AP-42 Section 11.6
Reference 1
Report Sect.
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Air Pollution Engineering Manual

AIR & WASTE MANAGEMENT
ASSOCIATION
SINCE 1907

Edited by
Anthony J. Buonicore
Wayne T. Davis

VNR VAN NOSTRAND REINHOLD
New York

venturi wet scrubber. It is not uncommon to find wet scrubbers that are not venturi in design, but these types are usually found on HMA mixing facilities that are not covered by the NSPS for HMA facilities. Generally, a high-pressure (20 inches, water gauge) venturi scrubber is required to meet the NSPS requirements. In addition to controlling particulate emissions, the venturi scrubber is likely to remove some of the process hydrocarbon emissions from the exhaust gas before discharge into the environment. However, owing to the high power requirements and water-discharge permitting issues, and also as a result of pressure exerted by some state air quality agencies, the wet scrubber is not as frequently installed as is the baghouse on HMA facilities.

The baghouse has proven to be very reliable with regard to meeting the NSPS requirements for particulate loading of the exhaust gas discharged to the environment. The high-pressure venturi scrubber is also reliable, but it requires considerable attention and daily and weekly maintenance to maintain a high degree of particulate removal efficiency.

Gaseous and Toxic Air Pollution Control Measures

Since no pressure has been exerted on the HMA industry with regard to the control of gaseous and/or toxic air pollutant emissions, add-on air pollution control equipment has not been evaluated for this process. However, the results of the New Jersey stack testing program for carbon monoxide and hydrocarbons indicate that operating management practices and proper process equipment design can significantly reduce the release of these two gaseous air pollutants into the environment.

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3. K. O'C. Gunkel and A. C. Bowles, "Drum mix asphalt plants—Maryland's experience," presented at the Air Pollution Control Association's 78th Annual Meeting, Detroit, MI, June 1975.

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PORTLAND CEMENT

Walter L. Greer, Michael D. Johnson, Edward L. Morton, Errol C. Raught, Hans E. Steuch and Claude B. Trusty, Jr.

Portland cement is a fine powder, usually gray in color, that consists of a mixture of the hydraulic cement minerals, dicalcium silicate, tricalcium silicate, tricalcium aluminate, and tetracalcium aluminoferrite, to which one or more forms of calcium sulfate have been added. Portland cement accounts for about 95% of the cement production in the United States. Masonry cement represents most of the balance of domestic cement production and is also produced in portland cement plants.

Portland cement and masonry cement are produced in several different types or formulations for specific purposes or properties. Chemical and physical specifications for the types of portland and masonry cements are written by several agencies, of which the most widely used are those provided by the American Society for Testing and Materials (ASTM). The most common types of portland cement are designated by the Roman numerals I through V. Types of masonry cement are designated by the letters N, S, and M.

The production of portland cement is a four-step process: (1) acquisition of raw materials, (2) preparation of the raw materials for pyroprocessing, (3) pyroprocessing of the raw materials to form portland cement clinker, and (4) grinding of the clinker to portland cement. In terms of productive capacity, a properly designed portland cement plant has the pyroprocessing operation as the limiting factor. Figure 1 is a basic flow diagram of the portland cement process. Figure 2 presents a layout of the cement plant most recently built in the United States and Figure 3 shows another modern cement plant. While the various unit operations and unit processes in portland cement plants accomplish the same end result, no flow diagram can fully represent all plants. Each plant is unique in layout and appearance owing to variations in climate, location, topography, raw materials, fuels, and preferences of equipment vendors and owners. These plants are capital intensive. In 1990, there were 111 plants in the United States producing approximately 80 million tons of portland cement.[1] Portland cement plants can run 24 hours per day for extended periods—six months or more with only minor downtime for maintenance is not unusual.

Raw materials are selected, crushed, ground, and proportioned so that the resulting mixture has the desired fineness and chemical composition for delivery to the pyroprocessing system. The major chemical constituents of portland cement are calcium, silicon, aluminum, iron, and oxygen. Carbon is a major constituent of the cement raw mix, but that element is eliminated during processing. Minor constituents, generally in a total amount of less than

