THE ROTARY CEMENT KILN

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Preface

Often regarded as the heart of the cement manufacturing plant, the kiln represents the largest single capital investment and consumes the major portion of the energy requirements in the plant. One of the most important phases of the manufacturing process takes place in the kiln. Regardless of how much effort is given to preparation of the kiln feed blend, the feed has to be properly burned in the kiln in order that a good quality product can be sold to the customer. For this reason, utmost importance should be given to the burning operation, as profits are affected by how efficiently the kilns are operated.

The rotary kiln requires specialized knowledge and experience on the part of the operator so he can successfully perform his job. Thus, with its complex instrumentation and multiple reactions, the kiln poses a significant challenge to the kiln operator. It is obvious that the kiln operator occupies one of the key positions in the production crew.

"The Rotary Cement Kiln" is the first handbook of its kind to deal not only with the theoretical aspect, but also with the actual control function of rotary kiln operation. It is the authors' hope that this book will fill a long-felt need for a practical guide for the kiln operator and others in the cement industry. Then too, much of the information will be found useful in other manufacturing industries using rotary kilns.

The authors discuss the theoretical fundamentals, including basic chemistry of portland cement, composition of the kiln feed and its influence on burnability, heat transfers, combustion, flames, fuels, and the air circuitry in a rotary kiln.

They then present a step-by-step description of the control functions for operation of a rotary kiln. The described burning procedures and techniques have been tested over many years on kilns of various dimensions, and experience has proven them to be entirely successful. Adopted on hundreds of kilns, they are the foundation for stable and economical operations.

The appendix includes a section with conversion tables, definitions of common terms relating to rotary kilns, and a suggested outline for a training program for new kiln operators.

The authors wish to express their thanks to their co-workers in the

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1 THE ROTARY KILN

History

Vertical furnaces and simple forms of shaft kilns were used for burning lime well over 2,000 years ago. History tells us that the Romans used a vertical furnace in which to burn a pozzolanic lime. Near Riverside, California are the remains of underground furnaces (Fig. 1:1) in which the early Mexican settlers burned limestone to make lime during the first part of the 19th century. In later times so-called bottle and shaft kilns were employed. Vertical kilns of the type shown in Fig. 1:2 were constructed in Southern California about the turn of the century.

Early development of the rotary kiln probably started about 1877 in England, but Frederick Ransome is usually credited with the first successful rotary kiln, which he patented in England in 1885. Although the first Ransome kilns were a major break-through in the cement industry at that time, many years passed before a successfully operating rotary kiln was put into production. It was mainly the pioneer work of American engineers a few years after Ransome's discovery that brought the concept of the rotary kiln out of its infancy. The first economical rotary kiln in America, developed by Hurry and Seaman of the Atlas Cement Company, went into production in 1895.

Shaft kilns with continuous feed are still used in Europe, but rotary kilns are dominant on the North American continent. Rotary kilns are preferred because they require less manpower to operate, have higher clinker output rates and, most important of all, yield a more uniform product, compared to shaft kilns. In contrast to these advantages of rotary kilns, shaft kilns have lower thermal and power requirements per ton of clinker produced.

The first Ransome kilns were 18 inches in diameter and 15 feet long. Later, about 1900, the rotary kiln was a lusty youngster 6 feet in diameter by 60 feet long. Today's giants (Fig. 1:3) are over 600 feet long

Fig. 1:1 Remains of underground furnaces that were used by early California Settlers for burning limestone to make lime. (*Riverside Division, American Cement Corp.*)

and 18 feet in diameter with a capacity of over 7,000 barrels per day. Controls for a modern kiln are frequently incorporated in a highly sophisticated computerized control room that monitors and directs operations throughout the plant, as shown in Figure 1:4.

Types of Rotary Kilns

Generally speaking, the clinker manufacturing processes used in rotary kilns can be divided into wet, semi-dry, and dry processes.

