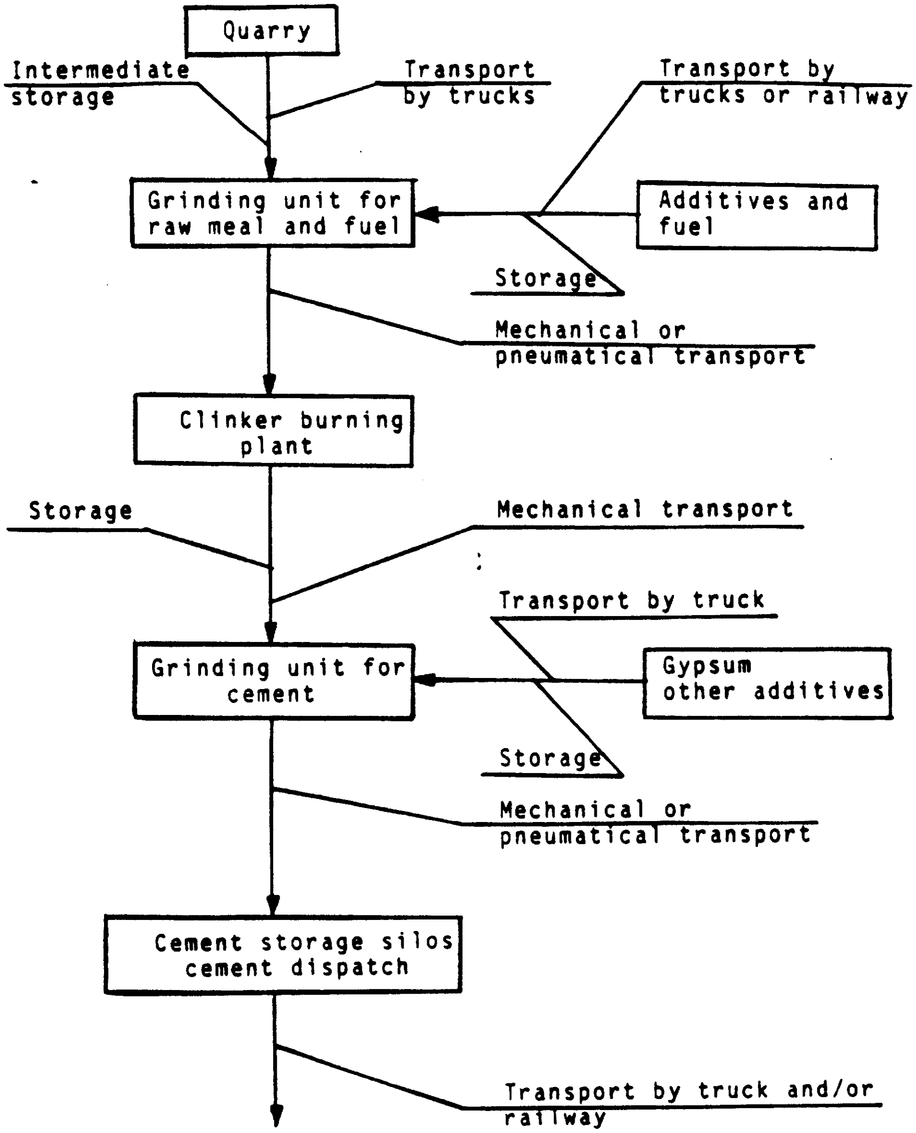
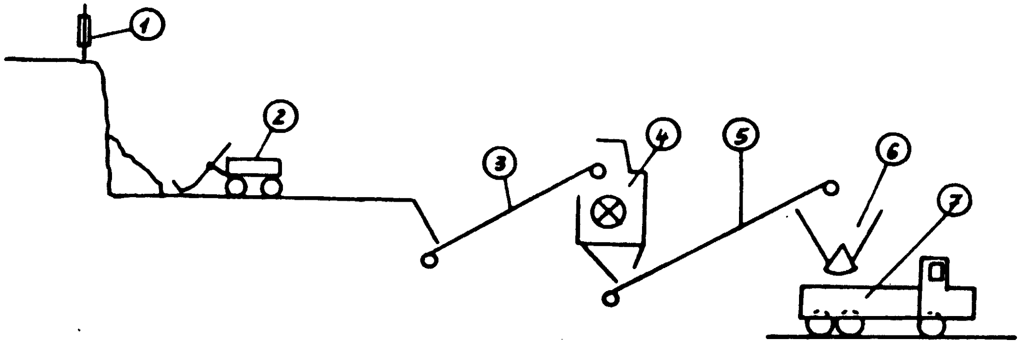


Figure 4.8 Schematic flow sheet of a mini cement factory

Source: Reference 47

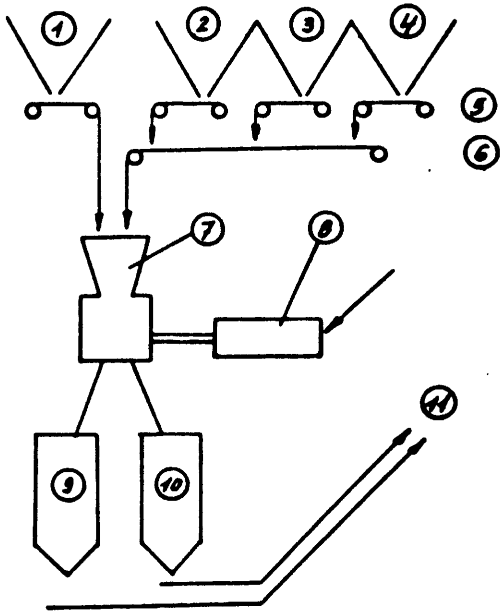


List of equipment:

(1) Drilling equipment for big holes
(2) Shovel loader for pieces of max. 1m^{3}size
(3) Apron conveyor feeder, capacity 75 t/h
(4) Impact crusher, capacity 75 t/h
(5) Belt conveyor, width 650 mm
(6) Intermediate storage silo

Figure 4.9 Schematic presentation of the quarry

Source: Reference 47



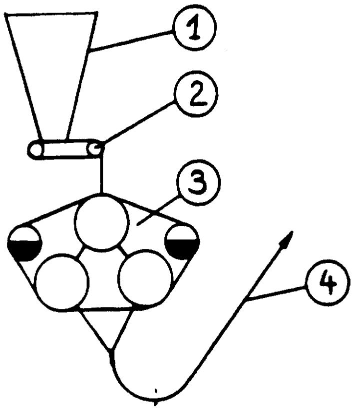
List of equipment:

(1) Feed hopper for limestone (marl)
(2),(3),(4) Feed hoppers for clay and other components
(5) Proportioning devices (weigh-feeders)
(6) Intermediate belt conveyor
(7) Drying-grinding roller- or ballmill
(8) Combustion chamber
(9) Storage silo for fuel oil (200 t)
(10) Storage silo for raw meal (1000 t)
(11) Pneumatic transport system for raw meal to the feed hoppers on the top of the kiln

Remark: In case the raw material analysis is varying considerably, a homogenizing system has to be installed.

Figure 4.10 Schematic presentation of a drying/grinding mill

Source: Reference: 47

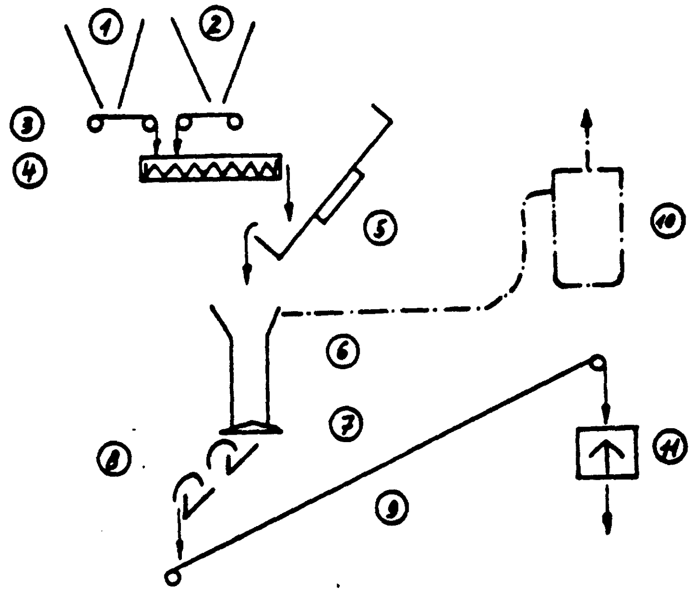


List of equipment:

(1) Feed hopper
(2) Proportioning device (weighfeeder)
(3) Vibratory mill
(4) Pneumatic transport to the feed hopper for ground fuel on the top of the kiln

Figure 4.11 Schematic presentation of the fuel grinding mill

Source: Reference 47

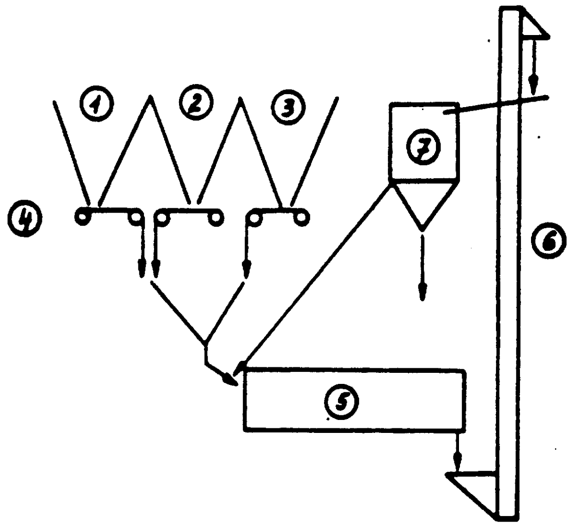


List of equipment:

(1) Feed hopper for ground fuel
(2) Feed hopper for raw meal
(3) Weighfeeders: Fuel max. 1,6 t/h
Raw meal 16,0 t/h max.
(4) Paddle mixer
(5) Dish pelletizer for a mixture of
16 t/h of raw meal and 1,6 t/h ground fuel
(6) Shaft kiln
(7) Discharge grate (rollers or plate)
(8) Discharge gate
(9) Apron conveyor
(10) Dust collector
(11) Clinker crusher

Figure 4.12 Schematic presentation of the burning plant

Source: Reference 47



List of equipment:

(1) Feed hopper for clinker
(2) Feed hopper for gypsum
(3) Feed hopper for other components
(4) Weighfeeders
(5) Ball mill, capacity 16 t/h, PZ 275
(6) Bucket elevator for Q = 50 t/h
(7) Sifter for Q = 16 t/h, PZ 275

Figure 4.13 Schematic presentation of the cement mill

Source: Reference 47

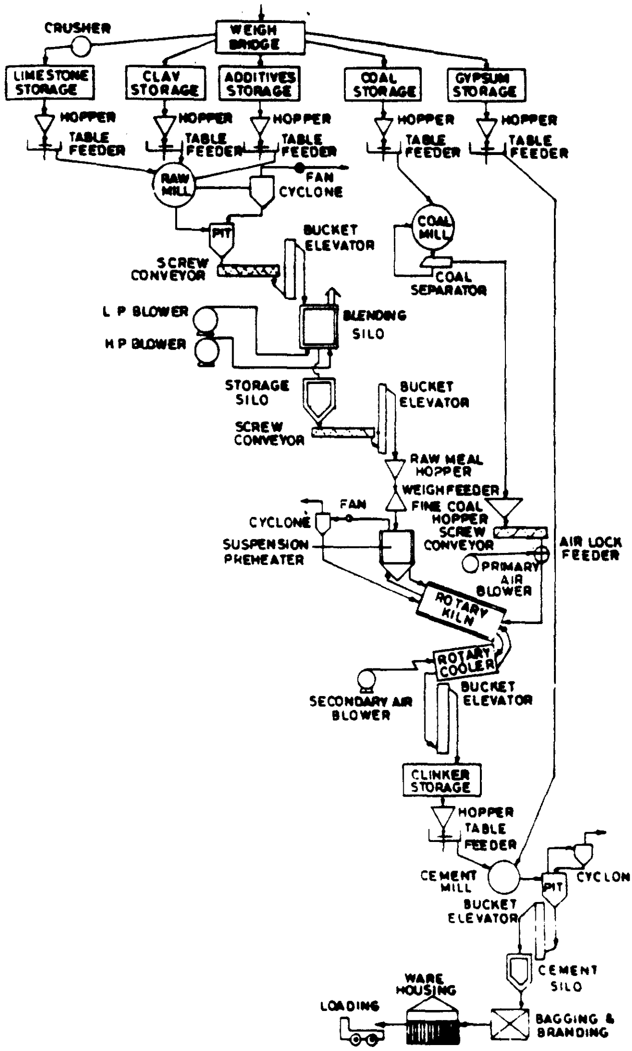


Figure 4.14 Flow sheet of a dry process small rotary kiln cement plant

Source: Reference 5

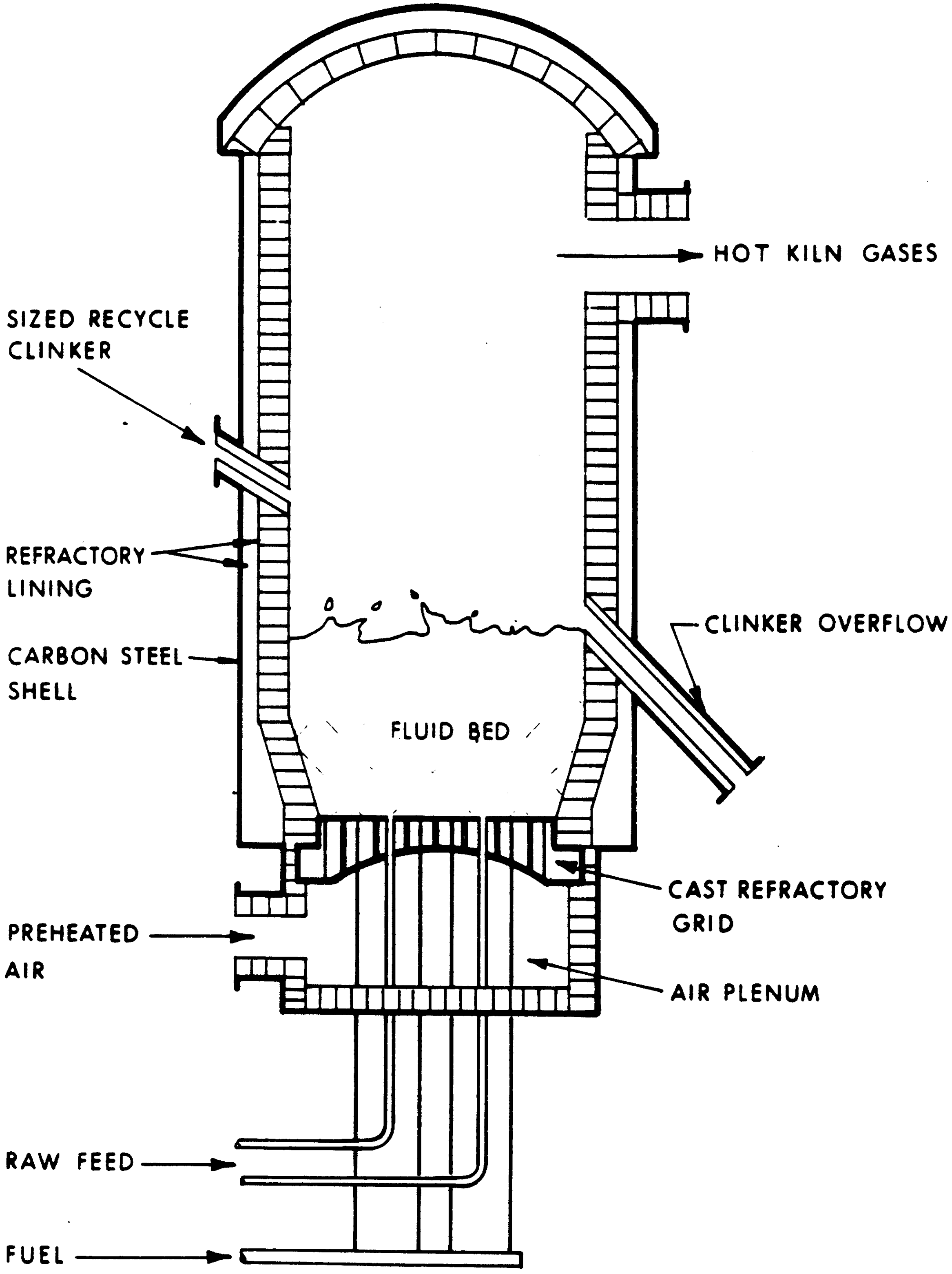
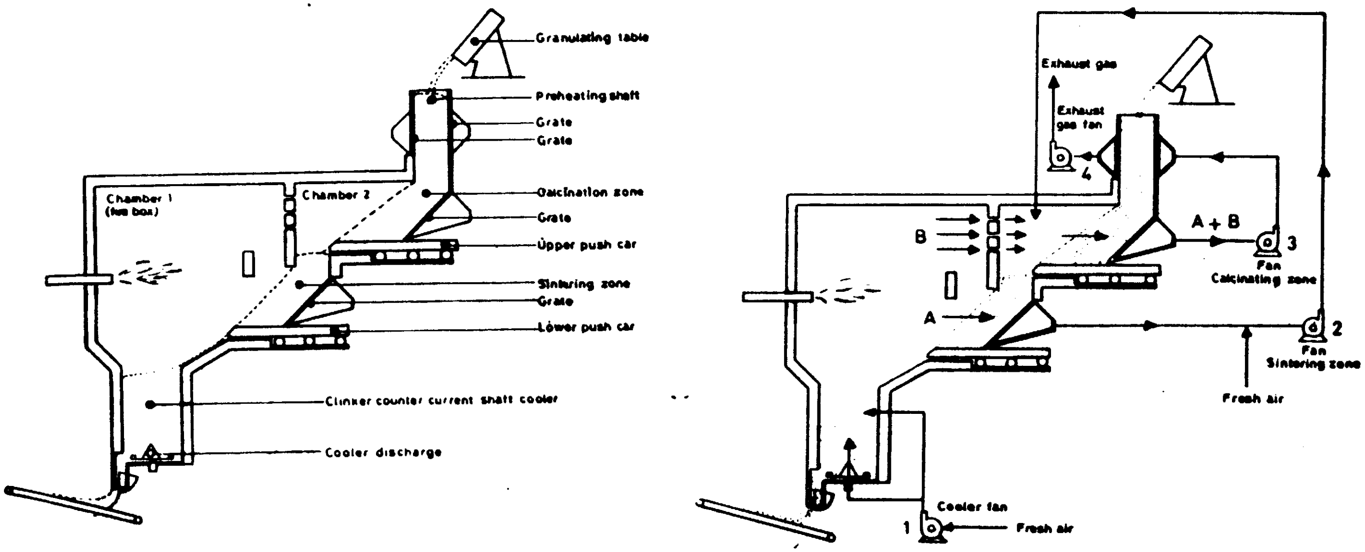