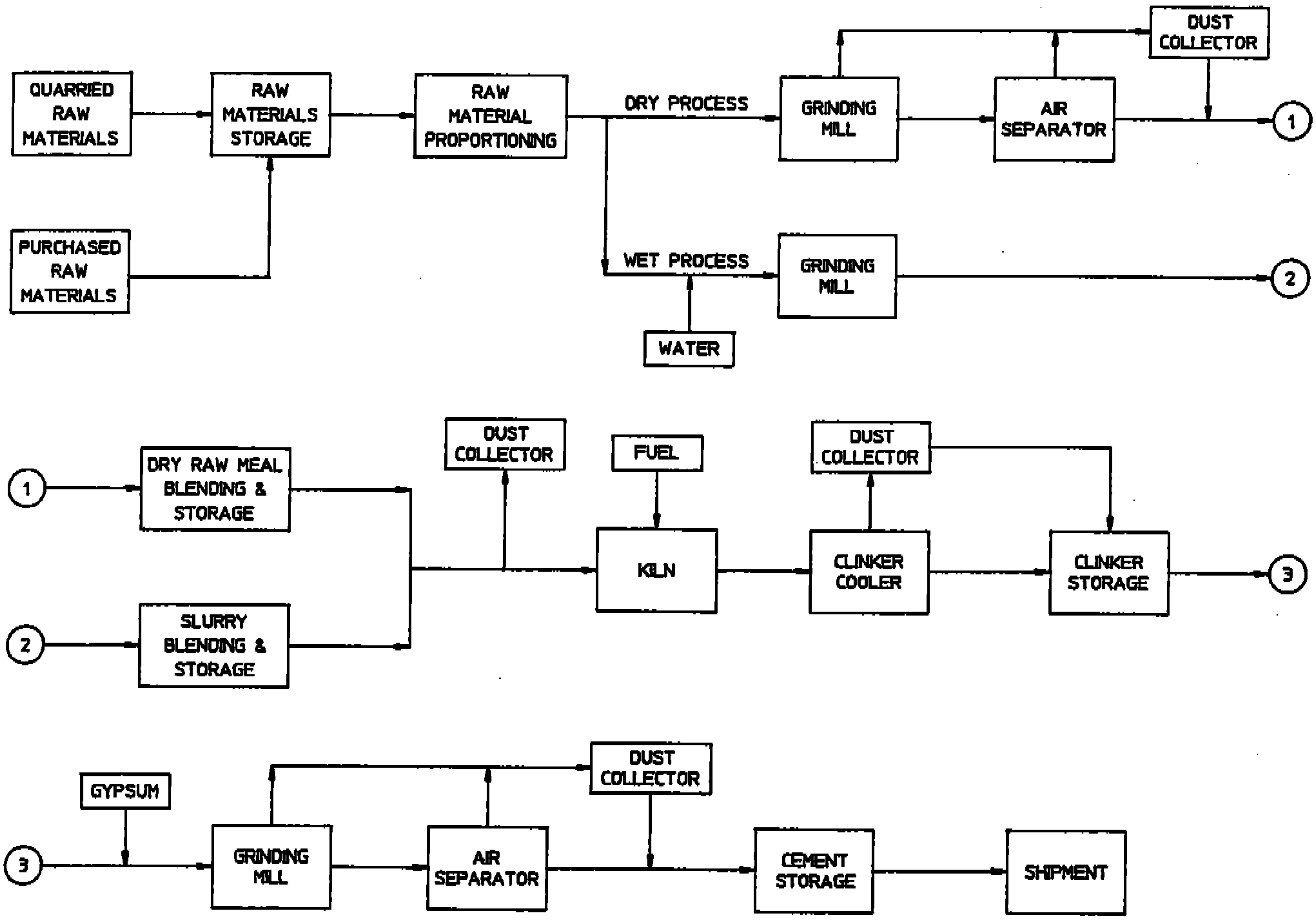

FIGURE 1. Basic Flow Diagram of the Portland Cement Manufacturing Process

5% by weight of the mixture, include magnesium, sulfur, sodium, and potassium. And since raw materials for portland cement usually come from the earth's crust, a wide variety of trace elements can be found in the cement, although these generally total less than 1% by weight of the mixture. Some of these naturally occurring trace elements can affect the performance of portland cement and/or appear in particulate emissions and process residues from cement plants. Most often, however, they harmlessly substitute for the four major metals in the crystalline matrix of the portland cement.

The more than 30 raw materials that are known to be used in the manufacture of portland cement can be divided into four categories: lime (calcareous), silica (siliceous), alumina (argillaceous), and iron (ferriferous). A limestone or other form of calcium carbonate will predominate in the mixture of raw materials. One or more quarries are usually associated with a portland cement plant. The terms slurry, raw meal, raw mix, and kiln feed are somewhat synonymous in naming the prepared raw materials or product of the raw mill department. At least 1575 kg (3388 pounds) of dry raw materials are required to produce 1000 kg (2200 pounds) of cement clinker. This ratio of feed to product can increase by several pounds due to the raw mix composition and dust removal. Most of the weight loss represents carbon dioxide, which is calcined from the calcium carbonate and emitted to the atmosphere during pyroprocessing.

Standard industry practice is to report the chemical analyses of raw materials, process intermediates, by-products, and portland cement as metal oxides, even though the constituents are rarely present in that form. If desired, the theoretical quantities of minerals in the cement matrix are calculated from the oxide analysis using specified formulas. Actual quantities of minerals may be determined by X-ray diffraction.

There are wet-process and dry-process portland cement plants. In the wet process, the ground raw materials are suspended in sufficient water to form a pumpable slurry. In the dry process, they are dried to a flowable powder. A variation of the dry process, the semidry process, uses a moist nodule or pellet to prepare the raw materials for pyroprocessing. Newer portland cement plants in the United States have almost exclusively used the dry process because of its lower thermal energy requirement. The Portland Cement Association estimated in 1988 that the average thermal energy used to produce a ton of cement in the United States