1.1 Wet Process

Into this group fall all processes in which the kiln feed enters the kiln in the form of a slurry with a moisture content of 30 to 40%. In

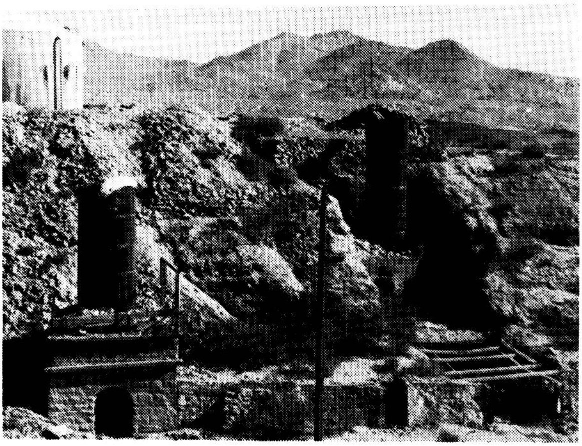

Fig. 1:2 Vertical shaft kilns were commonly in use in the latter part of the 19th century. (*Riverside Division, American Cement Corp.*)

comparison with a dry process kiln of the same diameter, a wet process kiln needs an additional zone (dehydration zone) to drive off the water from the kiln feed, hence must be considerably longer in order to achieve the same production rate.

To produce an equivalent amount of clinker, a wet process kiln requires theoretically more fuel than a dry process kiln because of the extra heat required to evaporate the water. However, in actual operation of a kiln this fundamental fact does not always hold entirely true. As one progresses in the reading of this book, the reasons for these discrepancies between theory and actual operation will become clearer and understandable.

Advantages of a wet process kiln are: feed is blended more uniformly than in the dry process, dust losses are usually smaller, and, in moist climate regions, wet processing of the raw material is more suitable than dry because of moisture already present in the blend materials.

1.2 Semi-Dry Process

This member in the group of rotary kilns is also widely known under the term *Grate Process Kiln*. Into this group fall the Polysius and the Lepol kilns. The most economical kilns, in regard to fuel consumption per unit of clinker, can be found in this group.

In the grate process, pulverized dry kiln feed is first pelletized into small nodules by means of 10 to 15% water addition, then the nodules

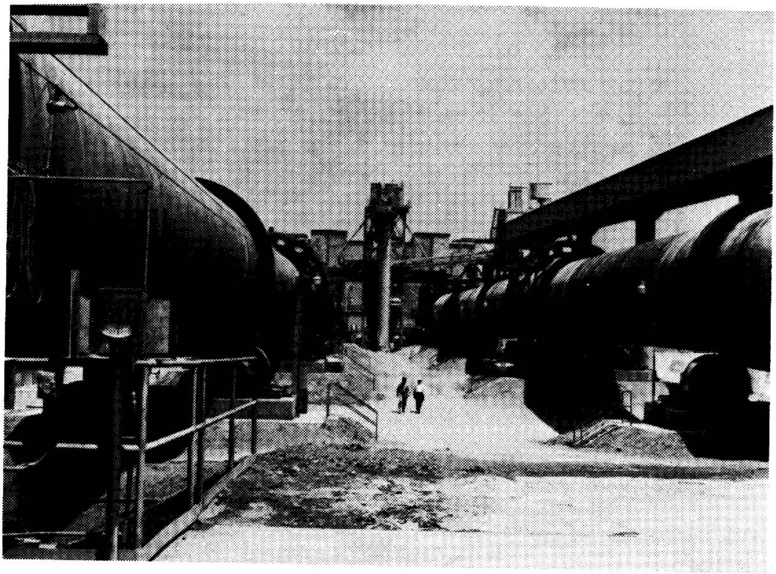

Fig. 1:3 Large rotary kilns in a modern cement plant. These kilns are 16 feet in diameter and over 500 feet long. (*Riverside Division, American Cement Corp.*)