Figure 4.15 Scıetıfic Design Fluidized Bed Kiln

Source: Reference 31



Material flow in Reba process

Gas flow in Reba process

Figure 4.16 Reba process

Source: Reference 5

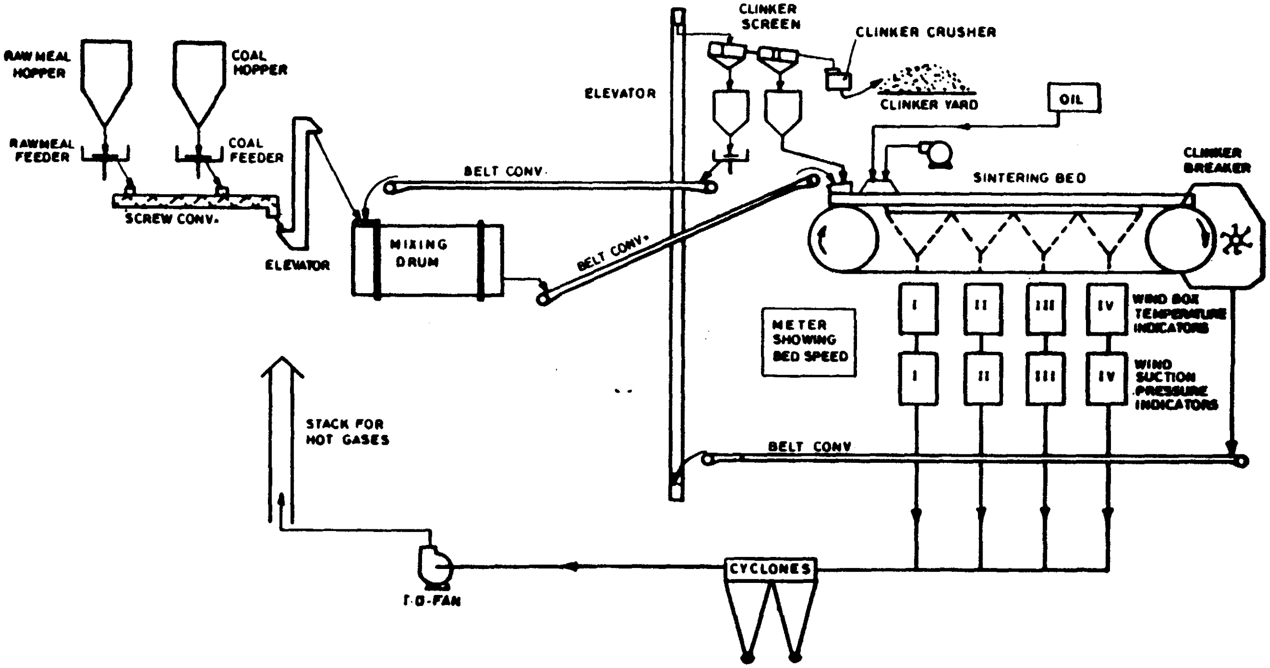


Figure 4.17 Lurgi sintering bed process

Source: Reference 5

5.0 ISSUES IN THE ECONOMICS OF CEMENT PLANT TECHNOLOGY

In this chapter four important issues that affect the economics of cement plants are discussed. The issue of natural economies of scale together with the issues of energy and transport efficiencies dictate the location and level of technology employed in cement plants. The capital-labor tradeoff is another consideration which dictates the level of technological investment in a cement plant.

5.1 Economies of Scale

Various studies have been carried out which demonstrate economies of scale for larger plants in cement production, both from investment and operating costs. Estimates of economies of scale in investment cost are shown in Table 5.1. The figures in the different columns are not comparable since they relate to different time periods and different countries. The table indicates clearly that the cost per ton of installed capacity is less greater the size of the plant. Studies in economies of scale also indicate that there is considerable saving in terms of unit operating costs directly proportionate to increase in production. Table 5.2 shows the variations in fixed and variable cost items in cement manufacturing. The data is specific to certain situations, however, it can be taken to represent the orders of magnitude of economies of scale for the "average situation" in the cement industry in the early 1970s. The economies of scale in various parts of the process can be represented in the form of index numbers, taking a 250,000 ton per year plant as 100 in Table 5.3. To get another idea of the economies of scale, one may note the figures in Table 5.4. The economies of scale shown in the table may need to be modified for developing countries to take into account different opportunity costs of factors. Even then the sizeable economies of scale are still likely to remain.

There exists a confusion between economies of scale with respect to the size of the kiln, plant and firm. In the studies quoted above, a new plant was taken as the unit for analysis. However no distinction was made of whether the plant had one kiln or more, whether it was constructed on an established site, whether the investing firm was a multi-plant operation or what level and type of technology was used. Thus it is important to specify what type of plant is being bought together with the end-product and only then scale economies can be put into proper perspective.

The choices of scale and product mix are always key issues in the cement industry. Scale is itself partly determined by the product mix if, for example, cement additives are used or export markets which require clinker are served. The use of low-cost additives which do not sacrifice product quality can very substantially boost the international competitiveness and profitability of projects since they reduce the amount of much higher cost clinker needed to produce any given volume of cement, while also lowering the scale of kiln required. In all situations, there are otherwise two major options to be taken into account in making the choice of plant scale. Firstly, investors in the cement industry usually face an important trade-off between plant size and the risks and costs of capacity underutilization. This issue arises because of the lumpiness of investment, the unattractiveness of exports for most producers and the fact that there are substantial economies of scale in cement production. The resolution of this trade-off is a function of many things particularly the expected economies of scale and market growth rates, possible variations in these, and the risk preference of investors. In practise, of course, all such scale decisions tend to be complicated by special circumstances such as choice between a smaller expansion project and a larger greenfield facility with initial overcapacity.

There is in theory another option which is faced in considering optimal plant scale. This is to simply delay investment until market growth justifies what is considered the most desirable scale for investment. Most investors are reluctant to consider this option if their projects already appear viable and there is a risk of losing their place in the market by doing so. For development planners, this latter option is important wherever market growth is reasonably rapid. This is because the investible resources which would have been required for the smaller plant may in the meantime earn satisfactory returns if invested elsewhere. An off setting advantage of development by stages is of course the implied earlier commencement along the industry's learning curve; a vital objective behind the initial thrust to industrialize. The advantage of industry decentralization may also intervene here in favor of the smaller initial scale.

The weakest link in the technical performance of cement plants has been in the pattern of build-up to full production. Most projects are projected to reach full production sooner than operations allow them to do so. Problems encountered frequently are those of stagnant market conditions, management problems, and unforeseen production difficulties (sometimes because of the raw materials used).

Rotary kilns have not been found to be economically feasible at outputs of less than 300 tons per day (tpd). Thus, even the smallest rotary kiln plant needs a minimum investment of $14 million. The most efficient rotary kilns of around 3000 tpd require an investment of over $100 million. This compares with a capital requirement of about $1.7 million for a 50 tpd VSK plant. Further, the large-scale plants have been found to have a minimum gestation period of three years in developing countries. The small VSK plants, on the other hand, take about 12 months to establish. This leads to a quicker return on investment and has a significant effect on the Internal Rate of Return (IRR) of the project.

The smallest efficient (300 tpd) rotary kilns need proven reserves of 2.5 million tons of good quality limestone to be economically feasible. VSKs, on the other hand, have been established with capacities as low as 5 tpd, though the highest rates of efficiency have been found at 50 and 100 tpd. 50 and 100 tpd plants need limestone deposits of just 0.4 and 0.8 million tons respectively.

5.2 Energy

In an energy-intensive industry like that of cement, development planners and investors alike have as great cause for concern about the cost of energy as they do about scale and location choices. The real potential for savings lies in influencing the amount of energy consumed than in the value of the fuel used and the reliability of a plant's supply of electricity.

The energy sources in a cement plant are classified as primary sources, like oil, coal, gas, other fuels and electricity, and secondary sources, consisting of waste heat from one phase of the process, which can be recovered and utilized in another phase of the process. The two most energy-intensive phases in cement manufacture are pyroprocessing and grinding. Pyroprocessing consumes mainly thermal energy in the form of oil, coal or gas, while grinding consumes mainly electric power.

Secondary heat contained in the hot kiln exhaust gases is utilized primarily in predrying and preheating materials before introduction into the raw mill for grinding and the kiln for burning. The waste heat contained in the exhaust gases from the clinker cooler serves to preheat combustion air and also to dry and preheat raw materials before entering the raw mill and kiln. A small amount of thermal energy may be needed as supplemental heat for drying purposes. Total thermal energy requirements in pyroprocessing of clinker normally range from about 750 to 2100 kcals/kg [.075 to .210 tons of oil equivalent per ton (toe/ton)] of clinker depending upon the specific process used and the operating efficiencies of the concerned cement plants.

In order of importance, the major consumption areas of electrical power are: grinding mills, fans, pumps and compressors in the pyroprocessing and homogenization areas, raw material crushing plant and all material handling systems. The electrical power consumed typically ranges from about 80 to 160kwh (.02 to .04 toe/ton) of cement. Fuel consumption typically accounts for about 75% to 90% of the total primary energy used in a plant and electrical power for the remaining 10% to 25%. Table 5.5 summarizes the normal ranges of energy consumption in the different stages of cement manufacture.

5.2.1 Comparative energy consumption in different processes:

The principal pyroprocessing systems discussed here are: (1) wet; (2) semi-wet with grate preheater; (3) semi-dry with grate preheater; (4) dry with long rotary kiln; (5) dry with 4-stage preheater; and (6) dry with 4-stage preheater and precalciner. The chart in Table 5.6 illustrates the average operating efficiencies for each type of process.

Wet processes (with slurry moisture content of between 24-48%) tend to have the highest specific energy consumption in pyroprocessing with a normal range of 1200 to 2100 kcals/kg of clinker (a weighted average of about 1400 kcals/kg). Evaporation of water and heat loss in steam absorb a high proportion (on average, 35%) of the total energy consumption.

In the Semi-wet process (slurry moisture content typically 17-22%) with grate preheater, the slurry is dewatered in mechanical filter presses and the resultant filter cake is then dried on a travelling-grate preheater before entry into the kiln. Average pyroprocessing energy consumption for such processes is about 950 kcals/kg of clinker.

In the Semi-dry process (moisture content typically 10-15%) with grate preheater, the dry feed is mixed with water and formed into pellets in special pelletizing equipment. In other respects, it is essentially the same as the semi-wet process. However, since the moisture content is lower, less heat is required for evaporation and the average energy consumption is around 835 kcals/kg of clinker.

Without preheating/precalcining, the dry process utilizing a long rotary kiln requires, on average, about 965 kcals/kg of clinker of which about 260 kcals (or 27%) represent heat loss in kiln and clinker cooler waste gases. By adding a preheater system to the kiln, the heat transfer is greatly improved because a higher percentage of the waste heat in kiln and clinker cooler exhaust gases is utilized to preheat and partly calcine (about 20-30%) the raw mix entering the kiln. As a result, less primary source heat is needed. Since less fuel is burned, less combustion gases are created and it becomes possible to obtain higher production for the same size of kiln, which further reduces specific energy consumption per kilogram of clinker due to the smaller radiation losses through the kiln shell. While a long dry kiln typically consumes around 965 kcal/kg, a 4-stage preheater system typically consumes about 800 kcal/kg of clinker corresponding to a savings of 18% of primary source thermal energy. Even lower specific energy consumptions (below 750 kcals/kg) have been reached in the "best practice" situations in West Germany and Japan. However, constraints imposed by the composition of the raw mix (presence of alkalies, for example) may limit the energy efficiency of preheater systems to between 850-900 kcals/kg of clinker.

In a precalciner system, a substantial portion (up to two-thirds) of the total fuel requirements can be burned upstream of the kiln using low grade fuels including industrial waste, shredded tires, and wood chips. As a result, the raw mix is already substantially calcined (up to a maximum of 85-90%) by the time it enters the kiln (as compared to 20-30% in a conventional preheater system). The addition of a precalciner therefore further increases kiln capacity. Specific energy consumption is essentially the same as in the case of preheater systems with similar constraints regarding raw mix composition. The comparative advantages and disadvantages of the different technologies discussed earlier are summarized in Table 5.7. Table 5.8 compares typical energy requirements for various cement processes, including a plant utilizing the Scientific Design (SD) Fluid Bed clinkering system. It is shown that the SD fluid bed process is basically competitive with the preheater design in overall energy use and much more economical in total energy than the long kiln designs.

Though thermal energy consumption in the dry process is substantially lower than in the wet process, particularly with the preheater/precalciner systems, the dry process does, however, entail a higher consumption of electrical power. A dry raw mill requires more power then a wet mill, and the homogenization and the pyroprocessing areas in the dry process contain a large number of fans operating at high pressure differentials with a significant power consumption. Average electrical power consumption in raw material preparation in wet process systems is usually about 22-23 kwh/ton of clinker (range 18-28 kwh/ton) and about 31-32 kwh/ton in dry process systems. However, the significant thermal energy savings in the preheater/precalciner systems offset the increased electrical power consumption several times over. Preheater/precalciner kilns are technologically more sophisticated than are the wet kilns and the long dry kilns and therefore become relatively more difficult to maintain and operate. Special attention must be given to the physical and chemical characteristics for raw materials and fuel in the design of such kilns.

Power consumption is influenced by the type of raw materials used and the type of grinding and crushing mills employed. Vertical roller mills require 40-60% of the kwh/ton of ball mills. Use of such mills in preference to tube mills in large cement plants is one direct way of economizing on power consumption. The roller mill can use preheater exhaust gases to dry raw feed stock, whereas the existing ball mill often needs additional fuel. Roller mills give a better content particle size distribution and can handle larger material sizes, a capability that reduces precrushing. Grinding aids are used in many plants to prevent agglomeration of fine particles, improve flow through the mill and reduce power consumption. Up to 10% savings have been reported through the use of such organic acids, alcohols, and amines.

Comparison of small and large scale plant energy consumption

The comparison is done for a company operating both small and large scale plants in Kenya. Cementia, a holding company based in Zurich, Switzerland with subsidiaries in various countries engaged in cement production, owns and operates the 1.27 million ton per year Bamburi cement plant in Mombasa, Kenya. This plant successfully operates in parallel a conventional dry process 4-stage preheater kiln and six vertical shaft kilns (Loesche design) with a total capacity of 420,000 tons per year. Cementia's operating experience on their Bamburi plant, as well as experience on various kiln supplied by Loesche indicate an average heat consumption for the whole plant of 950 to 1,000 kcal of clinker with raw materials containing 5% to 6% humidity. This consumption compares very favorably with the wet process (1,300 to 1,600 kcal) but is still higher than the 750 to 850 kcal achieved with the modern dry process rotary kiln with 4-stage suspension preheater. Power consumption for the whole plant with a shaft kiln is about 95-100 kwh per ton of cement versus 90-110kwh and 95-120Kwh for the wet process and the 4-stage dry process rotary kiln respectively. The refractory lining in the shaft kiln is not subject to dynamic loads and therefore wears out much less than in the rotary kiln. In the shaft kiln bricks are replaced on an average of every two years in the burning zone. The can last upto fifteen years in the cooling zone, while the life of the lining in the rotary kiln does not exceed 1-2 years. The long life of refractory bricks is the major factor in the high degree of reliability of the shaft kiln. Fast and easy startups of the plants are possible after frequent shutdowns as the better insulation keeps the heat up to 6-7 days.

The specifications for coal to be used in a vertical shaft kiln are significantly different from those for a rotary kiln. The coal to be used for cement manufacture in a rotary kiln should have a fairly high volatile content (10-30%) as that determines the length of the burning zone in the rotary kiln. On the other hand, vertical shaft kilns require only short-flamed coal with low volatile matter (not more than 14%, preferably below 7%). Rotary kilns can accept coals of calorific value of the order of 5500 kcal/kg. This calorific value is, however, low for use in vertical shaft kilns.

5.2.2 Energy consumption in developing countries

Energy consumption in the cement industry in selected developing countries is shown in Table 5.9. The energy consumption for cement in developing countries is directly correlated with the type of process used. Table 5.10 illustrates for selected countries the effect of choice of process on total energy consumption in the cement industry. The data shown for several industrialized countries relate to the mid-1970s when the wet process still accounted for a major share in their cement production and are therefore relevant for illustrative purposes.

The countries showing the highest per ton energy consumption are those (England, Pakistan, India) where wet process accounted for a high share of total cement production. Correspondingly, energy consumption was the lowest in the Federal Republic of Germany where the wet process accounted for only about 5% of total cement production. The differences in the specific consumption of both fuel and electricity among the different countries are not necessarily indicative of the operating efficiencies of their cement plants since, apart from the type of process, energy consumption is also affected by other factors specific to a given country, e.g., type of raw materials, prevailing cement and clinker standards.

Average thermal energy consumption per kilogram of clinker has decreased substantially over the last two decades as seen from Figure 5.1, which shows trends in selected industrialized country cement producers. Figure 5.1 shows a gradual reduction in thermal energy consumption taking place as dry process kilns and preheaters have increasingly replaced the wet process kiln, beginning in the late 1950s. The lower energy efficiency of the cement industry in the United States is due to a number of reasons which notably include (i) the availability of good quality, low-cost coal which has tended to reduce the economic incentives for improving energy efficiency; and (ii) the generally low profitability of many cement manufacturers caused by the high degree of competition in the face of a relatively slow-growing domestic market which has retarded the necessary major investments in new energy efficient equipment and facilities. In addition, for any country's cement industry, a number of other factors such as: extent of competition within its own market including the threat of imports at lower price where existing infrastructure permits such invasion; government regulations; incentive programs for energy savings; projected growth of domestic cement consumption; and aggresiveness in respect of exports will also influence the rate at which the cement industry will accelerate its energy savings program. For the countries shown, the most striking decreases in average thermal energy consumption occurred in Japan, England, France, and West Germany, all of which were able to significantly reduce their dependence on the wet process.