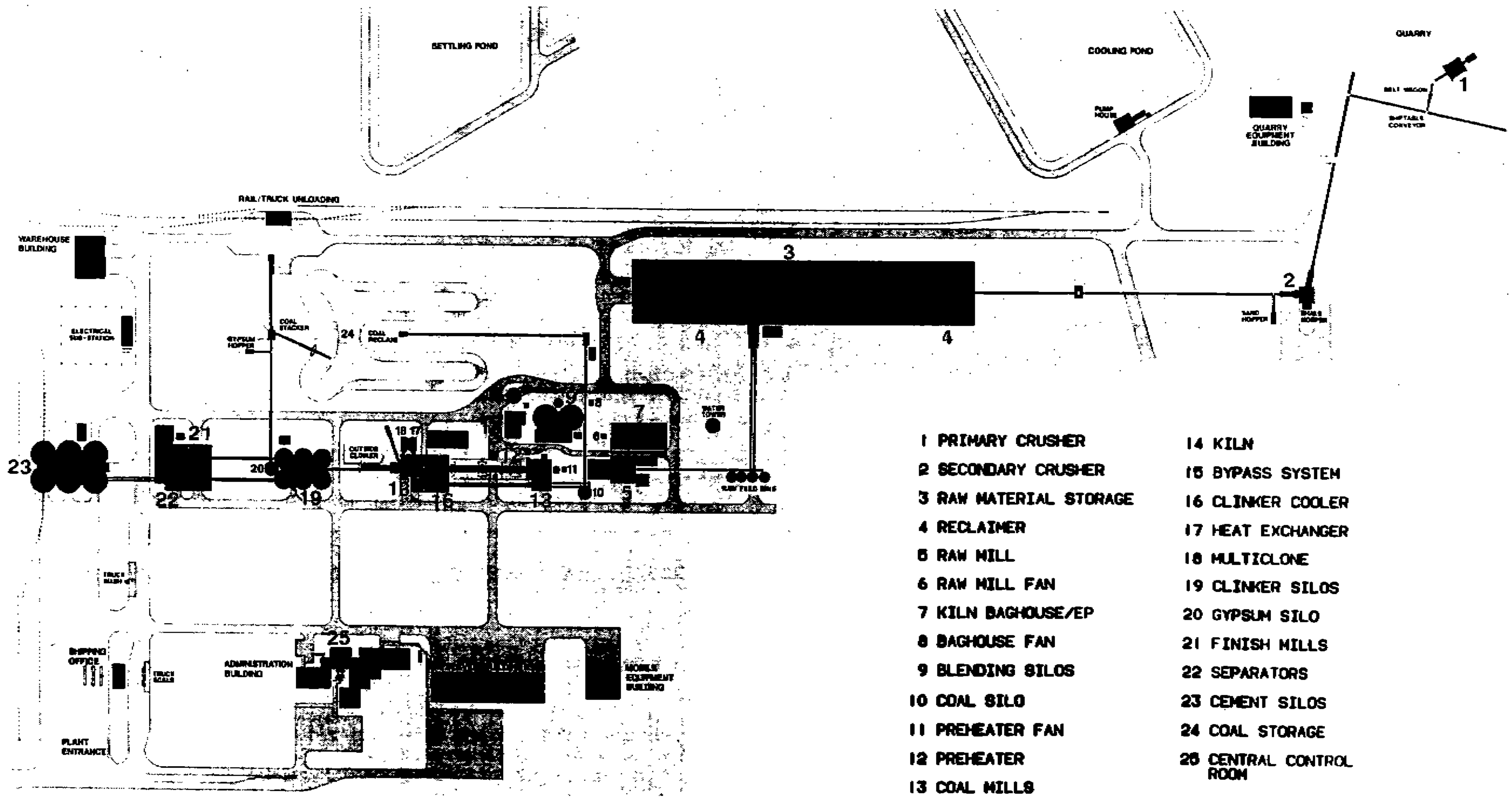

FIGURE 2. Cement Plant Layout

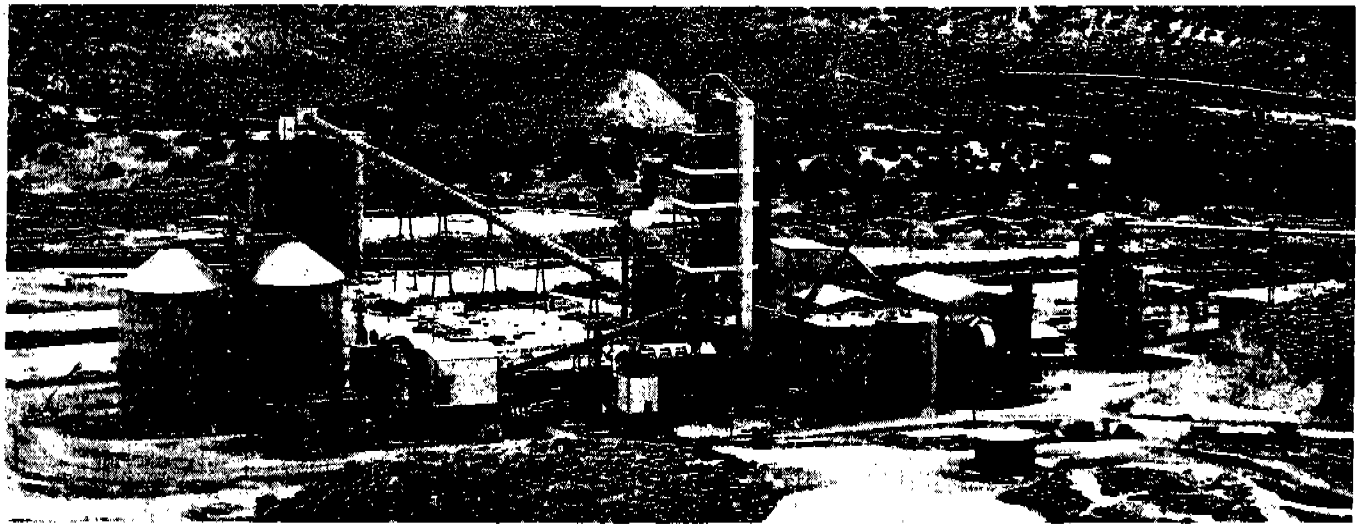

FIGURE 3. Modern Cement Plant

was about 4.4 million Btu. Thermal energy consumption ranges from about 3.0 to 7.0 million Btu per ton, depending on the age and design of the plant. Average electric energy consumption is about 0.5 million Btu (147 kWh) per ton of cement.

The prepared raw materials are fed to one of several pyroprocessing systems in the kiln or burning department. Each system accomplishes the same result via the following basic steps: evaporation of free water, evolution of combined water, calcination of the carbonate constituents (decarbonization), and formation of the portland cement minerals (clinkerization). The wet process uses rotary kilns exclusively. The semidry process uses a moving grate on which the moist nodules are dried and partially calcined by hot kiln exhaust gases before being fed to a rotary kiln. The dry process can also employ simple rotary kilns. Thermal efficiency can be improved, however, through the use of one or more cyclone-type preheater vessels that are arranged vertically, in series, ahead of the rotary kiln in the material flow. It can be further improved by diverting up to 60% of the thermal energy (i.e., fuel) required by the pyroprocessing system to a special calciner vessel located under the preheater vessels.

The rotary kiln is the heart of the portland cement process since the several and complex chemical reactions necessary to produce portland cement minerals take place there. The portland cement kiln is a slightly inclined, slowly rotating steel tube that is lined with appropriate refractory materials. The rotation of the kiln causes the solid materials to be slowly transported downhill from the feed end. Fuel is supplied at the lower or discharge end of the kiln. Many fuels can be used in the kiln, but coal has predominated in the United States since the mid-1970s. The choice of fuel is based on economics and availability. The hot, gaseous combustion products move countercurrent to the material flow, thereby transferring heat to the solids in the kiln load. Flame temperatures in excess of 3400°F result in the material temperatures of 2700–2800°F that are required to produce the hydraulic calcium and aluminum silicates.

The product of the rotary kiln is known as clinker. Heat from this clinker is recuperated in one of three types of clinker cooling devices and returned to the kiln by preheating combustion air.

The cooled clinker is mixed with a form of calcium sulfate, usually gypsum, and ground in ball or tube mills in the finish mill department to produce portland cement. Masonry cement is similarly produced from portland cement clinker, gypsum, and one or more calcareous materials.

Portland cements are shipped from the packhouse or shipping department in bulk or in paper bags by truck, rail, barge, or ship. Masonry cements are shipped in paper bags.