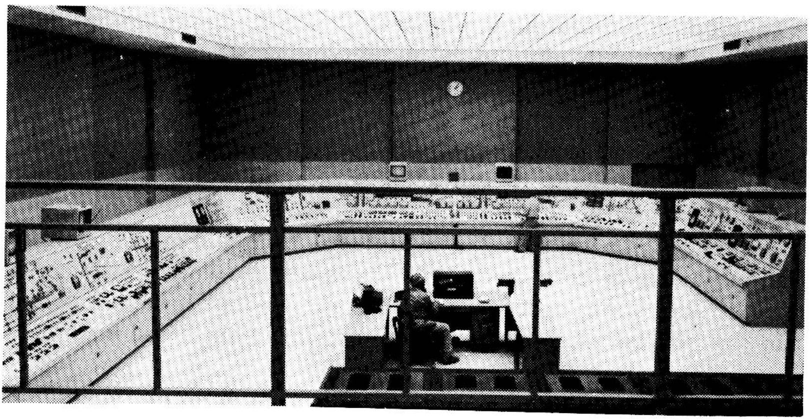

Fig. 1:4 Centralized control room from which the entire operation of a cement plant can be monitored and controlled. (*Riverside Division, American Cement Corp.*)

are fed onto a traveling grate where they are partly calcined before they enter the rotary kiln. Heating of the nodules is effected by the exit gases from the rotary kiln, the hot gases passing through the material bed from above as they are drawn downward through the grates by means of a fan. The partly calcined material then falls down a chute into the rotary kiln where final clinkerization takes place. Because the kiln feed is already partly calcined before it enter the kiln, the rotary kiln itself is only about one-third the usual length. Figure 1:5 is a schematic diagram of the flow of gas and material through a Lepol grate process preheater.

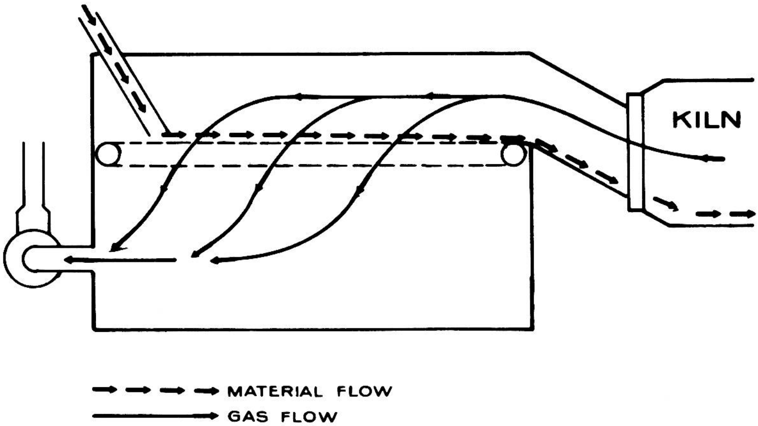

Fig. 1:5 Flow diagram of a Lepol preheater. Pelletized feed fed onto a traveling grate, is heated and partly calcined by hot kiln exit gases before it enters the kiln.

One advantage of grate process kilns is the uniform size of clinker leaving the kiln, an aspect that is decidedly beneficial for grinding the clinker. However, there are some features not found in conventional rotary kilns that need very close attention; for example, production of the nodules and control of the thickness of the feed bed over the traveling grates. Such a kiln usually requires additional labor to attend the granulator plant.

1.3 Dry Process

As the term indicates, in this process the kiln feed enters the kiln in dry powder form. A multitude of dry kiln designs are used today, most