Unlike consumption of thermal energy, specific power consumption in cement manufacture has tended to increase rather than decrease over the same period of time, due mainly to the increasing share of the dry process in total production (which requires higher specific power consumption in raw material preparation). Table 5.11 shows the trends since 1972 for selected industrialized countries. The increased use of coal instead of oil in pyroprocessing also tends to increase specific power consumption since the coal has to be ground in mills driven by electric motors. In view of these circumstances, there have been a number of specific improvements in the efficiency of grinding equipment in the interst of reducing the power consumption. Also the increased use of grinding aids has tended to lower power consumption. In dry process plants the more energy efficient roller mill has increasingly replaced the standard ball mill for raw milling. The growing use of additives in cement manufacture has also tended to lower power consumption in cement manufacture by reducing the amount of clinker required to be ground per ton of cement.

5.2.3 Fuel substitution

During the early days of cement manufacture in the industrialized countries, coal was burned as a fuel in the cement kilns since it was so readily available. As the developing countries began to manufacture cement, they tended to use oil, which was easier to use, and, which at the prices prevailing at the time was actually cheaper to use than imported coal. The energy shock of 1973 caused changes in the pattern of fuel use because of the manifold increase in oil prices. Between 1973 and 1980, international oil prices increased from $2.7 per barrel to $27 per barrel (as represented by the average FOB (freight on board) realized price for Saudi Arabian light crude oil) while international coal prices increased from $20.9 per ton to $56.0 per ton (as represented by the FOB export price of United States bituminous coal). In a number of gas producing countries with established distribution systems and market outlets, the price of natural gas increased at about the same rate as oil. The higher rate of increase in prices of oil and gas has led to the substitution of these fuels by coal in a number of plants which have access to low cost coal in countries where capital and technology were made available for conversion from oil-based to coal-based systems. Table 5.12 shows the significant changes in fuel sources that have occurred since 1974 for selected industrialized countries, and the scope for such changes in selected developing countries. For the developing countries shown, oil still represents the most significant fuel source, though many conversions from oil to coal and other fuels have taken place since 1978.

The basic requirement of a kiln fuel is that it must have a high enough calorific content to produce a burning zone temperature of 1500-1600C. In addition, it must be possible to ignite and reignite it easily so that the flame is sustained even during temporary imbalances in the burning zone. In the precalciner kiln it is possible to utilize low quality fuel such as oil shale, inferior coal, and under some conditions, alternative fuels like industrial wastes, shredded tires, or wood chips, for instance, which would not serve in a conventional kiln where the lower limit for energy content of fuel is about 4500 kcals/kg. This flexibility of the precalciner becomes very important because there are so many deposits of inferior grade fuels which have limited application, and the precalciner systems allow the cement industry to lower cost by using these fuels, thereby permitting the scarcer high-grade fuels to be preserved for higher technology applications where their use is more appropriate.

The primary consideration in the economics of substituting coal for oil is the difference in their prices. Table 5.13 shows alternative rates of return obtainable for a range of price differentials between coal and oil by converting from an oil fired to an indirect coal fired system. As seen, depending upon the kiln size, oil to coal conversions can yield acceptable rates of return even at relatively low price differentials.

5.2.4 Conservation

Some of the more basic energy saving measures which can be readily implemented in the short-term without major capital expenditures are:

(a) Heat transfer improvements: Better heat transfer resulting in lower exhaust gas temperature can be accomplished in some kilns by the addition of internal heat exchange devices like chains and lifters. A reduction of about 100C in the exit gas temperature can reduce fuel consumption by about 120 kcals/kg of clinker.

(b) Reductions in slurry moisture: slurry moisture, a major factor influencing fuel consumption in wet process plants, can be reduced by use of chemical additives and by modifications of the piping system. Reducing the moisture content of the slurry from 40% to 35% could save about 80 kcals/kg of clinker.

(c) Improvements in the burning properties of the raw mix: A hard burning raw mix is a major cause of high energy usage in the kiln; as a general guideline, about 22 kcals/kg of clinker can be saved by lowering the sintering temperature by 100C in the kiln. By appropriate alterations in the chemical composition of the mix, and by improvements in the homogeneity and fineness of the mix, it will burn more readily.

(d) Reductions in dust losses: loss of clinker dust implies an energy loss of about 10 kcals/kg of clinker for each percent loss of material, mostly due to the extra raw material that has to be processed.

(e) Reductions in primary air and in air leakage: modifications to reduce the use of primary air in combustion from about 25% to 15% (measured as percent of required combustion air) help to reduce fuel consumption, and between 8 to 20 kcals/kg of clinker can thereby be saved. By reducing air infiltration at the kiln inlet and outlet seals by 10%, about 10 to 20 kcals/kg of clinker can be saved.

(f) Improvement in electrical energy consumption: Energy consumption in raw material grinding (typically 20-40 kwh/ton) can be improved by coarser grinding as long as it does not impair the burning characteristics of the raw mix; the resulting savings may amount to between 6kwh and 7 kwh per ton of cement. The utilization of roller mills instead of tube mills can reduce electrical consumption in raw material grinding by up to 25%. In cement grinding, the use of close-circuited cement grinding, optimization of the ball mill charge, use of segregating liners, precrushing of clinker, and use of grinding aids where cement standards permit them, can yield important savings in electrical energy consumption. The grinding mills are by far the largest consumers of electrical power with the next largest being the fans and compressors in the kiln systems and the homogenization area. The remaining electrical energy is consumed by a large number of smaller motors, mostly for material handling.

The principal long-term energy conservation measures are:

(a) Wet to dry process conversions: In full conversions, both the raw material preparation facilities and the kiln are converted to the dry process, while in partial conversion only the kiln is converted to dry or semi-dry process, and the raw mill remains wet. The main advantage of full conversions are the large thermal energy savings per kilogram of clinker produced, and increased kiln output, which can be substantial (doubling of capacity or more in some cases) depending upon the type of conversion. This is, however, very capital intensive at the same time. Partial conversions are needed when the raw material characteristics may create constraints for the conversion from the wet to the dry process. Such constraints include extremely high raw material moisture content (over 20%), special handling needs of certain raw materials like chalks and clays, beneficiation of raw material by flotation, and the acquisition of raw materials from remote quarries which require transportation by pipeline. The cost/benefit comparisons of the most popular type of conversions is shown in Table 5.14.

Full conversion from a wet to a long-dry kiln can yield savings up to 30-35%, while kiln capacity is increased by about 10%. Conversion to 1-stage, 2-stage preheaters or 4-stage preheater/precalciner kilns yield even greater energy savings (up to 45% as compared to the wet kiln), while greatly expanding kiln capacity, typically between 30 to 80% as compared to the original wet kiln. The choice between conversion to the grate preheater (semi-wet) process or 2-stage/4-stage preheater (dry process) systems depends upon certain characteristics of the raw materials such as, for instance, on whether the slurry is easy or not to handle in a filtering process, and on whether it exhibits high plasticity and will form strong nodules. As compared to the wet kiln, such conversions may typically yield energy savings up to 30% while production may increase by up to 50%.

(b) Production of blended cements: The blending of certain materials like granulated slag, fly ash and pozzolana with cement makes it possible to produce more cement from the same amount of clinker. As a result, the fuel consumption per ton of cement will be reduced. Experience in several countries has shown that up to 20% of the clinker can be replaced by fly ash, and upto 25% by blast furnace slag, without changing the character of ordinary Portland cement as a general purpose cement. Such blending is a well-known and widely accepted practise especially in Europe, and has permitted an estimated 20 to 40% savings in fuel consumption in certain countries. e.g., France and the Netherlands. Certain developing countries, e.g., Brazil, Mexico and India produce cement utilizing industrial by products such as fly ash and granulated slags, if they are available economically from local sources and low cost transportation is available.

5.2.5 Summary

The incremental efficiency of energy use helps to determine the type of process chosen (dry over wet or semi-wet) as well as profitability of a cement firm. It takes about 800,000-900,000 kilo-calories of fuel (about 85-90 kg of fuel oil) and about 115-145 kwh of electricity to produce one ton of Portland-grade cement in a modern dry process rotary kiln. This compares with about 1,500,000Kcal of fuel and 80Kwh of electricity per ton of cement in a wet process facility, and somewhere in between for a semi-wet process (or semi-dry process) plant. There is a partially offsetting trade-off against capital costs in adopting the wet process.

The use of low cost fuels is the key to energy savings. A 10% improvement in the energy efficiency of a dry-process plant would save only a little over $2/ton of cement produced (in 1980 terms), while substitution for fuel oil of cheaper locally-available alternatives (surplus gas, coal, petroleum coke, and even imported coal), could save at least 2-3 times as much, depending on the available options.

The other major area for energy savings shows up less in unit energy costs than in improvements in capacity utilization. Unreliability of external power supplies has taken a substantial toll in terms of start-up problems and foregone capacity utilization.

The effects of higher energy costs on the cement industry have tended to be offset by cost saving technological changes. The industry in the United States provides an interesting illustration. Energy intensive wet process cement plants that began operations around 1960 reportedly had total energy costs of around $11-12 per metric ton of cement. Depending on their size, these plants had capital costs ranging from $80-115 per metric ton of capacity. When the price of fuel oil increased sharply in the 1970's, many of these plants switched to coal, and thus were able to hold unit energy costs in 1980 to about $17-18 per metric ton of cement. Had those same plants also converted from the wet to the dry process, energy costs would have remained close to 1960 levels (or been almost twice that where coal was not substituted for fuel oil). Therefore, an important effect of the changes in energy costs appears to have been a significant improvement in the plant's competitive advantage by making technological adjustments. In the future, the economies of scale that now are feasible in cement production could also help offset, at least partially, the energy-induced cost pressures.

The effect of higher energy prices on transport costs has tended to increase the already high natural protection factor in localized cement

5.3 Transportation

Transport costs carry preponderant weight in all investment decisions in the cement industry. This stems from the low value to volume and weight ratios of the products, and the fact that it takes between 1.65 and 1.95 tons of raw materials to produce one ton of end product (the lower figure for Portland grade cement). It is sometimes said that the cement industry is in the transport business.

In the first place, international transportation costs (usually by sea) are normally significant enough to justify local manufacture of cement, and probably also clinker, in most developing countries. Landed CIF import prices of cement of no less than $60-70/ton (in bags) in 1980 in most part of the developing world suggest the economic viability in coastal locations of typical medium-sized greenfield (new) plants. In more remote inland markets the case for local manufacture is even stronger.

In general, domestic transport costs within the developing countries (mostly by land) tend to have a much more significant impact on plant location decisions in the cement industry. Typical land transport costs in developing countries of $0.05-0.10 or more per ton-kilometer (in 1980 terms, excluding subsidies) mean, for example, that clinker producing plants normally have to be located quite close to their limestone source if they are to remain competitive with imports or with other domestic producers (1.3 tons of limestone are needed per ton of Portland grade cement). For the same reason, proximity to markets is a decisive consideration within countries. For plants serving coastal markets, it is usually essential that the limestone be adjacent to the market area, or competitiveness against imports will be sharpely eroded. Likewise, for markets inland, the use of any suitable limestone deposit which is a shorter (economic) distance from the market than is the port of entry for imports will enhance competitiveness against imports.

In the case of inland markets, in particular, and in view of the remoteness and small size of many such markets, and the different size and suitability of the various limestone deposits scattered throughout most countries, the implications for unit capital costs of alternative scales of manufacture have also to be considered along with the location factor. In this context a rough rule of thumb for assessing the cost of reducing the scale of greenfield plants is that, other things equal and infrastructure aside, the unit capital cost per ton of output will rise by about one-third if the scale is halved. Applying this rule a 250,000 ton per year plant, for example which is 100-200 kilometers closer to an inland market than a 500,000 ton unit, could be fully competitive in that market. This assumes that the larger plant does not choose to supply the smaller inland market on the basis of marginal costs. Even in the United States where transport infrastructure is at an advanced stage of development, about 200 miles is now considered the competitive limit to land shipment of cement.

For a given density of demand, the larger the unit size of a cement plant, the larger is its aggregate transportation cost. Savings on transport costs are important as they constitute a significant element of total delivered cement costs in developing countries. In India, for example, cement transport constitutes about 6% to 8% of total rail freight traffic. The resource costs of cement transport, excluding packaging, handling, and allowances for loss or pilfering have been estimated to average about 15% to 20% of the value of cement. In India, the transport and distribution costs average $10.31 (Rs. 100) per ton for a distance of about 700 kilometers by rail depending on the traction and line density, whereas the ex-works cement price averages $34.18 (Rs. 335) per ton. Though the transport costs in India have been distorted because of a policy of freight equalization of cement for rail transport, India has a much more developed rail network compared to many developing countries for which the transport costs would be even more significant. China has a much less well developed transportation network than India, which encourages its policy of decentralized production. In China, in order to reach district centers, cement from large centralized plants would frequently need to be transported by road, which would greatly add to the price of cement.

Other factors can, of course, intervene to tip the balance decisively in favor of a particular location. Variations in the suitability of raw materials at different sites and the varying availability and costs of fuel, labor, and water can obviously be of key importance here; and regional development benefits in outlying areas ought not to be overlooked. Likewise, the availability and market acceptability of cement additives can also swing the balance in favor of one location as against another, although the option of shipping clinker from a feeder domestic plant to outlying grinding facilities may then become viable.

Cement produced in sub-optimal sized plants, can be competitive in specific locations even though there are significant economies of scale of large scale in its production and distribution. When deciding location, size and technology for the cement plants, it appears that in China transportation costs are much more important than investment costs per ton of finished product. That is to say that economies of scale due to reduced investments costs per ton of cement for large-scale centrally located plants rarely compensate for the increased transportation costs when compared with widely distributed smaller plants. For the same reasons, cement exports tend not to be an attractive proposition, unless supported by a significant production cost or freight advantages. Spurred by higher energy costs, the process of adopting significant technological changes has been accelerated in this energy intensive industry, both at the production stage and in the international handling and shipping of this product. To a large extent, these technological changes have offset the impact of higher energy costs for producers with access to low cost and/or alternative energy sources. One consequence of these changes has been a shift in the comparative advantage of cement manufacture and distribution toward producers who have made the necessary structural adjustments.

One reflection of this shift has been a doubling of international trade in cement (relative to world consumption) particularly in clinker, the intermediate product which embodies most of the energy cost. In the future where cement markets are small and there is an absence of low-cost energy sources, it may become more important to grind clinker in coastal locations. Today exporters of cement to developing countries can have considerable energy cost advantages which, together with economy of scale advantages, enable them to charge prices which more than offset the transport costs for clinker. While this trend may be a harbinger of greater changes to come, cement still remains one of the most highly naturally protected industrial commodities because of its low value to weight and volume ratio. Hence, developing countries with even small domestic markets can still remain competitive in cement manufacture.

5.4 Capital and Labor

This discussion will focus on the analysis of the capital and labor requirements in cement plants.

Analysis of capital requirements

Fixed investment in a cement plant includes equipment for the plant and quarrying installations together with the cost of the buildings and storage facilities and the cost of construction (land clearing, provision of civil facilities). Sometimes electric power generating equipment is also installed on the site because of large consumption needs and problems with delivering power in remote locations. Investment requirements for each of these items depends upon the technical requirements of the plant and on the location requirements. On the technical level, the prime determinants of plant capacity are the size and number of kilns. The capacities of the other equipment, including equipment in the quarry, crushers and mills, are chosen in conformance to these key items. There appears to be considerable standardization of sizes for those items which bulk large in investment costs; this is due apparently to the efforts of the manufacturers (of this type of equipment) to reduce their own production costs. As shown in Chapters three and four, considerable flexibility exists with regard to equipment in large and small-scale plants. Local conditions play a very important role in determining costs for the plants. Land clearing and improvements (drains, sewers, roads, railway, etc.) are affected by the remoteness of the plant.

The influence of scale operations on total investment costs may be observed on the basis of that collected for a number of countries in the early 1960s as shown in Figure 5.2. Data for the United States relates to wet process plants, for West Germany it is based upon information from an industrial handbook, and for the Soviet Union it is based upon actual plants. The three sets of data indicate the existence of a constant elasticity between size and total investment costs; that is a constant ratio between the percentage increase in size and the percentage increase in total investment costs. The elasticity varies from 0.64 in the German data, 0.66 in the Soviet data, to 0.77 in the United States data.

The developing countries are expected to show variations in unit costs (exact figures not available) similar to that in developed countries. The differences in costs reflect mainly the additional costs of international freight, import profits, internal transportation and handling of equipment. As to the cost of construction, which tends to be lower in developing countries, the high costs of imported equipment used in cement plants tends to offset the former. The use of elaborate quality control and pollution control equipment in the United States tends to increase the unit investment costs with respect to both the European and the developing countries.

Analysis of labor requirements

Data on labor requirements for cement production for different scales of operation of plant indicate that total requirements increase very slightly with increase in size of plant; consequently labor inputs per unit of output fall sharply as scale increases. Data in Figure 5.3 and Table 5.15 shows this is the case for a variety of plants in the United States, the Soviet Union and Japan. These figures refer to production workers only; allowances must be made for administrative personnel. Estimates of labor inputs for selected countries, expressed in terms of man-hours per ton of cement, are contained in Table 5.16. There are minor variations in the data of the developed countries while the difference between India and the other countries is significant.

To summarize, labor inputs per unit of output vary significantly with size of operation. Moreover, there are variations corresponding to the alternative methods of materials handling in the plant while a considerable latitude exists with respect to quarrying operations.