Except for the quarry and rock crushing operation, the New Source Performance Standards (NSPS) that apply to a new or modified portland cement plant constructed after August 17, 1971, are contained in 40 CFR 60, Subpart F, *Standards of Performance for Portland Cement Plants*.[2]

Emission factors for portland cement plants are contained in Section 8.6 of the October 1986 Supplement to the U.S. Environmental Protection Agency (EPA) publication, *Compilation of Air Pollutant Emission Factors*, (AP-42).[3] These emission factors have limited usefulness because of the diversity of cement plant design and operation, as well as the old and limited data on which the factors are based. For these reasons, the AP-42 emission factors have not been included here.

An explanation of the operation of the common dust collection devices used in the cement industry, such as multiclones, fabric filters, and electrostatic precipitators (ESPs), is beyond our scope here but can be found elsewhere in this manual.

ACQUISITION OF RAW MATERIALS

Process Description

The initial step in the manufacture of portland cement is the acquisition of raw materials. The industry is considered an extractive industry since nearly all of the raw materials required are obtained from the earth's crust by mining or quarrying. Most cement plants are located near a source of calcium carbonate, which is most often limestone. Since about one third of the weight of the limestone is lost as carbon dioxide during pyroprocessing, process economics dictate that this lost weight be transported as short a distance as possible. Those plants that are not immediately associated with a limestone quarry often have a source of limestone or other form of calcium carbonate (e.g., aragonite) that is available by less expensive water transportation. However, there are a few exceptions to these generalizations on plant location.

Calcium is the metallic element of highest concentration in portland cement. The calcareous raw materials include limestone, chalk, marl, seashells, aragonite, and an impure limestone known in the industry as natural cement rock. Limestone, chalk, and cement rock are most often extracted from open-face quarries, but underground mining can be employed. Dredging and underwater mining techniques are used to develop deposits of calcareous raw materials in the ocean or below the water table. Gypsum and/or natural anhydrite (i.e., forms of calcium sulfate) from quarries or mines are calcium-bearing constituents of portland cement that are introduced as part of the final stage of its manufacture, finish grinding. It is rare for a cement plant to have a captive source of gypsum or anhydrite and these materials are usually purchased.

Silicon, aluminum, and iron are the next most prevalent metallic elements in normal portland cement and are listed in descending order of concentration. These metals are found in various siliceous, argillaceous, and ferriferous ores and minerals, such as sand, shale, clay, and iron ore. Although usually extracted in open-face quarries or pits, these raw materials can be dredged or excavated from underwater deposits. They can be obtained from captive sources adjacent to or away from the portland cement plant; however, it is often necessary or economical for the cement manufacturer to purchase them from outside sources.

The wastes and by-products of other industries are successfully employed as portland cement raw materials. Such materials include, but are not limited to, power plant fly ash, mill scale, and metal smelting slags.

The cement manufacturing process and the performance of portland cement are sometimes affected by trace elements that are found in virgin raw materials or wastes. Care must be exercised in selecting these raw materials to assure that trace elements will not be present in high enough concentrations to cause problems in the plant or product.

Air Emissions Characterization

Quarries at cement plants are similar to other stone quarries. The necessary operations include rock drilling, blasting, excavation, loading, hauling, crushing, screening, materials handling, stockpiling, and storing. There are many different operating methods, types of equipment, and equipment brands that are used to accomplish these tasks. Particulate matter is the primary air pollutant associated with quarry operations. In some locations, exhaust emissions from mobile equipment may be of concern. There are usually no atmospheric air pollution problems at underground mines or underwater operations.

The NSPS that apply to quarry and crushing operations at portland cement plants are contained in 40 CFR 60, Subpart 000, *Standards of Performance for Nonmetallic Mineral Processing*.[4] These standards are applicable to those affected facilities that commenced construction, reconstruction, or modification after August 31, 1983.

Raw materials can also be the source of some environmentally undesirable emissions from the kiln stack later in the process. If the raw materials contain naturally occurring hydrocarbons, such as petroleum or kerogens, these materials can evaporate in the relatively cooler portions of the pyroprocessing system and appear at the stack exit as a "blue haze." Sulfur and chlorine from raw materials can participate in reactions with the small amount of ammonia in fossil fuel combustion products to form a "detached plume" of ammonium sulfate or ammonium chloride. Nitrogenous constituents of the raw materials can possibly contribute to NO_x emissions that are unrelated to combustion. Sulfides in raw materials have been identified as contributors to sulfur dioxide (SO_2) emissions under some operating conditions.

Air Pollution Control Measures

Control measures for particulate emissions in quarries include water sprays with and without surfactants, foams, chemical dust suppressants, wind screens, equipment enclosures, paving, mechanical collectors and fabric filters on operating equipment, and material storage buildings, enclosures, bins, and silos with and without exhaust venting to fabric filters. Collected dust is returned to the process.

Typical fabric filters found in the quarry are pulse jet in newer plants and reverse air or shaker types in the older plants. Table 1 presents typical data.

Purchased raw materials, including coal or petroleum coke for fuel, can also generate particulate emissions as a result of vehicle loading and unloading, material handling, stockpiling, and haulage. The particulate emission control measures for purchased materials are the same as those listed for quarries.

RAW MILLING

Process Description

The second step in the manufacture of portland cement is the preparation of the raw materials for pyroprocessing. This operation in the raw mill department combines the blending of appropriate raw materials for proper chemical composition with particle-size reduction through grinding.

Grinding is required to achieve optimum fuel efficiency in the cement kiln and to develop maximum strength potential and durability in portland cement concrete. Typically, the raw material in the kiln feed is ground to about 85% passing a 200-mesh (74-μm) sieve or 90% passing a 170-mesh (88-μm) sieve. Usually less than 1% of the material is retained on the 50-mesh (297-μm) sieve. The actual fineness that is required depends on the reactivity of the raw material components. Material that is too finely ground wastes energy and reduces the productive capacity of the raw mill. Unnecessary grinding can also result in excessive dusting in the cement kiln. This dust reduces available draft in the kiln and upsets the combustion process, thereby potentially lowering product quality and kiln production rates. Raw milling processes are either wet or dry, depending on the type of pyroprocessing system(s) at the plant.