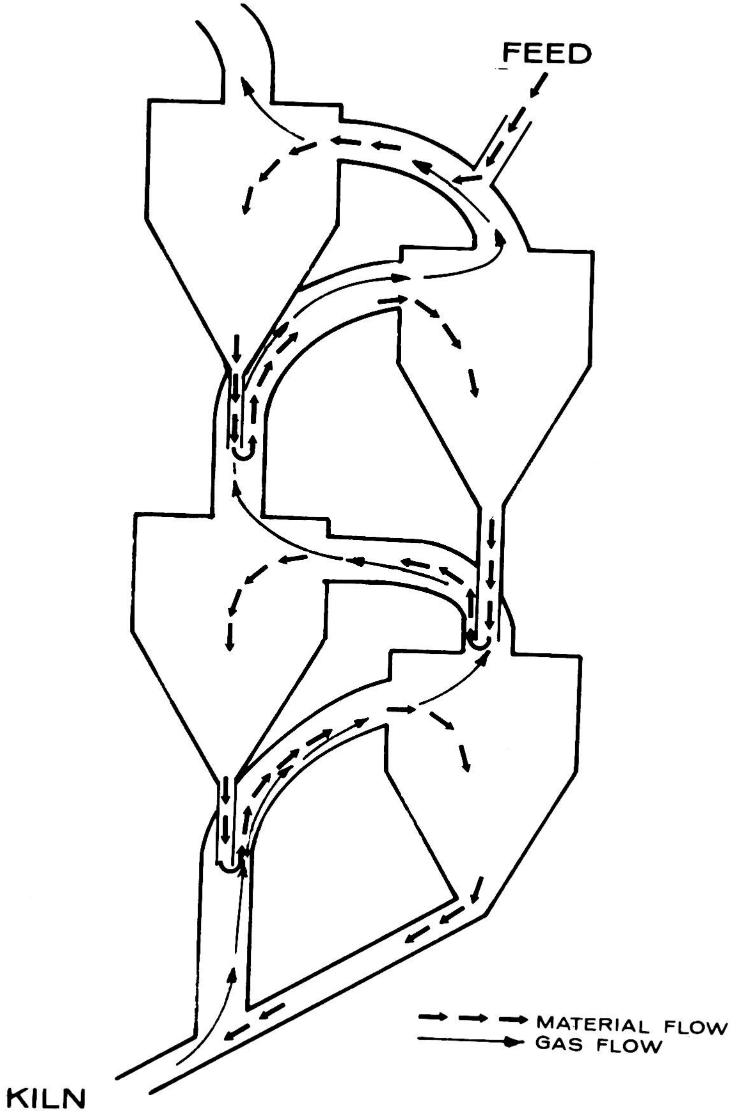

Fig. 1:6 Flow diagram of a Humboldt gas suspension preheater, a multi-stage counterflow process which draws the gases through a series of cyclone collectors. The pulverized material, which is fed counter to the gas flow, becomes suspended in the gas stream and is heated in successive stages until discharged through the kiln-feed pipe.

of them having provisions to recover part of the large amount of heat from the kiln exit gases which otherwise would be lost. These can be subdivided into the following groups:

Gas suspension preheater kilns
Kilns with internal heat exchangers
Kilns with heat recovery units for the generation of power.

In the gas suspension preheater kiln, the dry feed is preheated and partly calcined in a battery of heat exchanger vessels before it enters the rotary kiln. The heat exchange between the gas and the material in the vessels takes place while both are in suspension. Although many different designs of preheater kilns are available from many manufacturers, one of the most widely used is the Humboldt (Fig. 1:6).

Another system of recouperating heat from the high back end temperatures is the utilization of chains, almost identical to those employed in wet process kilns (Fig. 1:7). Although not quite as efficient as preheater vessels, chains have been found effective and practical on the large and long kilns that have come into use since 1950. These internal heat exchangers, because of their simplicity and ease of operation, are popular with kiln operators.

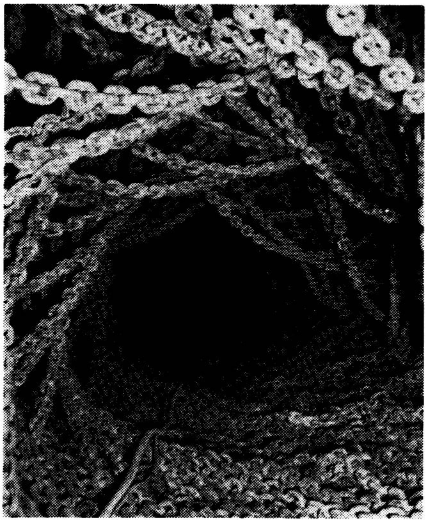

Fig. 1:7 The chain section of a kiln. The chains absorb heat from the hot gas and transmit the heat to the kiln feed. (*American Chain & Cable Co., Inc.*)

The gases enter the chains at a temperature of approximately 1500°F (815°C) and leave the kiln exit at a temperature around 850°F (450°C). In countercurrent flow, the material enters the chains with a temperature of 120°F (50°C) and emerges from the chain section with a temperature of approximately 1350°F (730°C).