Table 5.1

Estimations of cost per ton of installed capacity

Capacity in tons per year	Dollar cost per ton of installed capacity			
	1960 a/	1970 b/	1970 c/	1976 d/
30,000		168		
50,000		116		
100,000	120	80	72	
200,000	100			
250,000		60		
300,000			60	
400,000	83			
500,000	80	55		
550,000				103
600,000			48	
1,000,000	56	42		
1,100,000				78
1,200,000			43.2	
1,400,000				

Source: Reference 39

Table 5.2

Variations of manufacturing cost with size of cement plant

Cost item	Plant size in tons a year					
	30,000	50,000	100,000	250,000	500,000	1,000,000
Variable costs						
Fuel	4.07	3.58	3.13	2.70	2.36	2.14
Electricity (variable)	1.45	1.41	1.27	1.16	1.04	0.94
Production surplus and maintenance materials	2.05	2.05	2.05	2.05	2.05	2.05
Subtotal	7.57	7.04	6.45	5.91	5.45	5.13
Fixed costs at 100% capacity utilisation						
Labour	12.13	7.28	4.64	2.32	1.61	1.09
Electricity (fixed)	0.72	0.69	0.64	0.58	0.53	0.49
General plant expenses	2.13	1.28	0.64	0.32	0.26	0.17
Depreciation	18.48	12.76	8.80	6.60	6.05	4.62
Subtotal	33.46	22.01	14.72	9.82	8.45	6.37
Total cost of bulk cement	41.03	29.05	21.17	15.73	13.90	11.50
Addition for packing in 50 kg cement bags	2.20	2.20	2.00	2.00	1.90	1.90
Total cost of cement in bags	43.23	31.25	23.17	17.73	15.80	13.40

Source: Reference 39

Table 5.3

Economies of scale in the cement industry

Annual capacity of plant (tons)	Variable cost	Fixed cost	Total manufacturing cost of bagged cement
30,000	128	340	221
50,000	119	224	176
100,000	109	150	130
250,000	100	100	100
500,000	92	86	89
1,000,000	87	65	76

Source: Reference 39

Table 5.4

Economies of scale

Capacity (Tonnes per day of Cement)	Index of Capital Cost of Plant	Index of Unit Cost
500	44	220
1000	57	142
2500	100	100

Source: Reference 27

Table 5.5

Energy Consumption by Manufacturing Stage

	FUEL			ELECTRICITY			TOTAL	
	Normal Range	Average		Normal Range	Average		Average	
	kcals/kg of clinker	kcals/kg of clinker	toe/ton of cement	kwh/ton of cement	kwh/ton of cement	toe/ton of cement	toe/ton of cement	% share
Quarrying	5-15	10	.0010	2-6	4	.0010	.0020	1
Raw Material Grinding & Preparation				20-40	30	.0075	.0075	6
Pyroprocessing	750-2,100	1,100	.1100	15-30	22	.0055	.1155	82
Clinker Grinding				35-64	50	.0125	.0125	9
Miscellaneous				10-16	13	.0033	.0033	2
Total	755-2,115	1,110	.1110	82-156	119	.0298	.1408	100
% Share in Total			79			21		100

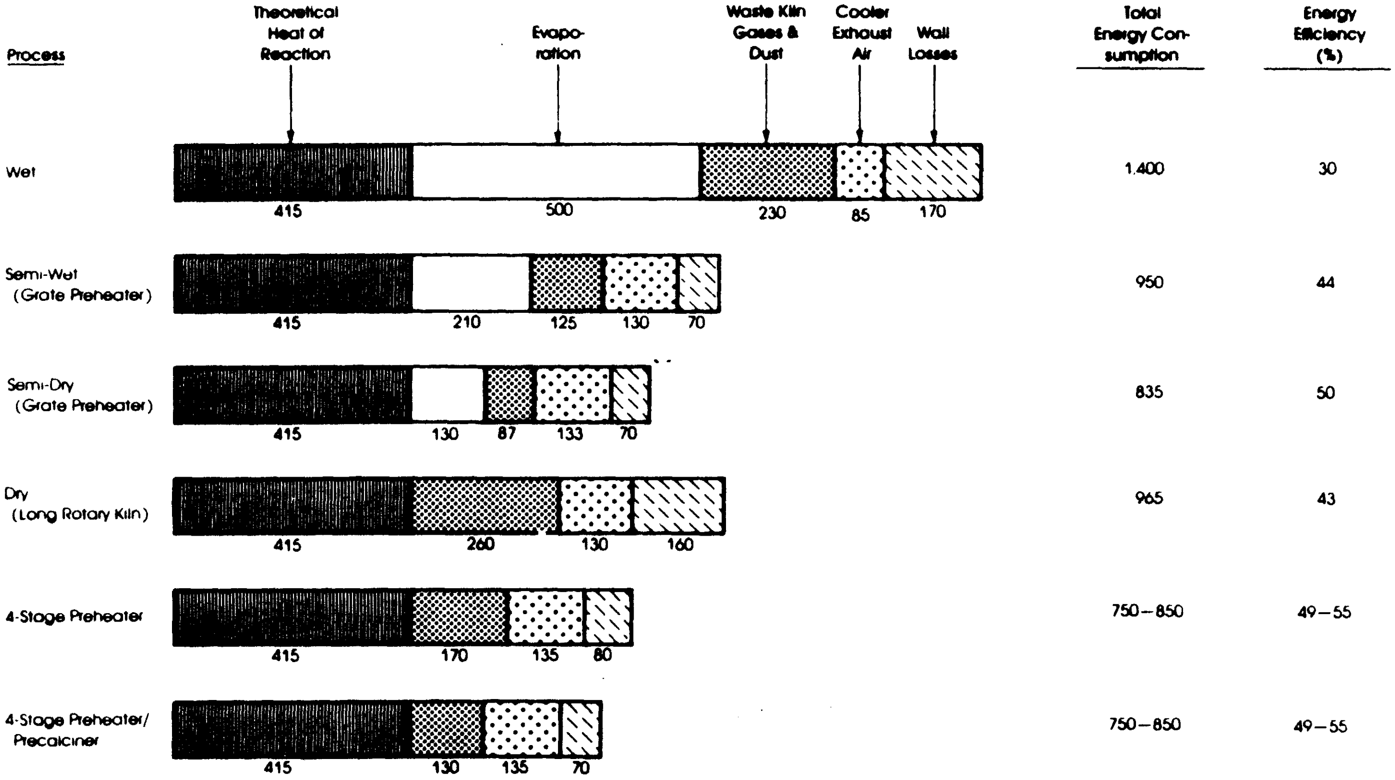
<u>Notes:</u> Averages include weighted averages as appropriate. Average clinker to cement conversion ratio assumed, 1.00:1.04.

Energy equivalents assumed: 1 kwh = 2,500 kcals (based on energy conversion efficiency in modern power plants, though, in specific cases, the conversion efficiency may be as low as 3,500 kcals per kwh); 1 toe = 10^7 kcals.

Source: Reference 16

Table 5.6

Comparative Thermal Energy Consumption in Various Pyroprocessing Systems (kcals/kg of clinker)



Note Energy efficiency is the percentage ratio of the theoretical heat of reaction to the total energy consumption

Source: Reference 16

Table 5.7

Comparative Features of Different Cement Production Technologies

		Kiln Process						
Evaluation feature		Wet	Grate (pellets)	Grate (filtercake)	Long Dry	One stage preheater	4 stage preheater	4 stage preheater w. precalciner
Thermal energy consumption	kcal/kg	1,400	800-900	940-1,060	880-1,000	860-950	750-850	750-850
Electric power consumption in kiln system	kwh/ton	18-27	18-28	18-28	20-22	22-24	27-31	30-34
Availability of secondary heat	Maximum percentage moisture in raw material which can be handled by secondary heat	N/A	4%	N/A	10%	9%	7-8%	7-8%
Sensitivity to raw materials characteristics	desirable	-	high nodule strength	filterability	-	-	low alkalies low chloride	low alkalies low chloride
	undesirable	high plasticity	-	-	-	-	-	-
	critical area	chain system	preheater grate	filter	-	-	preheater	preheater

Source: Reference 16

Table 5.8

Energy requirements of the Fluidized-bed kiln

(Purchased Power Fuel Efficiency = 30% on a Delivered Basis)

	Feed Preparation (quarry, crush, dry, mix feed)	Clinkering (burn, cool)	Finishing (grind, pack)	Available Energy Recovery (steam/power generation, dryer fuel savings)	Net Energy Required After Energy Recovery
Wet, Long Kiln					
Electrical	406,000	286,000	710,000	-	1,402,000
Fuel	16,000	5,560,000	-	-	5,576,000
	422,000	5,846,000	710,000		6,978,000
Dry, Long Kiln					
Electrical	534,000	315,000	760,000		1,609,000
Fuel	336,000	4,600,000	-	(320,000)	4,616,000
	870,000	4,915,000	760,000	(320,000)	6,225,000
Preheater, Short Kiln					
Electrical	534,000	374,000	760,000	(346,000)	1,322,000
Fuel	336,000	3,200,000	-	(300,000)	3,236,000
	870,000	3,574,000	760,000	(646,000)	4,558,000
S.D. Fluid Bed Kiln					
Electrical	490,000	-	760,000	(1,400,000)	(150,000)
Fuel	310,000	5,000,000	-	(180,000)	5,130,000
	800,000	5,000,000	760,000	(1,580,000)	4,980,000

Source: Reference 31

Table 5.9

Energy Consumption in the Cement Industry in Selected Developing Countries

	Annual Energy Consumption in Cement (10^{12} kcals)	Percentage of Commercial Energy Consumption	Percentage of Energy as Fuel	Average Kiln Heat Consumption (kcals/kg cl.)
Argentina	9.13	2	79	1030
Bolivia	0.81	5	77	930
Brazil	36.80	5	76	1040
Cameroon	0.11	n.a.	83	1100
Caribbean	4.00	4	85	1485
Chile	2.17	3	72	1140
Colombia	10.41	8	85	1620
Ecuador	2.02	5	78	1075
Ethiopia	0.24	5	85	1120
Gabon	0.26	3	86	1450
Indonesia	9.18	3	77	970
Malawi	0.18	8	80	950
Malaysia	3.75	5	80	1110
Mali	0.10	7	87	1900
Morocco	6.12	15	79	1085
Mozambique	1.40	10	80	1045
Niger	0.06	4	83	1300
Nigeria	6.51	12	81	1135
Pakistan	6.93	7	93	1670
Panama	1.05	8	82	1350
Paraguay	0.37	9	85	1500
Senegal	0.57	8	82	1120
Sri Lanka	0.83	7	77	905
Togo	0.73	41	76	830
Tunisia	3.54	14	81	990
Uruguay	1.33	6	84	1385

Source: Reference 16

Table 5.10

Energy Consumption in the Cement Industry in Selected Countries

	Year	Production (million tons)		% Share by Wet Process	Energy Consumed		Per ton Energy Consumption	
		Clinker	Cement		Fuel (mtoe)	Electricity (gwh)	Fuel [a] (toe)	Electricity [b] (kwh)
ICs	1976	68.6	71.2	59	10.9	11,480[c]	0.158	140
- FR of Germany	1974	31.0	35.6	5	2.8	3,552	0.090	100
- UK	1974	17.7	18.4	69	2.6	1,818	0.147	99
- France	1973	27.5	31.9	30	2.9	2,935	0.105	92
DCs								
- India	1977/78	16.5	19.5	65	2.7	2,400	0.163	123
- Turkey	1978	14.8	15.4	10	1.6	n.a.	0.108	n.a.
- Portugal	1977	3.8	4.4	30	0.5	578	0.132	131
- Tunisia	1981	2.1	2.2	21	0.2	264	0.100	120
- Pakistan	1979/80	3.1	3.3	90	0.5	330	0.161	100
- Philippines	1979	3.9	4.1	27	0.5	615	0.128	150

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a/ Per ton of clinker.

b/ Per ton of cement.

c/ For 1979 corresponding to cement production of 82.0 mt.

Source: Reference 16

Table 5.11

Average Electrical Energy Consumption in Cement Manufacture in Selected Industrialized Countries

(kwh/ton of cement)

	1972		1976		1980	
	Share of Dry Process (%)	Power Consumption/ton	Share of Dry Process (%)	Power Consumption/ton	Share of Dry Process (%)	Power Consumption/ton
France [a]	68	92	80	95	90	102
FR of Germany	92	100	95	103	97	108
USA	28	137	41	140	48	142

a/ For France, share of dry process also includes semi-dry and semi-wet processes.

Source: Reference 16

Table 5.12

Shares of Different Fuels in Thermal Energy Consumption in Cement (%)

	1974			1978			1980		
	Oil	Coal	Gas	Oil	Coal	Gas	Oil	Coal	Gas
ICs									
- USA	12	44	44				5	75	20
- FR of Germany	74	6	20				49	41	10
- France	85	4	11				67	20	13
- UK	6	80	14				2	97	1
- Canada	40	10	50				34	30	36
DCs									
- Argentina				34	3	63			
- Brazil				100	-	-			
- Egypt				100	-	-			
- Indonesia				83	17	-			
- Morocco				100	-	-			
- Nigeria				73	27	-			
- Pakistan				-	-	100			
- Portugal				100	-	-			
- Turkey				75	25	-			
- Philippines				97	3	-			

Notes: For the ICs, the shares are based on the oil-equivalents of the different energy sources. For the DCs, the figures refer to the percentage of total cement capacity produced by plants utilizing the different fuel sources.

Source: Reference 16

Table 5.13

Kiln Capacity (tpd)	Approximate Rates of Return on Oil to Coal Conversions									
	Oil/Coal Cost Differential (in US$/toe)									
	30	40	50	60	70	80	90	100	110	120
750	8	14	18	23	27	32	36	40	44	48
1,500	20	28	35	43	50	57	64	72	79	86
3,000	33	45	57	69	81	93	105	117	129	141

Source: Reference 16

Table 5.14 Comparative Costs/Benefits of Alternative Conversions

	Wet	Long Dry	2-Stage Preheater	4-Stage Preheater/ Precalciner	Grate Preheater with Filtration
For Original Wet Kiln of 750 Tons Per Day					
Capacity (tpd)	750	800	960	1,350	1,125
Energy Consumption (kcals/kg)	1,500	1,050	950	800	1,080
Typical Conversion Capital Cost Range (US$ mil.)	-	7-10	12-16	30-40	26-35
For Original Wet Kiln of 1,500 Tons Per Day					
Capacity (tpd)	1,500	1,600	1,920	2,700	2,250
Energy Consumption (kcals/kg)	1,500	1,000	950	800	1,060
Typical Conversion Capital Cost Range (US$ mil.)	-	15-21	17-23	45-60	41-55

Notes: All capital cost estimates are indicative estimates only of the broad order of magnitudes involved for the different cases and are not site- or country-specific. In any given case, the costs could be different from those indicated on account of factors and circumstances specific to the case.

Electrical energy conversion ratio assumed: 1 kwh = 2,500 kcals.

Source: Reference 16

Table 5.15

Production workers related to plant capacities in certain countries

(Production workers per 1,000 tons annual capacity)

Plant capacity (thousand-tons per year)	*Japan*[a]	*USSR*[b]	*USA*
100	1.24	...	0.75
200	0.82	1.55	0.48
400	0.62	0.93	0.32
500	0.58	0.78	0.30
1,000	...	0.54	0.15

Source: Reference 49

Table 5.16

Average labour productivity in major cement producing countries

(Man-hours per ton of cement unless otherwise specified)

Country	*Year*	*Production and related workers*	*Administrative and clerical staff*	*Total*	*Share of production and related workers as percentage of total*
France	1960	1.83	0.50	2.33	77
Germany (Federal Republic)	1958	2.25	0.23	2.48	91
	1959	1.84	0.34	2.18	84
	1960	1.76	0.34	2.10	84
India	1956	11.00	1.9	12.90	85
Italy	1960	2.02	0.36	2.38	85
Japan	1958	1.79	0.74	2.53	71
	1959	1.54	0.72	2.26	68
Netherlands	1960	1.19	0.25	1.44	83
Switzerland	1960	1.34	0.25	1.59	84
USSR	1958	3.51	0.62	4.13	85
	1959	3.13	0.55	3.68	85
	1960	2.86	0.50	3.36	85
United Kingdom ..	1960	2.54	0.63	3.17	80
United States	1958	1.33	0.28	1.61	83
	1959	1.22	0.26	1.48	82
	1960	1.25	0.28	1.53	82

Source: Reference 49

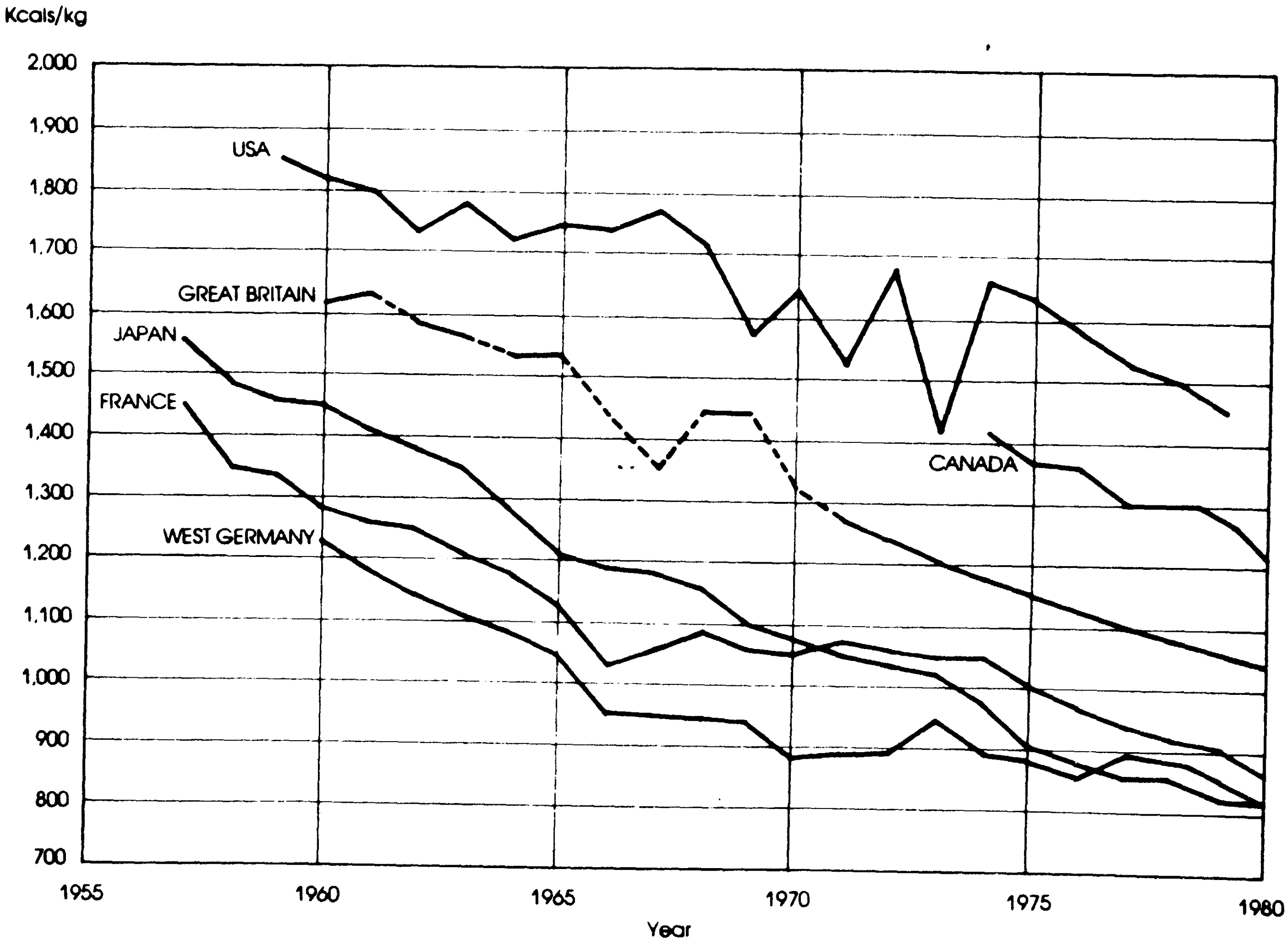


Figure 5.1 Trends in Thermal Energy Consumption in Cement in selected industrialized countries, 1950-81 (kcal/kg of clinker)