When raw materials are dried before grinding or when the physical properties of the moist materials permit handling, the raw materials are usually proportioned with weigh feeder systems located in the process flow ahead of a mill feed bin or the raw mill itself. If required and justified by process economics, raw materials can also be proportioned and blended in large (e.g., 1000 feet long) linear or circular stacker-reclaimer systems, which are sometimes located in closed buildings.

Cement raw materials are received in the raw mill department with a moisture content varying from 2% to 35%. In the dry process, this moisture is usually reduced to less than 1% before or during grinding. Drying prior to grinding is accomplished in impact dryers, drum dryers, paddle-equipped rapid dryers, air separators, or autogenous mills. Drying can also be carried out during grinding of the raw mix in ball and tube mills or roller mills. Thermal energy for drying can be supplied by separate, direct-fired coal, oil, or gas burners that heat the airstream that passes through the drying apparatus or mill. The most efficient and popular source of heat for drying is the hot exit gases from the pyroprocessing system. These gases can come from the kiln, the clinker cooler, the alkali bypass system, or a combination of these sources. Unless the hot gases are supplied from the clinker cooler, the gases passing through dryers and raw mills will contain products of combustion, as well as solid particles. The selection of the drying method depends on the physical properties of the raw materials, the type of pyroprocessing system in the plant, the availability and cost of energy, and the preferences of owners, managers, and vendors.

Ball and tube mills (i.e., long ball mills) are rotating, horizontal steel tubes that contain steel balls and are used to provide comminution or grinding of the raw materals. Air separators are frequently used in conjunction with these mills in the dry process to separate materials of adequate fineness from the coarse particles that must be returned to the grinding mill for additional work (i.e., closed-circuit grinding). The design and operation of these mills and air separators are discussed in the following description of finish milling. The hot gases required for simultaneous drying and grinding in a ball mill system can enter the feed end of the mill and flow concurrently with the raw materials. Otherwise, the unground raw materials and the hot gases are introduced simultaneously into the air separator. Some operators feel that this latter procedure provides for more efficient drying, easier operation of the mill circuit, and early removal from the mill system of those materials that are already sufficiently ground. The separator does, however, experience additional wear.

Vertical roller mills are very popular in new, dry-process portland cement plants because of their relative simplicity and high efficiency. The principle of operation of these mills is similar to that of a mortar and pestle. In this case, the pestle (rolls) is stationary and the mortar (table) rotates. Raw materials are dropped on the rotating table to be crushed and ground between the rolls and the table. Hot gases enter the mill through an annular duct at table height. As ground material is forced off the table into the hot gas stream, it is entrained in the gases, dried, and transported upward to internal separators from which coarse material is returned to the mill by gravity. Figure 4 is a process diagram of a typical vertical roller mill raw milling circuit; Figure 5 shows an installed roller mill.

Materials are transported to, within, and away from dry raw milling systems by a variety of mechanisms, including screw conveyors, belt conveyors, drag conveyors, bucket elevators, air slide conveyors, and pneumatic conveying systems.

The dry raw mix is pneumatically blended and stored in specially constructed silos until it is fed to the pyroprocessing system.

TABLE 1. Fabric Filters in Quarries

	Pulse Jet	Reverse Air/Shaker
acfm	5,000–25,000	5,000–25,000
Fabric type	Polyester	Polyester
Temperature range, °F	<275	<275
A/C ratio[a]	6:1	2.5:1
Inlet loading, gr/acf	5–40	5–40
Expected outlet emissions, gr/acf	0.02	0.02
Particle size out, μm	>1.0	>1.0

[a]Air-to-cloth ratio (acf/ft^2).

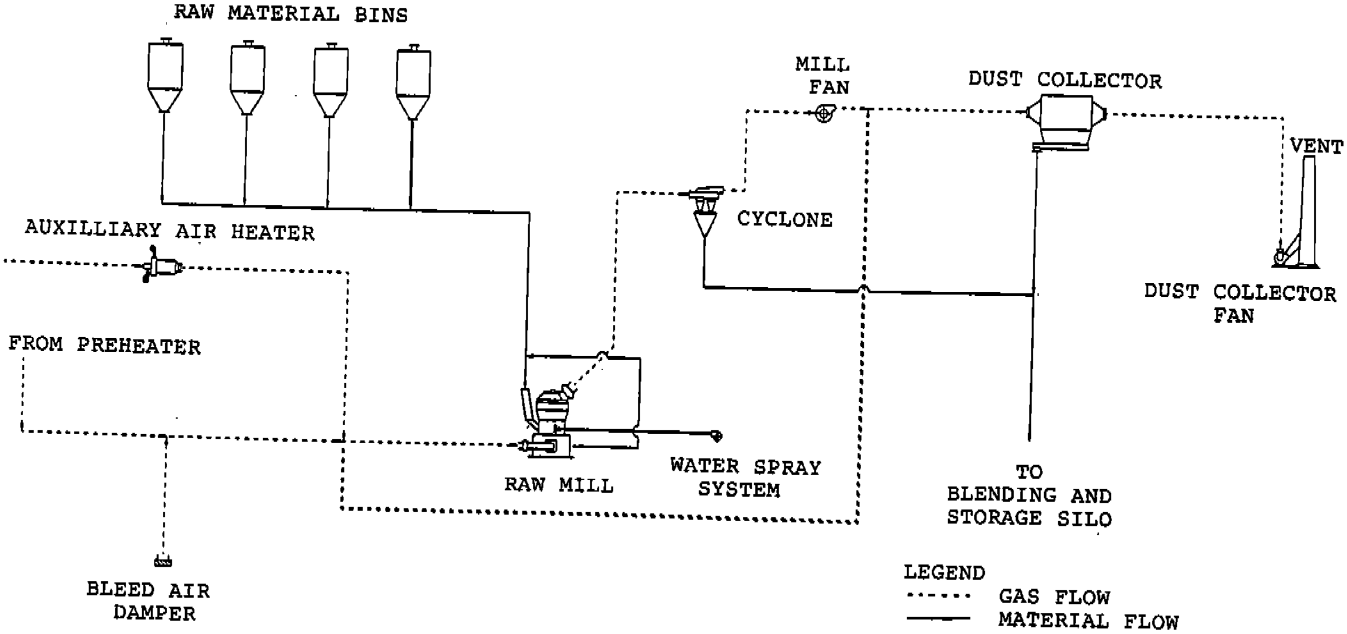

FIGURE 4. Raw Mill Schematic Diagram

In the wet process, water is added to the raw mill during the grinding of the raw materials in ball or tube mills, thereby producing a pumpable slip or slurry of approximately 65% solids. The slurry is agitated, blended, and stored in various kinds and sizes of cylindrical tanks or slurry basins until it is fed to the pyroprocessing system. Until recently, the advantage of the wet process was that the chemical composition of the kiln feed could be controlled more closely since slurries blend more easily than powders. Modern equipment can now blend raw meal powders satisfactorily.