In the last group are the dry process kiln systems in which the high exit gas temperatures are used to produce steam for the generation of power. Because of rising labor cost and lowering electricity rates this type of system in recent years has fallen into disfavor in the cement industry. These systems are being replaced by the more efficient heat economizing preheater kilns, or kilns with internal preheaters.

In the short time span of 80 years, rotary kilns have undergone vast changes. In one area alone, fuel efficiency, great improvements have been made as new and improved fuels and equipment have become available. Machine designs have changed considerably, and the means by which the kilns are controlled have kept pace with the march of modernization. In recent years, the trend has been toward automation, better and more refined instruments being incorporated into the kiln system. Many rotary kilns are today under full automatic control by a computer.

Despite of all the improvements made over the years, the fact remains that even the most efficient kiln in operation today still operates at a very low efficiency when compared with manufacturing processes of other industries. Beyond any doubt, the last word in rotary kiln design has not been spoken yet. There are many areas in the kiln system where a major breakthrough sooner or later will have to come in order to reduce the large amount of the presently existing heat losses.

The Refractory

Because of the high temperatures existing inside a kiln during the clinker manufacturing process, it is necessary to protect the steel shell of the kiln with a refractory lining. If this protection were not provided, the shell would disintegrate within a few hours. A refractory is a material, usually nonmetallic, that is used to withstand high temperature. In a kiln, the refractory usually consists of brick of special composition and sizes as shown in Fig. 1:8. Some usage in recent years has been made of a cast lining continuously placed in a manner similar to placing concrete in a structure. In this method, the interior is progressively formed by means of special planks, welded anchors, and snapties. The kiln is rotated as necessary during placement of each section of lining so the

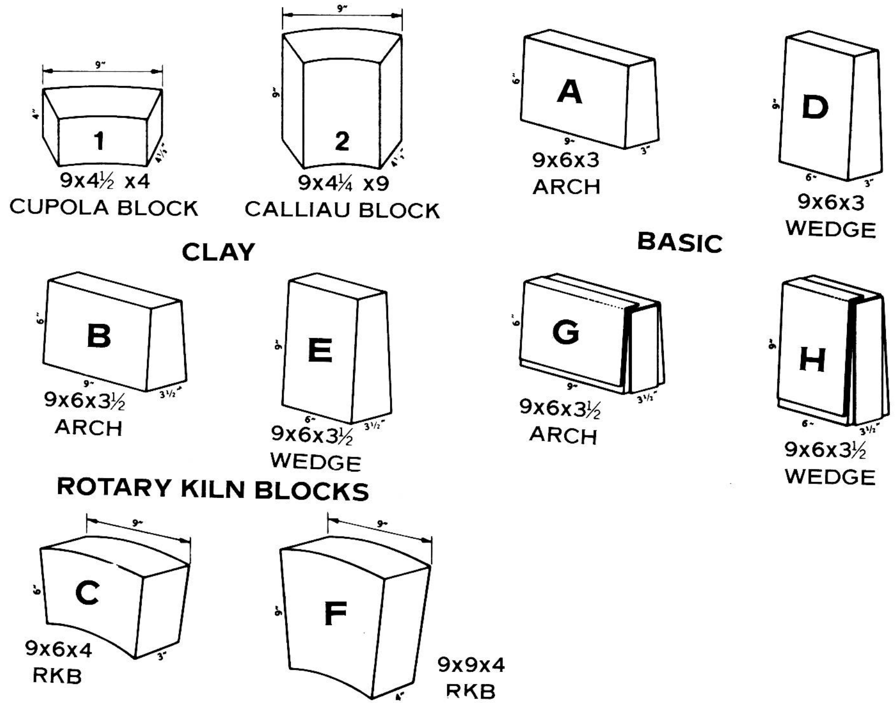

Fig. 1:8 Bricks for the refractory lining come in several sizes and shapes. (*Kaiser Refractories.*)

workmen are always working at the same level.