Source: Reference 16

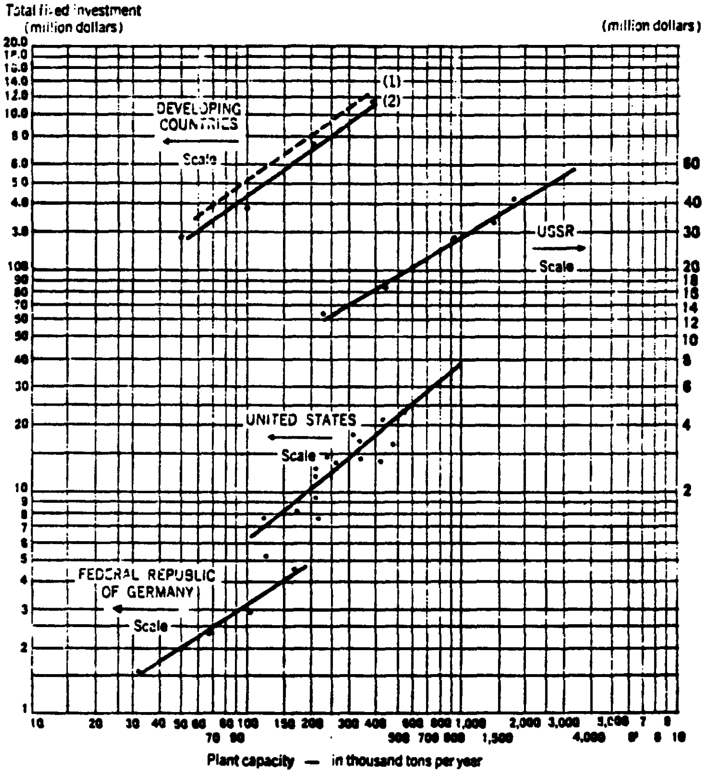
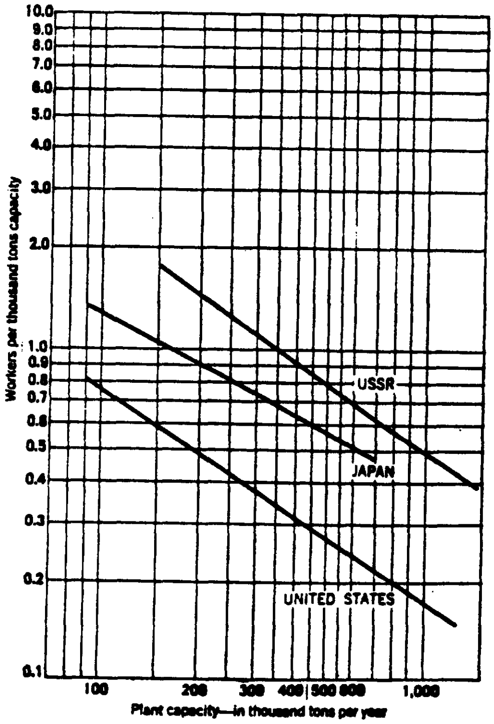


Figure 5.2 Fixed Investments and Plant Capacities
Figure 5.3 Production workers and plant Capacities



Source: Reference 49

6.0 THE POLICY FRAMEWORK FOR CEMENT IN DEVELOPING COUNTRIES

Investment in such important industrial facilities as cement plants in developing countries does not take place in a perfect political and socioeconomic environment. Various governmental and institutional instruments affect the competition and profit levels in the industry. Quality issues arise both at the plant machinery level and in the type of end-products produced. Numerous interest groups are involved in such large capital intensive ventures, and local, regional, and industrial politics often dictate which technological options are to be exploited in cement production. This chapter discusses some of the relatively important issues and instruments in the political-economy of cement plants.

6.1 Instruments affecting competition in the industry

The political instruments affecting competition in the cement industry are: (i) licensing and/or direct state ownership, (ii) market segmentation and import controls, and (iii) interest groups. Each of these issues are discussed below:

6.1.1 Licensing and/or direct state ownership

For various reasons, governments have played significant roles in cement production in developing countries and have at times controlled all cement distribution. State involvement in these areas has arisen as a logical extension of arguments for other types of intervention in the cement industry. Such reasons have included official concerns for price stability and uniformity, for assured availability of cement for priority purposes and, sometimes, for ensuring a competitive atmosphere and efficiency in the industry.

Additional factors have entered into government's decisions to involve itself in cement production. Unavailability of private capital is a key one, though this sometimes reflects upon government policy rather than upon the lack of potentially interested private sources of finance. Government pricing and other policies may provide market signals which discourage the mobilization of private capital where it could otherwise be made available. Alternatively, the government may want to promote a project in a certain way that is untenable for private parties. Larger project scale, the testing of untried technologies, the remoteness or difficulty of the terrain, the extensiveness of infrastructural requirements, and regional development objectives are some of the more common reasons for state involvement. Most African countries became independent in the sixties, and many investors had a wait-and-see attitude about new ventures. Also, most markets were small. Due to the shortage of private capital and entrepreneurship, many African governments found it necessary to set up or buy enterprises and provide them with capital.

As state ventures, however, the resulting cement projects tend to be subject to a number of costly restrictions on enterprise autonomy, such as complex official procurement procedures and other decision processes which tend to raise the costs and delay project executions, larger social objectives to raise employment levels and improve income distribution, wage level restrictions for skilled workers which can impair efficiency, and requirements to provide subsidized end products to priority consumers. Such restrictions, together with the other basic project differences of state ventures, can sometimes be reflected in higher capital costs, longer project implementation periods, lower operating efficiencies and higher employment levels.

6.1.2 Market segmentation and import controls

These are policy instruments occassionally employed in countries where cement production and distribution are in mixed private/public hands or where the state is substantially involved in the production and distribution of cement. The effects are analogous to producer-specific subsidies. Zoning or segmentation of cement markets has similar effects by reducing or eliminating competition among producers. In fact producer subsidies and market segmentation are commonly used together to give cement consumers relatively uniform prices throughout a country. At the same time, market segmentation also helps to serve regional development objectives in outlying areas.

In most developing countries, import protection has not figured as importantly as other forms of protection in the development of the cement industry. Duties on cement imports are typically no more than 10%, in view of the high natural protection factor. Moreover, in most developing countries, when the industry has had surplus capacity, cement and clinker have been either prohibited or simply not made by the agency, often state-owned or designated, that has such import rights.

6.1.3 Interest groups

The machinery in the cement plants (both small and large) is supplied by some dozen leading firms in the western world and some few firms in the developing countries. These firms have been developing technology in the context of meeting the needs of producers in developed economies mostly and some industrializing countries. Not only do they also supply a major portion of developing country needs but many machinery producers in the industrializing countries replicate these basic large-scale cement technologies, either by virtue of existing, or historic, technical collaboration agreements. Clearly, therefore they are locked into this family of large-scale technologies, and not only do they fail to give requisite attention to small scale cement plants, but most observers report that they also actively lobby against the subsidization and development of these alternatives. While there is no reason in principle why they should oppose the development of these alternatives, there appears to be an institutional momentum which explains their active commitment to developed-country-based-cement-processing technologies.

Local cement manufacturers and distributors have their own reasons for wanting to control the equity of new local cement projects, independent of the prospective returns from the new investment itself. Ownership often conveys entitlement to distribute the product in this, as well as other industries, resulting in higher profit margins. Not only are investment requirements less at the distribution stage, but government price controls also tend to be less damaging than at the factory door. In any case, existing cement manufacturers and distributors have a strong incentive to contain the entry of new, independent actors into the industry, who might generate potentially costly competition. Oligopolistic practises to stabilize prices and allocate market shares are common in the industry, and are preserved through interlocking ownerships, if not outright control, of new projects by existing companies.

Investors such as local financial institutions in developing countries tend to be attracted to equity offerings in cement companies. These projects are perceived to be relatively straightforward, offering opportunities for large single equity investments (in addition to loans) with relatively assured utility-type returns. The return on equity frequently is assured at government-guaranteed levels, usually with some prospect of even higher returns if projects perform exceptionally well.

6.2 Instruments affecting profitability and factor utilization

The instruments mostly used to affect profitability and factor utilization in the cement industry are: (i) price controls, (ii) freight equalization, and (iii) subsidies. These issues are discussed below:

6.2.1 Price controls and surveillance systems

Price distortions were prevalent in the cement industry throughout the 1970s because of the reluctance of many governments, following the first oil shock, to adjust domestic energy and cement prices upward to reflect what turned out to be long term real increases in their international prices. The unwillingness of the governments to allow cement prices to adjust to reflect higher energy costs made the task of predicting demand, and thus the sizing of plants, more difficult than usual. Restrictions on energy price increases, at the same time, made the choice of process difficult because market prices gave signals different from those based on economic values of the cost of energy.

One of the most plausible reasons for the use of price controls seems to be the periodic government concerns about inflation in a vital investment goods sector, and about possible monopolistic or oligopolistic abuses. The unprecedented escalation of cement production costs experienced in the 1970s undoubtedly helped to trigger these concerns as cement companies tried to pass on cost increases. On the other hand, economic realism appears to have led to at least temporary relaxation of cement price controls in Thailand and Argentina in the mid- to late-1970s in order to induce investment in the industry. In both countries investment had lagged behind domestic demand growth because of low profitability and lack of incentives. Price control has been more persistent in Guatemala and Colombia where investments to increase cement capacity have not been necessary in recent years. Cement consumption has stagnated in Guatemala, and in Colombia substantial export-oriented capacity that was established earlier has begun to be diverted to serve domestic markets. Nevertheless Colombia has remained one of the main world exporters of cement in recent years.

Governments seem to control cement prices in order to strike a balance between price stability and an assured supply of a commodity considered to be essential. The use of the price control device is, however, not without potential costs. Price controls act essentially as a ceiling on what can be charged for a commodity in times when the demand would be high. However, in times of slack demand, such a price regime does not enable the producer to sell all his output at the established price, leading either to low capacity utilization, or to lower price realization, or both. Thus, price control acts only as a one-way street to an enterprise; while it denies the enterprise excess earnings in a period of strong demand, it does not protect the company from low earnings in times of slack demand.

In Thailand and Colombia, there may have been a potentially significant longer-term loss of cement export receipts as a consequence of the severity of past domestic cement price controls. The same may have been true during most of the 1970s in Turkey, and will probably only now cease to be the case in India where the partial dismantling of controls which were announced in early 1982. Because of the relatively high impact of transport costs on the cement industry, exports normally offer cash contribution margins insufficient to support even the lowest-cost cement producers unless a share of their sales goes to more lucrative domestic markets. When this important natural price advantage is diminished by price controls, it obliges potential exporters to sell a larger share of their output in domestic markets than otherwise would be the case. In economic terms, most of the benefits of low cost production in such countries have been transferred from the producers to domestic consumers and/or to the government, thereby reducing the incentive to expand production. Unless counteracted by offsetting export subsidies, export receipts may have been lost.

In addition, price controls can result in disincentives to timely project implementation and operation. Conversely, more liberal pricing policies can result in greater efficiency where they provide incentives to producers. In Morocco and Egypt, cost plus pricing, together with other assurances of protection, may have been partly responsible for the tendency towards higher capital costs in cement projects. A different type of inefficiency resulted in Turkey where cement price ceilings in the 1970s severely reduced, and sometimes even eliminated, the profits available from existing operations. It also affected the incentives and the ability of the investors to complete their projects in the construction phase.

By way of contrast, in Argentina and Indonesia liberal cement pricing policies undoubtedly helped to accelerate expansion of the cement industry and to foster efficiency during times of scarcity. The more rapid start-up and higher capacity utilization of projects in Argentina and Indonesia were almost certainly induced by the lucrative market opportunities that resulted from the adoption of these policies. A similar rapid expansion of the cement industry in India could occur as a result of the recent price control liberalization efforts.

The effects of cement price controls can be significant, though sometimes less visible, on the side of cement consumption. Uneconomic consumption of cement can be encouraged where domestic cement prices are set at levels below the full economic cost of production. In situations of cement scarcity, artificial price suppression can place a burden on cement allocation mechanisms. Reports are particularly common in such circumstances of graft, corruption and black marketeering.

As one of the major consumers of cement in most countries, governments generally have a conflict of interest in dealing with the issue of cement prices. Some countries, such as Guatemala, Egypt, and India have attempted to minimize these problems by introducing two-tiered, or even multi-tiered, pricing systems in which cement prices paid by government are the lowest. Part of the rationale for direct entry by government into cement manufacture can also stem from desires to minimize any wider adverse effects of price controls, while simultaneously assuring availability of cement to meet government policies.

In heavily state controlled environments, like those in Morocco, Egypt and India (the price control systems for cement were modified in Morocco and India in early 1982), the extra complication of paying different prices to different producers has been introduced. This further increases the burden of administering price control systems in an equitable fashion which avoids undesirable consequences of the types already mentioned. It accentuates the risks that firms will lose some of the discipline and commercial incentive for efficiency which free-market forces can provide.

Partial and gradual decontrol of cement prices can be achieved by setting a controlled quota which is reduced over time, and by eliminating transport subsidies. A controlled quota can be set up as a percentage of installed capacity with all production in excess of the quota being sold on the free market. The controlled quota can be set nationally for all cement producers or regionally for plants according to their location. The former is preferable, however, for administrative simplicity. By defining the controlled quota in terms of installed capacity, the producer normally has an incentive to maximize output since he can sell anything in excess of the quota in the free market. The system also introduces the concept of marginal cost pricing since, even if the free market price were to fall below the controlled price, it could still be economical to increase output, provided the marginal cost were lower than the marginal revenue of the additional production.

6.2.2 Freight equalization

There are two major principles involved in the allocation of transport costs on a commodity such as cement. The first is that of equity, allowing all cement producers access at a similar price. The second principle is that in which the producer pays the transport costs which are incurred; clearly the farther away from the site of production, the higher the price to the producer. The Chinese have generally tended to use the latter principle which provides a form of natural protection to the small-scale cement plants in China. On the other hand, freight equalization used by countries such as India has undermined these protective barriers to small-scale plants.

Several countries have met their regional development objectives in outlying areas through the use of freight equalization subsidies. These provide producers and consumers with uniform cement prices throughout a country, regardless of location. Freight subsidies have the unfavorable side-effect of reducing producer sensitivity to freight costs in choosing plant locations; their use, hence, calls for extra government vigilance to avoid costly distortions in the structure of the industry.

The basic objective of the policy of freight equalization is to have a uniform destination price throughout the country. A pooled average freight charge is built into the free-on-rail (or -truck) destination price of cement. Actual freight charges incurred by any plant are simply notational in the sense that they only help to define the average freight charge to be imposed uniformly on all plants. Under this system, cement transport costs from a given plant to a certain location are subsidized (or taxed) to the extent that actual freight charges per ton exceed (or fall short of) the average freight charges per ton of cement transported from all plants. This policy encourages an inefficient allocation of resources for the following reasons:

(1) Transportation costs incurred are not counted as real costs to the economy and this leads to an overexpansion of the transport system. As a result the demand for transport services is higher than if transport costs were fully payable.

(2) A possibly more important point is that the transportation costs that would be saved as a result of better location of production units are not counted as benefits arising from a given investment. Consequently, investments that may lead to lower economic costs of supplying a given area may not take place because of inadequate consideration of those

benefits.

(3) Existing units located near markets face relatively disadvantageous prices for their output and may decide not to expand, even if on economic grounds their expansion would be desirable and profitable if the savings of transportation costs were to be properly counted. On the other hand, some producers located far away from consumption areas which currently appear viable might cease to do so once shortages are eliminated and if there is proper accounting of transport costs.

(4) Prospective producers of cement near consumption areas are not much encouraged by the present system to invest in exploration of limestone deposits. They would be more encouraged to do so if prices were to reflect actual economic conditions. In effect the policy of freight equalization tends to increase the economic rents imputable to limestone deposits that are far away from consumption areas, to the detriment of those located nearby.

(5) In areas where the economic cost of supplying cement is much higher than the financial cost, consumers are not being adequately encouraged to economize on the use of cement and to substitute for it other less expensive building materials whenever possible.

6.2.3 Other subsidies

Producer subsidies and penalties are one of the principal means by which different selling price treatment is accorded different producers. Typically, obligatory cement fund contributions by established, low-cost cement producers are used to subsidize the newer ones during their early operating years. Besides adding in a general way to the complexity of administering the industry, this practice demands, in particular, closer government scrutiny of private investment decisions in the industry. Subsidies also weaken the decision that would be taken if market forces are allowed to govern. For example, new, as opposed to expansion projects, may tend to be more readily promoted; a pattern which is evident in countries like Morocco and Egypt.

Subsidized energy prices in the developing world throughout the 1970s often shielded cement projects and other industrial ventures from pressures to adopt more energy-efficient technologies. Moreover, the development of coal supplies was delayed by the continued subsidization of fuel oil in many countries.

6.3 Quality issues

Despite the continued existence of apparently profitable small-scale vertical shaft kiln plants in the Western world and the dramatic rise in production by this approach in China, there are doubts expressed by many technical experts in the cement industry as to the quality of product from these plants. The efficiency of the shaft kiln has been considerably improved over the last 25 years, and cement from these plants has been shown to meet the same specifications as normal Portland cement from rotary kiln plants. The improvements in technique over the past 25 years have resulted in homogenization by means of preblending, uniform kiln feed without excessive moisture using the pan type nodulizers, efficient kiln ventilation using Rootes blowers, good fuel economy by exact proportioning of fuel and raw mix combined with efficient insulation of the kiln, minimum air leakages using efficiently sealed discharge gates, continuous operation because of the kiln design and the discharge grate, and generally robust equipment with dust free enclosures for motors, gears, and bearings.