In the semidry process, the dry raw mix is transformed into pellets by the addition of water in a pelletizing device such as a pan pelletizer. These pellets are then directly fed to a moving grate preheater at the start of the pyroprocessing system. In a little-used European system described as the semiwet process, slurry is filtered in filter presses to reduce the moisture content. Nodules of the filter cake are formed in kneading mills and pans before the raw mix is fed to a grate preheater kiln system.

Air Emissions Characterization

The raw material feeders, stackers, blenders, and reclaimers can produce fugitive dust emissions. Transfer points on belt conveyor systems and bucket elevators that serve to transport raw materials from storage to the raw mill department can also generate fugitive dust emissions.

The dry raw mills and the auxiliary equipment are all designed to run under negative pressure to suppress particulate emissions. Nevertheless, poorly designed or maintained seals and closures throughout the system can result in fugitive dust emissions. If these systems experience positive pressure through a fan failure or other cause, short-term particulate emissions can be expected until the system can be shut down.

During colder weather, the vents from dryers, raw mills, and air separators may exhibit a steam plume that is sometimes confused with particulate emissions. The condensate will dissipate within a few feet of the emission point. Fabric filters in the vent circuits for dryers, raw mills, and air separators must be insulated to prevent internal moisture

resultant blinding of bags.

ılate emissions from the wet grinding

materials-handling systems ahead of

Air Pollution Control Measures

Dust collecting devices in the raw mill and raw mix storage areas include mechanical cyclones, fabric filters, and, rarely, ESPs. Mechanical collectors are usually used in series with one of the other devices. The collected dust is returned to the mill system or raw mix stream.

Typical fabric filters found in the raw mill area are pulse jets in the newer or upgraded plants and reverse air or shaker types in the older plants. Cartridge-type filters can be found on materials-handling equipment. Table 2 presents typical data for independent raw mill systems. Vertical mills are most often associated with the pyroprocessing system. The air pollution control measures for these mills will be found in the following section on pyroprocessing.

FIGURE 5. Vertical Roller Mill

PYROPROCESSING

Process Description

The third step in the manufacture of portland cement is the pyroprocessing of the raw mix into portland cement clinker. Clinkers are gray-colored, glass-hard, spherical-shaped nodules that generally range from ⅛ inch to 2 inches in diameter. The clinkers are predominantly composed of the cement minerals, dicalcium silicate, tricalcium silicate, calcium aluminate, and tetracalcium aluminoferrite, that result from chemical reactions between the cement raw materials that are completed at the temperature of incipient fusion. The chemical reactions and physical changes that describe the transformation are very complex. A simplified version of the major sequential events is as follows:

TABLE 2. Fabric Filters for Raw Mill Systems

	Pulse Jet	Reverse Air/Shaker	Cartridge
acfm	10,000–50,000	10,000–50,000	2,000–10,000
Fabric type	Polyester	Polyester	Paper, polyester
Temperature range, °F	<275	<275	<180, 275
A/C ratio	5:1	2.5:1	<2:1, N/A
Inlet loading, gr/acf	5–20	5–20	5–20
Expected outlet emissions, gr/acf	0.02	0.02	0.02
Particle size out, μm	>0.5	>0.5	>0.5

- Evaporation of free water.
- Evolution of combined water in the argillaceous components.
- Calcination of the calcium carbonate to calcium oxide.
- Reaction of calcium oxide with silica to form dicalcium silicate.
- Reaction of calcium oxide with the aluminum and iron-bearing constituents to form the liquid phase.
- Formation of the clinker nodules.
- Evaporation of volatile constituents (e.g., sodium, potassium, chlorides, and sulfates).
- Reaction of excess calcium oxide with dicalcium silicate to form tricalcium silicate.

The pyroprocessing system is generally described as containing three steps or zones: (1) drying or preheating, (2) calcining, and (3) burning or sintering. The pyroprocessing is accomplished in the burning or kiln department. The word "burning" is jargon that is used in the cement industry to describe the intense heat in the kilns. None of the constitutents of the cement raw mix actually combust during pyroprocessing.

The raw mix is fed to the pyroprocessing system as a slurry in the wet process, as a powder in the dry process, and as moist pellets in the semidry process. A rotary kiln is the common element in all pyroprocessing systems, and it will always contain the burning zone and all or part of the calcining zone. All of the pyroprocessing steps occur in the rotary kiln in wet-process and long, dry-process (i.e., no preheater) systems. The application of chemical engineering principles to cement pyroprocessing has resulted in equipment additions to the rotary kiln system that can accomplish preheating and most of the calcining more quickly and efficiently outside of the kiln. In the semidry process, the drying or preheating step and a small degree of calcination are accomplished outside the kiln on a system of moving grates through which hot kiln gases are passed.

Rotary kilns are rotating, cylindrical steel tubes with length-to-diameter ratios in the approximate range of 15:1 to 35:1. The kiln size and relative proportions are determined by the process type and productive capacity of the pyroprocessing system. Wet-process kilns of over 700 feet in length and up to 23 feet in diameter are in operation. However, many wet- and all dry-process kilns are shorter—and dry-process kilns that are equipped with preheaters are shorter yet. The kiln rotates about the longitudinal axis, which is slightly inclined to the horizontal, at a speed of from 1 to 3.5 rpm. Refractory material lines the kiln to protect the steel shell from the intense heat and to retain heat within the kiln. The inclination and rotation of the tube result in the transport of solid materials from the upper or feed end to the lower or discharge end. The solids (i.e., load) occupy no more than 15–20% of the internal volume of the rotary kiln inside the refractory. There will be hundreds of tons of material within the kiln at any particular time. Material transit time is measured in hours. Heat energy is supplied to the discharge end of the kiln through combustion of a variety of fuels. The flow of hot, gaseous combustion products is, therefore, countercurrent to the material flow. Heat is transferred from the flame and hot gases to provide the driving force for the required chemical reactions. The solid material is heated to more than 2700°F by flame temperatures in excess of 3400°F.