Among kiln operators, refractory failure is considered the most critical upset in a kiln operation. Refractory failure inside the rotary kiln is indicated when the kiln shell becomes red hot because the refractory lining has either been entirely lost or has become so thin in an area that the kiln shell becomes overheated. Such a condition is dangerous because once the protection supplied by the refractory has been removed, the steel shell could easily be warped to such an extent that replacement of an entire kiln shell section becomes necessary. In most instances, however, damage can be avoided if the kiln is shut down for lining replacement as soon as the shell starts to show a large red spot. Because of the importance of such a situation, remedial procedures for hot shell conditions are described in Section 6.5.

Replacement of the kiln lining, especially in the burning zone, is unfortunately a frequent necessity, exerting a large strain on the operating budget and on production schedules. For example, replacement of an entire burning zone lining over a length of 50 feet in a 16-foot diameter kiln costs in excess of $30,000. This figure represents only the cost of the refractory itself and does not include the added expense of installation, nor the hidden cost resulting from loss of production and the extra fuel required to bring the kiln back to operating temperatures.

Life of the lining in the burning zone of a rotary kiln can vary from 50 days to a full year or more. In other words it is possible for the refractory in one kiln to have ten times the life expectancy of the refractory in another kiln. The reasons for these large discrepancies in lining life can be found in factors relating directly to the type of refractory used, its shape, and its installation. On the other hand, kiln operating conditions, type of kiln feed, and the mechanical soundness of existing kiln equipment have by far the greatest influence on lining life. Later in this chapter we will come back to detailed discussion of these factors.

1.4 Refractory Requirements and Properties

Certain requirements have to be imposed upon the refractory, depending on the conditions it will be exposed to in the area of the kiln where it is to be used.

Resistance to High Temperatures. The refractory has to withstand the temperatures that can prevail under adverse conditions as well as those that prevail under normal conditions in the zone where it is being used. Not only does it require the ability to withstand high temperatures without melting, it also must maintain its structural strength at temperatures below its melting point, and must maintain a constant volume when exposed for prolonged times to the high temperatures.

Spalling Resistance. Any kiln shutdown, start-up, or severe operating upset usually creates large temperature changes in the kiln, and the refractory must possess the necessary shock resistence to withstand such temperature variations. Failure to possess this quality can cause the brick to crack. These cracks, generally referred to as spalling, develop in a horizontal direction on the brick.

Spalling results from thermal shock. The same reaction can be observed with a drinking glass: If we set a cold glass into very hot water the thermal shock causes the glass to crack. However, if we slowly raise the temperature of the water containing the glass, there is no thermal shock and the glass is not damaged. The same applies to the refractory in the kiln. When a cold kiln is fired, the temperature of the refractory must be raised very slowly to avoid spalling.

Resistance to Chemical Attack (Slag Resistance). During the process of clinkerizing, ash, slag, and vapors formed during the combustion process can attack the refractory, reacting chemically with brick, depending on the type of fuel used. Furthermore, dust and alkalies entrained in the kiln gases can adhere to the bricks in the burning zone and react with the refractory. The ability of a refractory to withstand these chemical attacks is called its slag resistance. A brick that does not possess this resistance could be considerably weakened by chemical attack, resulting in premature refractory failure.

Abrasion Resistance. Conditions encountered in a rotary kiln make it necessary that the refractory withstand the abrasive action resulting from the sliding kiln feed bed and also by dust entrained in the moving gas stream. This abrasion resistance is a prerequisite for all bricks installed in front of and behind the burning zone where coating is not usually formed.

Coatability. One of the most important qualities required from the refractory in the burning zone where the highest temperatures exist, is its ability to take on a good coating and to hold this coating for a prolonged length of time. The importance of coating in the burning zone is discussed in Chapter 6. Just as the refractory acts as a protection for the kiln-shell, so the coating in turn acts as a protection for the refractory, thus serving to prolong the life of the brick in the burning zone.

1.5 Tests of Refractories

Selection of the best refractory for a given area in the kiln is not an easy task for the person who has to make this choice. This is especially true for a kiln in a new cement plant where no previous experience can