In a vertical shaft kiln, solids entering the top of the kiln are heated by hot combustion gases until they reach combustion temperature in the fire zone. Below the fire zone, solids are cooled by incoming combustion air. In this way substantial heat is recovered from both solids and gases before they leave the kiln. The problem of uneven heating and movement through the kiln that plagued the early vertical shaft kilns have been largely overcome in modern vertical shaft kilns by the use of the pelletized feed, incorporating the correct amount of fuel into the pellets of raw meal. With a pelletized feed of uniform particles size, there is uniform resistance to gas flow across the bed and chanelling is unlikely to occur. Accumulations of solid fuel and thus "hot spots" cannot happen as each pellet contains its own correctly proportioned amount of fuel. With modern refractories, problems of reaction with the walls and "hang up" are eliminated. In vertical shaft kilns using discrete particles of fuel, it is said to be necessary to use a fuel of low reactivity to minimize the loss of fuel values caused by the reaction of carbon dioxide and carbon to produce carbon monoxide. This reaction causes instability in the kiln operation but with the fuel incorporated into the pellets, the importance of this effect is reduced.

In view of the above points, there seems to be no reason to suppose that a properly designed and and operated vertical kiln is not capable of producing cement of similar quality to that produced by the rotary kiln. Of course small vertical kiln cannot be expected to produce quality clinker without adequate control and skilled personnel, but for many applications this is not required. The Chinese commune plants, for example, produce for a need rather than a specification and while the quality of cement produced by some of their smaller plants may not be high, this should not be used as a major criterion in assessing the capabilities of the vertical shaft kilns.

Cement quality is frequently regarded as fixed, however, there could be real economic advantages in using, where possible and safe, cements of lower strength than the standard Portland cement. The potential savings are attractive. Although no definitive figures are available, it is estimated that only 20 percent of world-wide consumption of cement requires the full strength of international cement standards. Approximately another 40 percent is used for structural purposes where a somewhat lower strength would be tolerated if it was well controlled. The remaining 40 percent has uses such as mortars, plasters, foundation concretes, concrete blocks, soil stabilization for which low grade cements would be acceptable.

The use of low-cost additives in the mix, which do not adversely alter the product quality, can also substantially boost the international competitiveness and profitability of projects since they reduce the amount of much higher cost clinker needed to produce any given volume of cement. By their use it is also possible to lower the scale of kiln required. In some instances, where market size and the quality of raw materials justify it, a producer can also vary the product mix so as to include higher value specialty cements. Unfortunately some of the commercial advantage is lost in most cases from the downgrading of the products' market prices as a reflection of either consumer reactions to lower quality perceptions (whether or not the cement is equally suitable for the purpose) or of pressures from domestic competitors and price control systems. Changing product standards takes time and can be difficult. Moreover, where product quality is diminished or product specifications are otherwise significantly altered, such changes can involve risks to final consumers unless building practises alter in tandem with changing cement characteristics. When product quality is lowered, a particular concern is to avoid excessive use by builders of additives in mortar and concrete, which might result in faulty construction.

6.4 Market failures

The explanations of market failures in the cement technology selection process lie in the area of: (i) erroneous economic policies, (ii) institutional factors of an economic/financial and engineering nature, and (iii) incomplete development of alternative technologies such as small-scale cement plants.

(a) Erroneous economic policy

Freight equalization and distorted market pricing are the primary contributors to erroneous economic policies. These issues are discussed below.

(i) Freight equalization

The freight cost equalization system provides a complicated pattern of cross subsidization among producers and consumers in different regions of a country. It is possible to identify some gainers from such a system, but a substantial amount of transporation resources are lost in the process which do not seem to justify the gains received. Nor does it seem possible to justify freight cost equalization as an instrument for changing the pattern of regional development by helping those areas which would otherwise face adverse transport costs, since there are more direct and effective instruments for achieving this than freight equalization, such as direct investment or transfers to producers in a given region of the country. Moreover, far from benefitting a given region, freight equalization may inhibit further investment in cement plants there because of the implicit transport subsidies granted to distant producers. In this sense, the policy of freight equalization may discriminate against small cement plants which could be efficient suppliers of cement in certain remote regions were it not for the larger firms with lower operating costs reaching those markets without bearing transportation costs.

In order to reduce expensive transportation flows among different regions of a country, a gradual reduction of the scope of freight equalization can contribute to modify the pattern of regional production and investment. To effect this, instead of full refund of transportation cost, a portion of transport costs can be subject to pooling, and this portion can be decreased over time. The gradual reduction of freight pooling can be a step in guiding the locations of new investment in the cement production industry in developing countries.

(ii) Distorted market prices

Market prices in developing countries tend to undervalue foreign exchange, capital, and energy, and overvalue labor. Since these market prices provide both the signals which induce technical change and influence the pace of diffusion of technologies, it is probable that the true social opportunity costs are misrepresented to decision makers. Control of input prices (overpricing of labor and underpricing of energy, capital and foreign exchange) has typically favored the large scale plant. These distortions induce a gap between social and private rates of return for small scale cement technology that is larger than for other technologies. Shadow prices may make it appear that small scale cement technology is more desirable than other larger plant technologies. Moreover, often output prices accepted by public sector companies which operate the large-scale plants prevent small investors from entering the market and drive the existing small producers out.

(b) Institutional factors

The institutional framework (licensing, project proposal preparation, project financing estimates) typically favors a few large foreign financed projects, over a large number of smaller projects involving essentially local financing. Lenders have difficulties in properly evaluating many small projects. Often, imported components for the large projects are excluded from duties, and companies engaging in a large scale priority project are exempted from various taxes, whereas smaller plants will not be exempted. Typically the large scale project, with a high proportion of foreign deliveries, enjoys bilateral assistance in the form of low cost credits, exemption of duties and institutional support. Also, there is typically a small number of equipment suppliers and engineering firms who dominate the choice of technology in small plants. Moreover required technical assistance is expensive for the smaller plant due to diseconomies of scale, and central training facilities catering to small plants do not exist.

Building codes and material standards may have been adopted or taken over by the emerging developing countries from those developed by the industrialized countries. Often, these codes specify high quality Portland cement standards for purposes where a lower quality product would equally satisfy the given performance requirement. More appropriate codes based on firm performance standards rather than material standards, might open the door for lower quality cement as well as inexpensive substitutes of cement in many sectors like housing, irrigation works, dams, transport networks and soil stabilization)

(c) Technological limitations

Product quality of small plants, particularly when run inefficiently is often erratic entailing a higher risk for the user of the cement from small plants. Also, some of the technologies for small scale production may have technical problems, or hidden costs, which can prevent them from working successfully on a commercial basis. Further development may be needed to fully commercialize these technologies.

6.5 Policy options

Developing countries can be classified into three groups according to the degree of intervention undertaken in the cement industry by the authorities. They have basically four types of options in satisfying their cement needs. Group I countries are those in which the cement industry is predominantly or completely private; in which market zones are not artificially segmented by the authorities; in which price controls are partially or periodically relaxed to encourage new investment; and in which government subsidies (penalties) are minor or non-existent. Thailand, Argentina, Guatemala and Colombia would be examples which fit this general description. Group II countries are those in which cement production and distribution are in mixed private/public hands; in which market segmentation is not enforced; and in which price controls and/or subsidies (penalties) are sometimes significant. Indonesia, the Dominican Republic and Turkey would be examples which fit this category. Group III countries are those in which the state is substantially involved in production and/or distribution; in which the state often enforces market segmentation if it does not control distribution totally; and in which price controls and/or subsidies (penalties) are always important. Morocco, India, and Egypt would be examples which fit this description. Egypt is really in a class of its own to the extent that its new private joint venture cement projects have the option of freeing themselves from state invlovement; attendant loss of energy price subsidies and greater market risks have tended to discourage this, despite the associated feedom of marketing and much higher selling prices.

The options available to all of these group of countries in supplying cement to their local markets are:

1) to import the cement, bagged ready for use;

2) to import bulk cement and bag it locally;

3) to import clinker (always in bulk) and grind it locally with additives to provide cement of the preferred types; and

4) to produce clinker as well as the cement locally.

The first two alternatives relate to the economics of shipping cement rather than to producing it. Substantial savings are possible through local bagging activity for countries importing large quantities of cement. Even if these imports are not expected to be permanent, hence making investments in land-based silos and bagging stations are unjustified, it may still be feasible and attractive to lease floating bagging plants of the type employed by Mediterranean exporters such as Greece. As an example, Egypt in 1979-80 was able to save on the order of $10/ton on imported cement by leasing floating silos/bagging plants from its cement supplier in Greece, making its landed cement prices (bagged, on the truck at the port) about $55-60/ton. Savings included the avoidance of higher shipping costs on bagged versus bulk cement, of port demurrage, of 3-4% unloading losses, and of the use of stronger, more expensive 6-ply bags (3-ply were used instead). The fact that, at around the same time, smaller cement importers in the neighboring East African region were paying landed prices up to double those of Egypt, indicates how substantial the scope can be for realizing shipping economies as order sizes increase and local bagging becomes feasible.

When a cement market is still small but within easy access for foreign exporters by international shipping, clinker grinding may become an economically attractive option. Whether it does so is primarily a function of the availability of clinker imports on a reliable, long-term basis, at internationally competitive prices. Clinker is easier to handle, ship and store than cement (especially bagged cement), and hence there can be shipping cost savings to increase the already substantial margin between the FOB export prices of clinker and cement; for example, a $15-20 difference per ton between the two for Mediterranean suppliers in 1981. Such a $15-20 per ton FOB difference (as compared to bagged cement) can be more than doubled on a landed CIF basis. This then provides ample conversion margins for supporting even small scale clinker-grinding plants (12-15 metric tons per hour or 95-120,000 tons per year), operating at low capacity utilization levels. This margin will of course be much narrower where cement import in bulk is a feasible option. But the larger market size necessary to make bulk shipment attractive should also offer greater economies of scale in the clinker grinding plant, particularly on the capital cost side. The size of the available conversion margin between the delivered prices of cement and clinker can be further raised by the use of low-cost additives where market conditions permit and suitable materials such as pozzolanic materials, e.g., slag, are available locally.

Where cement markets are large enough, or sufficiently remote, and if suitable raw materials are within easy reach, and energy is not inordinately expensive, clinker manufacture itself becomes economically attractive. As regards capital cost, the inclusion in a project of a strong local sponsor/owner, experienced in the cement industry, appears an almost indispensable advantage in containing project capital costs. Where local sponsors are less experienced, costs can be contained by the selective use of foreign technical expertise. Where reliance of foreign expertise has to be substantial, capital costs are likely to be correspondingly higher, but project implementation periods may even be improved. Where local sponsors have no cement industry expertise, substantial equity involvement of a strong foreign sponsor/technical partner appears preferable to relying only on technical assistance agreements with foreign sources of know-how. Turnkey contracts do not always help to contain costs, particularly in cases where project specifications are changed subsequently. Finally, substantial sponsorship by local public sector cement companies bring in risks, in particular, of higher capital costs.

For a number of reasons, investment decisions in the cement industry tend to be closely intertwined with broader issues of development strategy. First, decisions on where to locate cement projects are complicated by the fact that deposits of the principal raw material ingredient, limestone, are numerous and widespread. Moreover, the economics of cement production and distribution tend to favor local supply due to the low value to weight ratio; both cement and limestone are relatively expensive to transport. Local production, therefore, benefits from high natural protection. Thus, cement, produced in sub-optimal sized plants, can be competitive in specific locations even though there are significant economies of large scale in its production and distribution. For the same reasons, cement exports tend not to be an atractive proposition, unless supported by substantial production cost or freight advantages. As a result of these factors, local pressures commonly develop for market fragmentation and for investments in small scale cement projects wherever the latter can be supported by the growth of local demand. Prospective institutional investors in the cement industry, therefore, bear a special development responsibility; they should seek to develop a range of economically acceptable investment options that have different risk profiles, and not necessarily accept the first project concept that is put forward. In particular, special consideration must be given to the trade-off between potential capital costs savings resulting from the economies of scale possible with large projects, as against the higher risk of capacity underutilization.

Cement manufacturers associations can be a helpful tool for the cement industries in developing countries, especially those in Africa. Typically these countries are small and have only one or two cement plants. As the case of West Africa with a prevailing lack of limestone deposits, many countries operate grinding plants using only imported clinker. Apart from Nigeria, typically markets are small and dispersed and do not permit plants with economies of scale, unless countries pool their markets and establish a regional plant. In some countries even that is not feasible, given their low population density. Thus the management of individual plants has difficulty in keeping itself informed about technological developments, international industry trends, and market trends in neighboring countries. Since prices are normally set by the government for the domestic market without regard for pricing systems in neighboring countries, cement smuggling occurs frequently. This adds to the price the final consumer has to pay.

A manufacturers association can help to spell out these problems among the parties concerned and could work out proposals for improving pricing systems, provide necessary background information for markets, can help to inform members about technological developments, and can provide guidance for developing norms and standards appropriate for member countries.

7.0 CASE STUDIES

Three case studies of developing countries in various stages of development are taken to understand some of the issues in their cement industries. The case study on India focuses on the recent developments in the small-scale plants in India. The Mali case study highlights the difficulty of providing cement in a land-locked African country whereas the Nepal study looks at energy issues in an energy-scarce land-locked country.

7.1 India

(a) Introduction

Cement manufacturing is a well established industry in India, accounting for about 1.2% of industrial production and employing over 85,000 persons. India set up its first cement plant in 1914 but it was during the mid-thirties and during the second world war that the industry expanded rapidly under a policy of protection given to incipient Indian industries. Between 1914 and 1950, installed capacity increased from 30,000 tons to about 3.3 million tons with an actual production in 1950-51 of 2.95 million tons. The annual rate of growth of the installed capacity averaged about 8.9% during 1950-51 to 1971-72, and declined to about 2.1% during 1971-72 and 1978-79. At the end of 1978-79 the annual capacity was 22.6 million tons. About 65% of the total capacity was based upon the wet process, and capacity utilization ranged from 40% to 100%; the average for the whole industry was 86%. Table 7.1 shows the increase in factories and cement production in India on a decennial basis upto 1964 and five-yearly basis since then. The development of the cement industry from 1970 can be divided into three periods: upto 1974-75, 1974-75 to 1978-79, and since 1979. Between 1969-70 and 1974-75 installed capacity increased from nearly 16 million tons per year to over 20 million tons per year at an annual rate of 4.6%. Production was virtually stagnant during this period at around 15 million tons per year. Capacity utilization, below 80% on average, was well below the levels prevalent in the 1960s. During the second period, growth in installed capacity remained extremely sluggish increasing at just 3.0 percent per annum through a recovery of capacity utilization rates to around 85% resulted in a faster production growth rate of 7.0%. In 1978-79, 22.55 million million tons per year of installed capacity produced 19.42 million tons of cement.

Beginning in 1979-80, there was an acceleration in the increase in installed capacity, the average growth rate upto 1984-85 being 11.9%. After a decline during the economically disastrous year of 1979-80, production too increased at a rapid pace (8.6% per annum) reaching an estimated level of 29 million tons in 1984-85. Capacity utilization however, had declined again to lower levels (around 70%) than at any time since the 1930s as installed capacity accelerated to 44 million tons. By 1989-90 production is expected to reach 48.7 million tons at a growth rate of 11% per annum.

India has experienced severe shortages in cement during the past 25 years. A continuous and growing shortage has eveloped since 1977, estimated to have been at least 15% of current cement availability in 1979. There are black markets in which prices are at least 25% higher than official prices and much higher in urban areas like Bombay and Delhi. Cement is rationed under a three-tiered system. Public sector users have first priority; users earmarked by Government have second priority; and the remainder is allocated to the states for sale in the open market at controlled prices. The handling of residual open market supplies varies from state to state with some states controlling or directly undertaking distribution even in this part of the market. The cement shortage is felt most heavily by private users, but also by high priority users. The present shortage is caused by strong demand growth, very slow growth in installed capacity for the last several years and inadequate utilization of existing capacity. The main reasons for the recent deterioration in the rate of capacity utilization are coal and power shortages.

(b) The case for small-scale cement plants

The case for developing and establishing small-scale cement plants in India has arisen from the problems emanating from both social and economic considerations. The concept of small-scale cement plants was visualized keeping in view several parameters of the country's needs; on the one hand to exploit the smaller deposits of limestone scattered all over the country, and on the other hand to contribute to uplift the local economy and development. This is especially important in the case of the relatively backward areas of the country. It is also a means of securing a wider ownership of the industry, bringing the investment within the reach of small and medium entrepreneurs, reducing the burden of freight by reducing the load in transportation of cement on the country's rail system, and also creating additional employment opportunities in rural areas.

In India, the small-scale cement industry has been extablished due to the pioneering effort of the Cement Research Institute of India (CRI), a national institution primarily set up with the objective of providing industrial and technological support to the Indian Cement Industry. CRI has developed a workable and viable technology for small-scale cement plants under Indian conditions of operation. This technology is based upon the vertical shaft kiln. Other designs for small-scale cement plants have also been marketed in India by technologists and entrepreneurs.

(c) Economic Analysis of small-scale cement production in India

A comparison of the investment and production economies of the available designs for small-scale cement production in India will serve two purposes: firstly, to enable an assessment of the economic efficiency of these techniques relative to one another and, secondly, to enable an analysis of the extent to which rationale for the reduced scale is justified in the Indian cement sector. This section examines the relative costs within the small-scale cement sector in India and also makes economic comparisons with the large-scale cement sector. Information in this section has been extracted from a preliminary report on the small-scale cement sector in India (Reference 10). Detailed information on an operating unit based on the RRL-Jorhat design was not available and the comparison is limited to the CRI, the Saboo and the ATDA designs.

(i) Investment costs: Table 7.2 summarizes the investment costs in the three VSK-based small-scale cement plants. Statistics for the Saboo design are based on quotes from Shree Engineers' (the designers and the manufacturers). For the CRI design, statistics for four scales of plants (30, 50, 100 and 200 tons per day) have been provided based upon estimates by CRI (the licensor) and Movers Ltd. (one of the major licensees and plant suppliers).

The figures in Table 7.2 suggest fairly substantial economies of scale in the various sizes of plants supplied by Movers/CRI. For the smaller-scale ATDA and Saboo technologies, investment costs per ton, at 919 and 792 respectively, are lower than those for the 30 tpd Movers/CRI plant. This is a reflection of the different levels of sophistication of each design. The Saboo design is the least sophisticated technologically, involving much less automation and instrumentation, therefore much greater risks in operation. The The Movers/CRI design, on the other hand incorporates fairly sophiticated techniques in instrumentation and control which reduce the risk of human error. The ATDA design lies in between the Saboo and the Movers/CRI design in terms of technological sophistication and, hence, the investment costs are also in between the other two.