Wet-process and long, dry-process pyroprocessing systems consist solely of the simple rotary kiln. Usually, a system of chains is provided at the feed end of the kiln in the drying or preheat zones to improve heat transfer from the hot gases to the solid materials. These chains are attached to the inside of the kiln shell in various patterns. As the kiln rotates, the chains are raised and exposed to the hot gases. Further kiln rotation causes the hot chains to fall into the cooler materials at the bottom of the kiln, thereby transferring the heat to the load.

Dry-process pyroprocessing systems have been improved in thermal efficiency and productive capacity through the addition of one or more cyclone-type preheater vessels in the gas stream after the rotary kiln. The vessels are arranged vertically, in series, and are supported by a structure known as the preheater tower. Hot exhaust gases from the rotary kiln pass countercurrent through the downward-moving raw materials in the preheater vessels. Compared with the simple rotary kiln, the heat transfer rate is significantly increased, the degree of heat utilization is more complete, and the process time is markedly reduced owing to the intimate contact of the solid particles with the hot gases. The required length of the rotary kiln is thereby reduced.

The hot gases from the preheater tower are often used as a source of heat for the drying of raw materials in the raw mill. The mechanical collectors, fabric filters, and/or ESPs that follow the raw mill are production machines as well as pollution control devices.

Additional thermal efficiencies and productivity gains have been achieved by diverting some fuel to a calciner vessel at the base of the preheater tower. At least 40% of the thermal energy is required in the rotary kiln. The amount of fuel that is introduced to the calciner is determined by the availability and source of the oxygen for combustion in the calciner. If available and allowed by environmental regulations, calciner systems can use lower-quality fuels (e.g., less volatile matter) and thereby further improve process economics.

In preheater and calciner kiln systems, it is often necessary to remove the undesirable volatile constituents through a bypass system located between the feed end of the rotary kiln and the preheater tower. Otherwise, the volatile constituents would condense somewhere in the preheater tower and subsequently recirculate to the kiln. Buildups of these condensed materials can also restrict process flows by blocking gas and material passages. In a bypass system, a portion of the kiln exit gas stream is withdrawn and quickly cooled by air or water to condense the volatile constituents to fine particles. The solid particles are removed from the gas stream by fabric filters or ESPs.

Figure 6 is a flow diagram of a four-stage preheater with calciner pyroprocessing system that is equipped with an alkali bypass and a reciprocating grate clinker cooler. Figure 7 shows a four-stage preheater kiln system next to the traditional rotary kiln that it replaced.

Air Emissions Characterization

In simple rotary kiln systems, some finely divided particles of raw mix, calcined kiln feed, clinker dust, and volatile constituents (e.g., potassium sulfate) are entrained in the exiting gas stream. These particles are almost entirely removed from the gas stream before the combustion products are vented to the atmosphere. Affected pyroprocessing systems always meet or exceed the NSPS for particulate emissions from portland cement plants. Even those plants built prior to 1971 that are not subject to NSPS usually meet these standards for particulate emissions.

The powder that is collected from the kiln exhaust gases is known as cement kiln dust (CKD). Some plants return all or a portion of the CKD to the process; others completely remove it from the process. The chemical composition and physical state of the CKD depend on the type of pyroprocessing system, the chemical composition of the raw materials and fuel, and the state of the process at any given time. The chemical composition of the CKD that is caught in the last field of an ESP is very similar to that of the particulate emissions from the kiln stack. The same generalization cannot be made about CKD caught in a fabric filter. Specifications for portland cement often contain limitations on the quantity of sodium and potassium. Since the volatile oxides and salts of these metals tend to migrate