(ii) Production costs: Available data on the production costs from various plants employing the respective designs is shown in Table 7.3. Statistics from Lokapur Cements in Karnataka State are used for the Movers/CRI design and those from Arif Cements in Jagdishpur (U.P. state) are used for the Saboo design. The ATDA statistics is based upon the experience at the plant outside Lucknow (U.P. state). While production costs for ATDA and the Movers/CRI plants are similar, those for the Saboo plant are somewhat higher. Detailed breakdown of the production costs are given in Tables 7.4, 7.5 and 7.6. Analysis of these tables yields the following features:

-The coal costs at the ATDA plant is higher because it uses steam coal for the rotary drier.

-Raw material costs are high for the Saboo plant because the limestone cost is very high (Rs 140/ton) and it is incurred because of the location of the plant at a distance of 250 kilometers from its raw material source. Labor costs are higher on a per ton basis because of the low production level of the plant relative to the other plants considered.

-ATDA's high power requirements are due to the extra drying requirements for the raw material whereas power consumption is low in the Saboo plant due to the more efficient grinding mills employed.

(iii) Sales realization: Local factors affect prices and the premium realized by different plants and a comparison of their profitability is difficult. Effective price controls, varying market prices and tax levels in different regions of the country lead to different sales realization statistics. These small plants are able to differentiate their products so as to obtain a price higher than that prevailing in the open market (controlled by the state).

(iv) Transport costs: Transportation costs for the small-scale plants is given in Table 7.7. The main component of transport costs incurred by the small-scale plants is that of fuel, however due to the poor siting, the Saboo plant incurs a high cost for transporting limestone.

(d) Comparison of small- and large-scale cement plants in India

Table 7.8 shows the cost data for the three VSK small-scale cement plants (ATDA, CRI-VSK, and Saboo), a small-scale rotary kiln cement plant in Western U.P. state and with figures available for a selection of large-scale cement plants (the figure used here are averages for 15 companies in the private sector). While raw material costs are substantially higher for the large-scale plants, power and fuel costs are considerably lower. It is likely that the high cost of the raw materials in the large plants is the result of relatively labor-intensive quarrying on a large scale in the organized-labor sector. Some of the older (large) plants are also reported to be transporting limestone over long distances or having to treat the poor quality of limestone still available in their immediate vicinity. Variations in the geological structure of the quarry also affects the mining techniques employed. Small-scale plants are less likely to face these problems since smaller deposits of limestone are likely to be more homogeneous.

Fuel costs are lower for large plants because of bulk purchase and transport. Low labor costs are generally the case in small plants because of the exemption from many of the labor laws governing employment in the large sector. Interest and depreciation charges are much lower for the large sector since this represents the ongoing costs incurred (interest on outstanding loans and depreciation on historic costs of fixed assets) whereas for the small-scale sector, the costs of new plants have been assumed.

Transport costs for the small-scale plants are given in Table 7.7. As a comparison the costs for large-scale plants is given in Table 7.9. Total transport costs incurred by large plants (over 16% of the selling price) are substantially higher than the 9-10% incurred by the well sited small plants. The transport savings from small-scale cement plants can be significant if the plant is properly sited.

Productivity ratios related to the small-scale plants and the large-scale plants is presented in Table 7.10. There are substantial differences between capital-output ratios in the two sectors. Within the small-scale sector, Movers/CRI has the best ratio (as a result of scale economies). The relatively low employment levels at the Movers/CRI plant result in high capital-labor and output-labor ratios.

(e) Economic valuation of small-scale cement production in India

It is necessary to compensate for distortions in the supply markets (subject to varying degrees of regulations) to obtain an economic value for the cement produced by the various techniques. The information in Table 7.8 is reworked in Table 7.11 using shadow prices for coal, power, labor and transport of cement. The conversion factors in Table 7.11 constitute an assessment of the extent of under- (or over-) pricing of these production factors within India. An annual cost has been imputed to capital in Table 7.11 by employing a capital recovery factor. The productive life assumed for the Saboo plant is seven years whereas other small-scale plants are expected to last fifteen years.

From the figures in Table 7.11, it seems that the Movers/CRI plant constitutes the most economic unit. The economic cost of cement from the Movers/CRI plant is 13% less than the ATDA plant and 30% less than the large-scale plants. Though there is some indication of scale economies in the small-scale plants, such comparison is difficult due to the varying levels of technical sophistication in each design.

Finally to set these economic costs and prices in context, the international prices of cement become relevant. Compared to ex-factory prices of Rs. 800-1000 per ton in India, the ex-factory price in West Germany is $30 or Rs. 350 per ton. Export prices from some European countries (Spain, Greece, Yugoslavia, etc.) are reported to be even lower at $20-22 or Rs. 235-260 per ton. Indian cement's resource cost is 3-4 times the international levels thus precluding the possibility of exports.

7.2 Mali

(a) Introduction

Mali is a landlocked Sahelian country in West Africa. It is semi-arid and among the poorest of countries in Africa and worldwide. Over 80% of its population is rural, and agriculture is the principal economic activity and main source of export earnings. Between 1970 and 1980 the population growth was 2.6%, the GNP growth was 4.5% and GNP/capita growth 2.2%. This impoverishment results from the predominance of subsistence agriculture under difficult climatic conditions (severe droughts) and in an environment with few natural resources, little infrastructure and high population growth.

Large concessional aid during the 1970s helped Mali to reorient its economy toward greater industrialization which was designed to reduce their dependency on agriculture and the weather. Since local production of modern building materials was insufficient, a large amount of foreign currency was spent to import and supply the market with these necessary commodities. The price of imported cement almost doubled the CIF (cost, insurance and freight) cost because the transport network is very poor and unreliable. As a result of the growing demand and the very high cost of imports (due to the long distance from foreign suppliers and necessary multiple handling of this low value to high volume commodity), Mali planned a cement plant which was not competitive with imports even at full capacity utilization.

Industrial development is constrained in Mali because of its land-locked situation. The nearest ocean port is 1000 kilometers in a neighboring country, Senegal. There is a railway system on the western side of the country on which Mali has to rely almost exclusively. Domestic energy sources are almost non-existent. Small and geographically scattered domestic markets contrain the development of potential industries that require investments in minimum capacity levels to exploit economies of scale in their production technologies. The lack of domestic financing and adequately trained manpower also constrains growth. Construction share of the Gross Domestic Investment (GDI) is 40% compared with 60% in intensively industrializing countries.

(b) Raw materials

West Africa is one of the few regions of the world where limestone is a scarce material. In fact, it is almost non existent. Most deposits are located in areas remote from urban consumption centers and are of relatively poor quality making them very costly to exploit for the cement industry. In Mali the Astro deposit, located 450 kilometers from the capital, Bamako, is still under investigation. The deposit is heterogeneous. Dolomitic limestone, marls and pure limestone predominate. The deposit is geologically difficult to exploit and its make up will have to be carefully studied for its possible use in cement plants.

Gypsum exploitation in Mali is dubious. The only known deposit is in the northeastern part of the country (1200 kilometers from Bamako). Mali has no domestic energy resources for commercial exploitation and, therefore, the siting of an energy intensive industry like cement production is difficult.

(c) Cement consumption, imports and distribution

The historical development of cement consumption (apparent) in Mali is shown in Table 7.12. Domestic cement production supplemention by imports began in 1970 in Mali. Selected cement consumption indicators for

Mali are given in Table 7.13. Despite the increase in cement consumption, Mali remains one of the lowest cement consumers in the world, in line with neighboring landlocked countries, but far below neighboring countries on the coast or with similar GNP per capita as shown in Table 7.14.

Given the predominance of rural population (80%) and their low level of income, consumption will vary with public investments. In Mali cement production is located in Diamou (450 kilometers west of Bamako) on the railroad line. The state owned plant (built by the U.S.S.R., employing the energy intensive wet process) has a capacity of 60,000 tons per year, but it has never operated above 90% capacity. Cement from this plant is not cost competitive with the price of imported cement. Imported cement is transported by rail from Dakar, Senegal, and by road from Abidjan, Ivory Coast. Frequent delays in the Dakar-Bamako line result in shifting imports of cement from Dakar to Abidjan, even though transport costs by road are $11-20/ton higher. Retail prices of cement are almost twice as high as the CIF prices at the nearest port. In 1981, for an average of $80/ton CIF price at an importing Atlantic port (Dakar, Abidjan, Lome), prices were $180 in Mali; this compares with $65 in India. Composition of retail prices for Mali in 1981 are shown in Table 7.15.

In Mali, the national cement company, Somiex, had the monopoly for cement imports and distribution, and for local production until 1978. Since, then imports have been liberalized. Somiex takes a margin of 10% on top of the delivered price in Bamako, and although theoretically, cement is priced uniformly throughout Mali, the distribution is concentrated (90%) around Bamako. The cement price is based on the imported cement costs, and because of this and the high energy costs in the local plant, local production is not competitive with the imports.

Data or any estimates from Mali must be considered cautiously because statistical information is almost nonexistent for most building materials. Also the tightness of the market supply creates an illegal trade among the Sahelian countries of Mali, Niger, and Upper Volta. A World Bank report estimates this illegal trade at 500,000 tons per year.

Market projections for demand are usually overly optimistic due to the reference country cement demand situations used in such forecasts, e.g., several forecasts are based on years in which there are large projects ongoing, without excluding the unique demand of some of these projects. Forecasting cement demand for the next decade in Mali is problematic because social and economic structures are changing and it is difficult to get a correlation of past cement consumption to GDP or to GDI. The World bank, however, projects a cement demand of 145,000 tons in 1990 based upon the past trend of consumption (15 years) and prospects of economic growth rates

(d) Future cement supply alternatives

From the demand point of view, it seems unlikely that Mali will have a market large enough to warrant building a new large-scale rotary-kiln cement plant. In Europe, the usual economical size for a rotary kiln plant is one with a production capacity of over 500,000 tons per year. The market for the region, i.e., Mali, Upper Volta and Niger is about 700,000 tons per year in 1990. This demand might lead decision makers to consider a regional plant located in one of these countries. This, however, would require: (1) existence of a strategically located, suitable and sufficiently large raw material deposit which to date has not been found; (2) existence of a good transport network among the countries to permit economical distribution of cement which is not foreseen in the next decade; and (3) agreement for a common regional project which will not be easy considering the economic and political impact of such a project. Due to the countries' location, export markets are virtually non-existent. Thus it seems that Mali should not consider any new project for domestic clinker production. The other solutions that remain are: (1) import bagged cement; (2) import bulk cement and bag it in the main distribution center of Bamako; (3) import clinker and grind it in the main distribution center; and (4) rehabilitate existing plants. The World Bank conduted a review of all these alternatives and the resulting rate of returns of the alternatives are shown in Table 7.16.

The clinker grinding station and the distribution of imported bagged cement appear to be the best alternatives for cement supply in Mali. Both alternatives are very sensitive to the domestic prices of cement: the grinding favors low prices whereas high prices dramatically improve the profitability of the distribution alternative. The clinker grinding alternative should be considered as the best one because: (1) compared to the distribution of cement, this alternative has higher value-added which will increse the use of local additives and employ labor; (2) it is a good opportunity for Mali to diversify its economy toward industry; (3) it is also a much more secure alternative because long-term contracts for clinker are usual, whereas bagged cement is typically traded in smaller lots on a spot-market basis.

The alternatives of rehabilitating and/or converting the existing plant in Mali may be promoted: (1) to avoid the shutdown of the plant and therefore employment cutback; (2) to maintain an existing distribution center and locally developed demand; and (3) to secure a partial local cement supply for strategic reasons and not rely on imports exclusively which, at times of international construction booms, can become scarce.

Therefore, as far as cement supply is concerned in Mali, the best strategy appears to be rehabilitation and/or conversion to a dry process plant or to expansion, together with the implementation of the clinker grinding alternative with the clinker grinding plant located in the main distribution center of Bamako.

7.3 Nepal

(a) Introduction

Use of Portland cement as a building material in Nepal is very recent and its manufacture is still in the infant stage. Modern buildings and large construction works mainly use Portland cement. Due to higher cost of cement and the fact that it is not easily availabile, house construction for majority of the population is still dependent on traditional binding materials. Consumption of cement from 1962 to 1977 is given in Table 7.17. Until very recently, Himal Cement Company Pvt. Ltd. was the only existing plant with a rated capacity of 160 tons per day vertical shaft kiln, employing the black meal process. Nepal's indigenous production by the single plant could hardly meet 15% to 20% of the total demand. Hence around 80% to 85% of the demand had to be met through imports from India, as well as other countries. The nearest plant in India is 500 kilometers from the border. As India has a shortage of cement, particularly in Northern India, imports from India could not alone meet the demand. Imports from other countries take at least three months. Nepal had to rely on imports until two projects, i.e., Hetauda Cement Ltd. (750 TPD) and Udaipur Cement Project (3000 TPD) commenced production. Himal

Cement is also planning the expansion in two phase of its 160 tpd plant to a 400 tpd plant. The planning calls for Himal Cement to cater to part of the demand in Kathmandu Valley, Hetaudu Cement to supply the Terai region, where it is located, and to supply the other parts of the country as well. Udaipur Cement would be export-oriented, catering primarily to India and Bangladesh. Forecasts on cement production are indicated in Table 7.18.

(b) Raw materials and equipment

Abundant sources of limestone are reported along the Mahabharat range from the eastern to the western part of the country. There are several limestone deposits still to be explored. Argillaceous materials such as clay, shale, and soil, are located all over the country and suitable deposits can always be found near the limestone deposits. Gypsum, pozzolana and volcanic materials for manufacture of blended cements are not available in Nepal. Additives like slag and fly ash, if required, would have to be imported from India.

Fuel of any kind has to be imported from India or via India. The presently used coke breeze at Himal Cement is imported from either Durgapur or Burnpur (both in India) which are 700-800 kilometers from the plant. Energy efficiency is thus an important consideration in the cement plants in Nepal.

Details on the vertical shaft kiln employed in the Himal Cement plant are shown in Table 7.19. In the Himal plant the fuel consumption is in the range of 930-960 kcal/kg clinker for clinkerization and about 80-150 kcal/kg for raw material drying. The power consumption is around 102-105 kwh per ton of cement.

(c) Energy efficiency problems

Energy efficiency problems facing the Himal cement plant are:

a) Inadequate supply of power, especially during the winter season. The plant is operated with very frequent intermissions of power supply. At other times it is operated beyond the voltage and frequency limitations of the driving motors in the plant.

b) Inadequate research and development efforts on fuel economy and power efficiency.

c) Poor maintenance due to shortage of spare parts, import of which requires nine to twelve months.

§d) Inadequate supply of coke breeze which hinders the plants output.

e) Operation under the public sector control, with complex rules and regulations, and absence of incentives for innovations and developments.

(d) How to improve energy efficiency?

In developing countries like Nepal, small-scale cement plants are attractive in terms of smaller investment costs, faster erection time, their use of low grade fuels and ample labor supplies at numerous locations. In Nepal, as in some other landlocked fuel-scarce countries, there is an acute undersupply of fuels to run these plants. The use of low grade fuel in vertical shaft kilns is an advantage for a country like Nepal which does not have to expend valuable foreign exchange on importing oil for firing its cement plants.

Manufacture of blended cements using slag, pozzolanas, and fly ash could contribute to energy consumption. So too can the manufacture of substitute binding materials like rice-husk cement.

Lignite is found around the periphery of the Kathmandu Valley and can be used by blending it with imported coal. Blending of the lignite with imported coke could reduce imports of high grade fuels and promote utilization of low grade fuels in the small scale plants.

Table 7.1
Cement Factories and Production in India

Years	Number of Factories	Production ('000 tonnes)	Annual Growth Rate During Period
1914	1	1	-
1924	6	260	-
1934	7	950	13.8
1944	17	1,600[1]	5.3
1954	25	4,300[1]	10.4
1964	36	9,690	8.4
1969	42	13,576	7.0
1974	50	14,263	1.0
1979	56	18,238	5.1
1983	75	25,400[2]	8.6
1984	77	29,142[2]	15.0

Source: Reference 10

[1] Estimated.

[2] Excluding production from mini-cement plants.

Table 7.2
Comparative Investment Costs of VSK plants in India

	ATDA	Saboo	Cement Research Institute of India					
	25tpd	20tpd	30tpd	50tpd.		100tpd		200tpd
Land	0.80	1.00	1.00	1.00		1.00		1.50
Building	18.47	16.31	18.50	21.71		28.72		47.46
Plant & Machinery			Movers	CRI 1/	Movers 2/	CRI	Movers	CRI
Raw meal section	15.60	7.00	18.35		23.86		42.13	
Noduliser & Clinkering section	8.05	5.00	14.56		15.56		33.11	
Cement Mill section	8.15	4.00	15.07		24.07		31.24	
Dust Collectors, Elevators & Conveyors	8.00	2.00	3/		3/		3/	
Miscella-neous	10.00	11.76	18.53		30.52		44.54	
Total	49.80	29.96	66.51	95.20	94.01	134.28	151.02	250.04
Pre-operative Expenses	6.77	5.00	9.00	13.59		16.32		26.16
TOTAL FIXED CAPITAL	75.84	52.27	95.01	131.50	130.31	180.32	197.06	334.16
Investment Cost/tonne(Rs)	919	792	960	797	790	546	597	506

1/ CRI estimates - details not provided
2/ Mover's quotes
3/ Included in the appropriate sections.

Source: Reference 10

Table 7.3

Comparative Production Costs of VSK plants in India

(Rs/t cement)

Item	ATDA 1/	Lokapur 2/	Arif 3/	RRL 4/
Raw Materials	69.74	70.35	187.42	90.06
Coal	183.68	157.50	144.00	121.55
Power	122.97	122.00	94.15	75.00
Labour	62.12	26.36	98.38	11.57
Other Production Costs	158.08	154.47	156.00	120.08
Interest	104.99 5/	74.85 5/	108.00 5/	95.27 6/
Depreciation	78.67 7/	63.13 7/	76.00 7/	44.27 7/
	780.25	668.66	863.95	557.80

1/ 7500 tpa 2/ 90 tpd @ 330 working days p.a. 3/ 5000 tpa

4/ 20 tpd @ 300 working days and 90% efficiency.

5/ 18% on working Capital, 12% on fixed Capital. 6/ 20% and 15%

7/ 5% on building, 10% on machinery.

Source: Reference 10

Table 7.4

Raw Materials and Fuel Requirements

	Cost Rs/tonne			Requirement/t Cement			Cost/t Cement (Rs)		
Raw Material	**ATDA**	**Lokapur**	**Arif**	**ATDA**	**Lokapur**	**Arif**	**ATDA**	**Lokapur**	**Arif**
Marl	25	—	—	1.48	—	—	37.00	—	—
Limestone	—	45	140	—	1.20	1.19	—	54.00	166.60
Kankar	40	—	—	0.03	—	—	3.20	—	—
Clay (Red Burning)	—	15	15	—	0.21	0.22	—	3,15	3.30
Laterite	—	—	320	—		0.011	—	—	3,52
Blue Dust	320	—	—	0.04	—	—	12.80	—	—
Total Raw Meal				1.60	1.41	1.42	53.00	57.15	173.42
Gypsum	279	330	280	0.06	0.04	0.05	16.74	13.20	14.00
							69.74	70.35	187.42
Coal									
Steam Coal	800	—	—	0.045	—	—	36.00	—	—
S.L.V. Coal	700	—	—	0.104	—	—	72.80	—	—
Coke Breeze	720	750	720	0.104	0.21	0.20	74.88	157.50	144.00
							183.68	157.50	144.00
Power (Kwh)				150	125	90	122.97	122.00	94.15

Source: Reference 10

Table 7.5

Labor requirements

Type	Number			Average pay/employee/month (Rs)			Total cost per year('000Rs)		
	ATDA	Lokapur	Arif	ATDA	Lokapur	Arif	ATDA	Lokapur	Arif
Administrative	11	9	7	591	1139	714	78.0	123.0	60.0
Technical									
(a) Plant	4	9	14	933	678	771	47.0	73.2	130.0
(b) Laboratory	8	5	5	453	780	860	33.0	46.8	52.0
Production									
(a) Semi-skilled	34	60	30	12/day	500	12/day	122.4	360.0	119.0
(b) Unskilled	65	34	50	8/day	411	8/day	156.0	180.1	132.0
Total	122	117	106				465.9 1/	783.1	493.0
Assumed Production (tpa)	7500	29700	5000						
Labour Costs/t cement (Rs)	62.12	26.36	98.38						

1/ Includes Rs. 24,500 for fringe benefits.

Source: Reference 10

Table 7.6

Other Production Costs

Item	Estimated Cost/year ('000 Rs.)			Cost/t (Rs)		
	ATDA	Lokapur	Arif	ATDA	Lokapur	Arif
Office overheads	90.0	348.1	60.0	12.00	11.72	12.00
Packing material	750.0	2673.0	500.0	100.00	90.00	100.00
Lubricants	50.7			6.76		
Repairs, Maintenance and Consumables	224.3	1353.7 1/	175.0 1/	29.91	45.58 2/	35.00
Insurance	70.6	213.0	45.0	9.41	7.17	9.00
	1185.6	4587.8	780.0	158.08	154.47	156.00

Source: Reference 10

1/ Includes cost of lubricants

2/ Assuming 33% fixed costs on the presently reported cost of Rs. 75662.

Table 7.7 Small scale plants: Transportation costs

Item	Transport Costs (Rs./tonne)			Transport Costs/t Cement (Rs.)		
	ATDA	Lokapur	Arif	ATDA	Lokapur	Arif
Limestone/Marl	5.00	10.00	110.00	7.40	12.00	130.90
Coal:						
Steam	153.00	-	-	6.89	-	-
SLV	324.00	-	-	33.70	-	-
Coke Breeze	380.00	360.00	380.00	39.52	75.60	76.00
Gypsum	182.81	224.83 1/	183.00	10.97	8.99	9.15
Total Raw Materials				98.48	96.59	216.05
Transport Cost as % of Production Cost				12.6	1′.6	25.0
Cement	19.20 2/	30.00	22.00 3/			
Total Transport Costs				117.68	126.59	238.05
Total Transport costs as % of selling price				9.8	9.5	19.2

Source: Reference 10

1/ Includes Rs. 195.50 by rail to Bagalkot and Rs. 29.33 by road from there.

2/ Estimated from 50% local sale @ Rs 25/t and 50% sold in Lucknow @ Rs. 13.35/t.

3/ Estimated from 50% sale in Lucknow Rs. 26.67/t, 30% in the nearby local areas e.g. Faizabad and Sultanpur @ Rs. 20/t and 20% locally at Jagdishpur @ Rs. 13.33/t.

Table 7.8
Comparison of cost data for small and large scale plants

(Rs/t Cement)

Installed Capacity	20 tpd		25 tpd		100 tpd		165 tpd		1450 tpd 1/	
Investment Cost	792.00		919.27		645.45		1154.18		1450.00 2/	
Sales Realisation	1035.00		995.00		939.70		919.89		818.00	
Production Costs	Cost	%	Cost	%	Cost	%	Cost	%	Cost	%
Raw Material	187.42	21.7	69.74	8.9	70.35	10.5	86.81	9.9	193.28	27.0
Coal	144.00	16.7	183.68	23.5	157.50	23.6	190.62	21.8)	147.38	20.6
Power	94.15	10.9	122.97	15.8	122.00	18.2	80.56	9.2)		
Labour	98.38	11.4	62.12	8.0	26.36	3.9	86.67	9.9	94.03	13.1
Other Production Costs	156.00	18.1	158.08	20.3	154.47	23.1	161.53	18.5	201.15	26.1
Interest	108.00	12.5	104.99	13.5	74.85	11.2	99.95	11.5	29.02	4.3
Depreciation	76.00	8.8	78.67	10.1	63.13	9.4	166.67	19.1	47.01	7.0
	863.95	100.0	780.25	100.0	668.66	100.0	872.81	100.0	711.87	100.0
Net Profit	171.05	16.5 3/	214.75	21.6 3/	271.04	28.8 3/	47.08	5.1 3/	106.13	13.0

Source: Reference 10

1/ Average for 15 large-scale cement companies in 1983-4 inflated to 1984-5 levels.

2/ Cost of new one million tonne plant.

3/ As % of sales.

Table 7.9

Large scale plants: Transportation costs

Item	Average distance from Plant (Kms)	Average Transport costs (Rs/tonne)	Consumption factor	Average Transport costs/t of Cement
Raw Materials				
Limestone	26[1]	12[4]	1.25-1.30	15.00-15.60
Coal	1000[2]	180[5]	0.28-0.32	50.40-57.60
Gypsum	1200-1500[3]	200-235[5]	0.05	10.00-11.75
Total Raw Materials				80.20
Transport costs as a % of Production Costs				11.3
Cement	650(Rail)	165.60	-	115.58[3]
	200(Road)	65.55		
Total Transport Costs				195.78
Total Transport Costs as a % of Selling Price				16.3

Source: Reference 10

[1] Estimated from NCAER, 1979

[2] MGR, 1984.

[3] Estimate based on location of gypsum producers

[4] Rail and rope-way facilities owned by plant

[5] Rail

[6] Derived and updated from CCO, 1982&MGR, 1984.

Table 7.10

Productivity

	Capital-Output[1]	Capital-Labour ('000 ₨)	Output-Labour ('000 ₨)	Tonnes/ Person
Arif	1.3	54.7	58.5	47.2
ATDA	1.7	69.3	73.8	61.5
Lokapur	1.0	212.9	337.6	253.3
ARC	4.0	204.1	132.8	118.0
Large Scale	3.2	265.4	332.2	337.3

Source: Reference 10

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[1] Fixed capital as a proportion of value added.

Table 7.11

Economic valuation of cement production and distribution

Conversion Factors :		
	Coal	1.33
	Power (Grid and Generator)	1.50
	Labour	0.30
	Transport (Cement)	1.20

(Rs./t cement)

	Arif(20)	ATDA(25)	Lokapur(100)	ARC(165)	Large-Scale (1450)
Production cost[1]	679.95	596.59	530.68	606.19	635.34
Transport (Cement)[2]	22.00	19.20	30.00	55.00	115.58
Total	701.95	615.79	560.63	661.19	751.42
Cost Increase/Decrease:					
Coal	47.52	60.61	53.50	62.90)	58.96
Power	47.08	61.49	61.00	40.28)	
Labour	[3]	[3]	[3]	(-) 17.33	(-) 18.61
Transport(Cement)	4.40	3.84	6.00	11.00	28.12
Net Increase	99.00	125.94	120.50	96.85	60.27
Annualised Capital Cost	229.37[4]	134.59[5]	94.70[6]	154.50[7]	10[illegible].12[8]
Total Economic Cost	1030.32	376.32	775.88	912.54	1008.8[illegible]
Internal Rate of Return (%)	17.6	25.5	34.2	18.1	7.6

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[1] At market prices, excluding interest and depreciation.
[2] At market prices.
[3] No reduction as statutory wage awards do not apply to these plants.
[4] 12% interest and 7 year plant life.
[5] 15 year plant life.
[6] 15 year plant life.
[7] 20 year plant life.
[8] 20 year plant life using replacement cost of the plant.

Source: Reference 10

Table 7.12

Apparent Cement Consumption (tons)

	Mali
1965	34,000
1970	40,000
1975	71,000
1977	63,000
1979	90,000
1980	85,000

Source: Reference 22 and The World Bank

Table 7.13

Selected Cement Consumption Indicators

	Mali	
	1970	1980
Cement/capita (kg)	7.5	12.2
GDI (In constant million of US$)	46.4	60.4
Construction Output (in constant million US$)	11.2	23.8
Cement/Million US$ GDI (tons)	0.86	1.4
Cement/Million US$ Construction (tons)	3.6	3.6

Source: Reference 22 and The World Bank

Table 7.14

Cement Consumption and Economic Data: International Comparison (1977 data)

	Population (thousands)	GNP/capita (US$)	Cement/capita (kg)	GDI (US$ million)
Mali	6,129	120	13	103
Upper Volta	5,465	140	12	172
Niger	4,862	190	10	213
Malawi	5,597	150	17	179
Senegal	5,240	380	62	327
Togo	2,350	280	92	215
Ghana	10,634	370	55	783
Ivory Coast	7,463	770	126	1,759
India	631,726	160	29	21,651
Burma	31,512	140	7	595
Bolivia	5,154	480	27	759

Source: Reference 22 and The World Bank

Table 7.15

Composition of prices (retail) in 1981
US $ per ton

	Mali	
Source	Dakar	Abidjan
Price FOB Source a/	80.0	80.0
Transport to Distribution Center	40.0	52.0
Total Cost	120.0	132.0
Taxes, Duties	29.0	20.0
Special Fund (prices, transport)	11.6	8.6
Margin	18.0	18.0
Retail Prices	178.6	178.6

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a/ Discrepancy among FOB source cost is due (i) to producing country: Mali imports european cement delivered Dakar or Abidjan.

Source: Reference 22 and The World Bank

Table 7.16

Estimated profitability of various cement supply alternatives (IRR %)

Alternative	Capacity (tons cement)	Mali
Diamou rehabilitation	60,000	15.0
Diamou conversion	185,000	13.0
Malbaza expansion	120,000	-
Integrated plant	300,000	1.2
	185,000	-0.7
Clinker Grinding	185,000	22.9
Cement bagging	185,000	19.5
Distribution center	185,000	25.8

Source: Reference 22 and The World Bank

Table 7.17

Consumption of Cement in Nepal

(Unit: Tons)

Fiscal Year	Import from India	Import from Overseas Countries	Production from Himal Cement Co.	Total Corrected Consumption
1962/63	3,035	32,230		36,265
1963/64	14,036	25,532		39,568
1964/65	23,959	37,380		61,339
1965/66	32,760	41,389		74,149
1966/67	15,585	19,417		38,002
1967/68	33,329	29,846		63,175
1968/69	54,401	17,162		71,563
1969/70	69,967	27,232		97,199
1970/71	65,245	23,088		88,333
1971/72	61,185	69,107		130,292
1972/73	59,000	78,581		137,581
1973/74	45,000	154,078		199,078
1974/75	56,080	163,321	14,000	233,401
1975/76	56,636	90,142	29,565	176,343
1976/77	127,470	77,071	42,036	246,577

Source: Reference 2

Table 7.18

Projected Future Consumption of Cement

(Unit: 1,000 Tons)

Fiscal Year	Department of Mines & Geology	World Bank/ UNIDO	Asian Development Bank	Holtec Engineers Pvt. Ltd. India	Onoda Engineering Consulting Co., Ltd. Japan	Engineering India, Ltd. India	United Consult- ants Nepal
1980/81	230	251	252	216			300
1981/82	253	276	278	235			
1982/83	278	304	305	256			
1983/84	306	334	336	279			
1984/85	336	-	370	304	407	391	372
1985/86	370	-	-	331			
1986/87	407	-	-	361			
1987/88	448	-	-	394			
1988/89	493	-	-	429			
1989/90	542	-	-	468	627	549	460
1994/95				721	964	770	

Source: Reference 2

Table 7.19

Comparison of shaft kilns

	Units	Bamburi Plant (Kenya)	Himal Plant (Nepal) Black Meal Process	CRI India	Deggan Plant (Austria) Black Meal Process
Inside effective diameter conical section	m	2.9	2.8	1.77	2.9
Inside effective diameter cylindrical section	m	2.4	2.5/2.6	1.18	2.6
Total height	m	8.25	8.0	8.2	8.55
Conical section height	m	1.35	1.2	2.1	1.7
Nodule diameter	mm	10-30	10-15	8-10	10-15
Nodule moisture content	%	15-18	12-13	12-13	14
Refractory thickness	mm	200-220	220	150	200
Air volume	m^3/h	30,000	10,000	4,800	12,000
Air pressure	mm WG	1,200	1,300-1,800	600-800	1,500
Exit gas temperature	°C	70-95	80-100	150	75-85
Clinker temperature	°C	390	80-200	60-100	80-150
Type of fuel		Anthracite Coal (Swaziland)	Coke Breeze (India)	Coke Breeze (India)	
Calorific value	Kcal/Kg	6,400	5,200	5,200	6,800
Volatile matter	%	-	1-3	1-3	4
Ash content	%	20.5	28-35	27	7
Heat consumption	Kcal/Kg	970	950-1,050	1,050	960
Normal output	t/h	7.40	6.7	1.25	7.7
Maximum output	t/h	8.60	7.5	1.3	8.8
Limestone (L) or coral (Co)	%	83.3 Co	80 L	70 L	70 L
Clay (Cl) or shale (S)	%	16.0 S	10 Cl		22 Cl
Coal addition or interground	%	9.2-10.0	9-10	-	8.0

Source: Reference 2

8.0 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This study clearly shows that there is a great deal of flexibility in the technology of cement production for developing countries. There are a variety of choices in the equipment and options available for selecting the type and level of technology. Large-scale rotary kiln plants can be set up for applications where adequate raw materials, energy sources and high density markets are available, whereas smaller vertical shaft kiln plants can be set up in isolated or rural areas where there are small and dispersed deposits of raw materials, energy sources are scarce, and where low density markets exist in addition to poor infrastructure for transportation.

Developing countries are primarily involved in the development of small-scale cement plant technologies and have shown the initiative because of the conditions prevailing in their local markets such as shortages in cement capacity, lower abor costs, a widely scattered need for cement and inadequate transportation infrastructure. Since the rotary kiln is not technically efficient and economically viable for lower capacities of production, a special thrust has been given to vertical shaft kiln technology and to its development work in the area of small-scale cement production. The developed countries have not shown much interest in developing small-scale cement plant technology because of "perfect" market sizes, availability of energy, raw materials and capital for larger plants, successful exploitation of economies of scale in the cement plants, usually high density of demand and well developed infrastructure for transport. Also, labor costs, which tend to be higher in the developed countries, favor larger plants with the smallest possible labor force.

There are doubts as to whether large-scale cement plant technology is appropriate in all circumstances, on account of the large capital input required, the long time-lag before plants can come into operation, the limited number of deposits of raw materials of sufficient size and quality, and because of the high average transportation costs between plants and points of consumption in low density markets. However, small-scale cement plant technology is in various stages of development and most of the available technologies have not been adequately tested commercially making it difficult to obtain reliable sources of appropriate technology transfer for smaller markets. There exists a great deal of potential for exploiting the small-scale technologies but adequate encouragement has not been given on an international basis to the respective developers of such technologies. This is mostly because there are doubts as to the quality of product available from such plants and the quality of the plants themselves.

Under Indian conditions the small-scale vertical shaft kiln cement plant does represent a viable alternative to the large-scale rotary kiln plant given appropriate technical and institutional conditions. While the relatively sophisticated Movers/CRI design is highly competitive with the large sector, the less sophisticated Saboo design offers competition under stringent condition that quality of the cement produced is carefully monitored by the entrepreneur and the operation is supervised by skilled workers. The ATDA technique is at present commercially untested but could represent a feasible alternative if the recurring operational problems are eliminated in a second generation plant. Also, the economic scale of the ATDA plant may be closer to that of the Movers/CRI plant, i.e., 100 tons per day.

The Indian case study shows that small-scale plants reduce the transport burden in cost terms from 16% of the selling price to under 10%. In a country with an overburdened transport infrastructure, this has to be seen as a very significant saving. To the extent that there are small deposits of cement grade limestone in other countries, concentration on small-scale plants can result in very considerable dispersal of cement production. To the extent that production is dispersed, local product availability will reduce the transport burden.

The unsuccessful exploitation of appropriate cement technology in developing countries is a result of the prevailing policy environment and the "status quo" in the supply of cement plant machinery in the international market. In most developing countries the economics inherent in the cement production process are distorted by inappropriate pricing mechanisms, improper fuel, transportation and credit subsidies, and the existence of a political bias in favor of large capital intensive "prestige" projects. Many countries have commissioned larger unit sizes because only such plants are supplied and in some cases subsidized by the established developed country manufacturers.

Recommendations

A research and development effort should be undertaken by the developers of small-scale cement plant technologies together with the major international development organizations to ascertain which environments are most suitable for such investments, to identify the constraints in transferring the technology to these environments, and the identification of private and institutional investors.

A joint venture between the large-scale plant manufacturers and the groups of developers of small-scale plants in the developing countries is needed to improve the quality of machinery available for smaller plants. The interest of the established machinery suppliers in such smaller markets is important if they must tackle the issue of providing appropriate cement plant technologies for developing countries and if they are to continually market their technologies in these countries.

Appropriate technologies for cement production in developing countries will be identified more accurately if they are assessed without the influence of distorting government policies and inappropriate market conditions arising due to subsidies and price controls. One of the responsibilities in project selection should be to ensure that such constraints do not eliminate from consideration otherwise appropriate technologies. Since there is flexibility in the technology of cement production, a free market approach can be instrumental in identifying the most suitable technology.

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