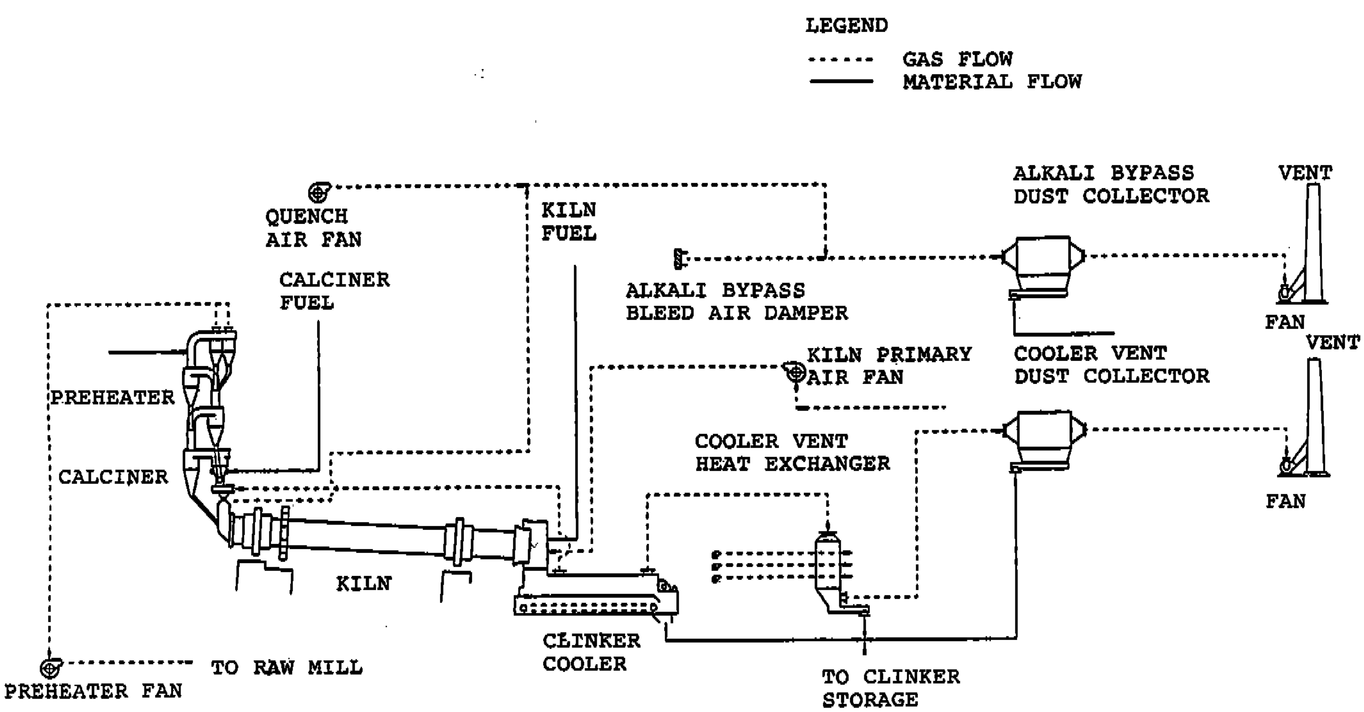

FIGURE 6. Pyroprocessing System Schematic Diagram

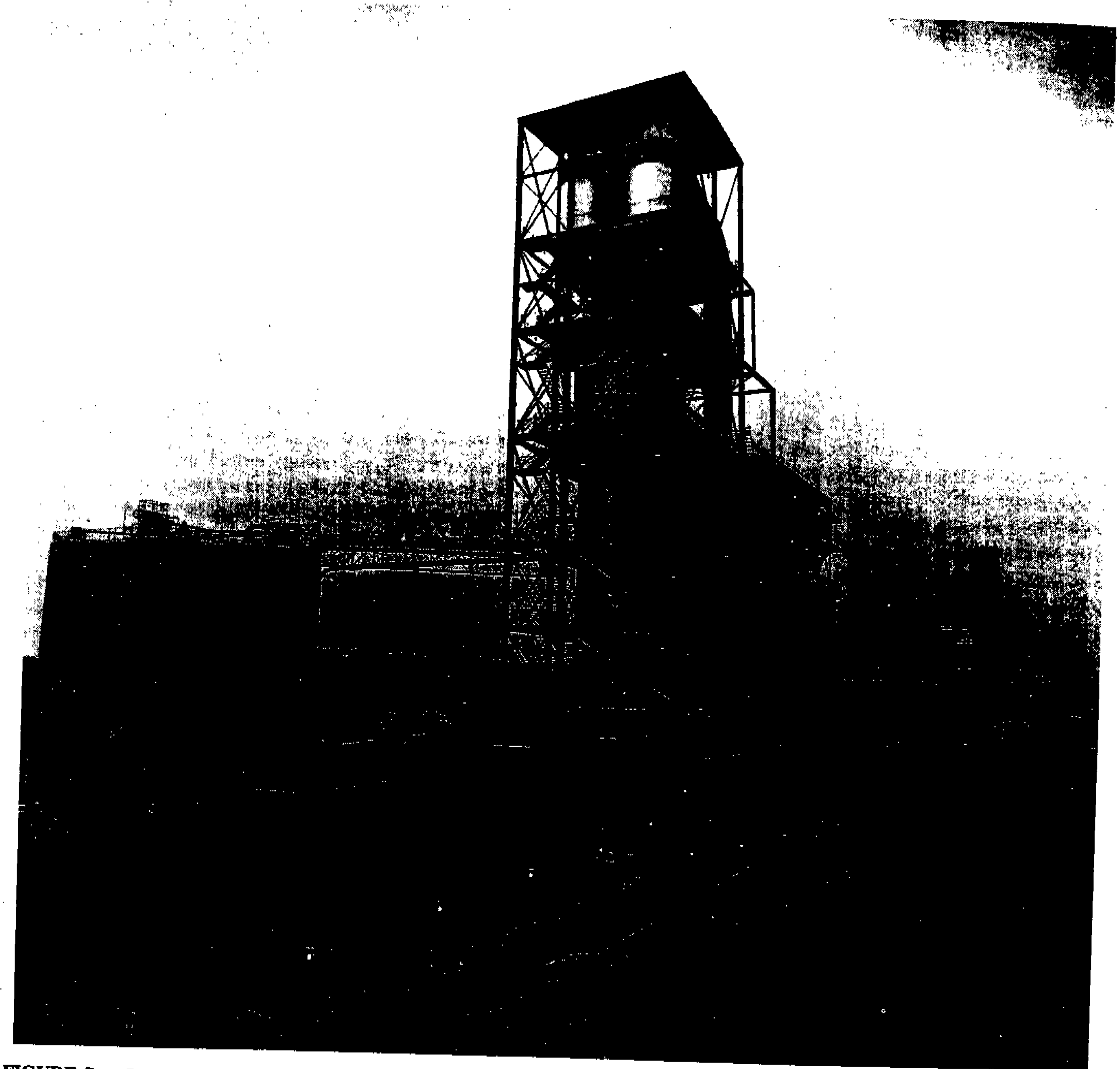

FIGURE 7. Preheater and Rotary Kilns

or partition to the CKD, some or all CKD is frequently removed from the pyroprocessing system to meet product quality standards. Bypass CKD is rich in sodium and potassium and is usually not returned to the process. The CKD from a preheater tower has the same general chemical and physical composition as the kiln feed and is returned to the process. The CKD that is removed from the system is used for a variety of beneficial purposes (e.g., waste stabilization) or managed at the cement plant in a monofill. The handling, storage, and deposition of CKD can result in fugitive dust emissions.

The bypass gases may be used in the raw mill, vented through a separate stack, or combined with kiln gases in the main kiln stack after particulate removal. The preheater gases may be vented to the atmosphere after particulate removal or used in the raw mill. Regardless of the treatment or use of combustion products and tempering air from the pyroprocessing system, when these gases are vented to the atmosphere, they must meet the NSPS opacity limit of 20% and the mass emission limit of 0.015 kg of particulate emissions per metric ton (0.30 lb/ton) of kiln feed (dry basis) on a combined basis from all emission points if the plant was built or modified after August 17, 1971.

The principal gaseous emissions from the pyroprocessing system in a typical descending order of volume are nitrogen, carbon dioxide, water, oxygen, nitrogen oxides, sulfur oxides, carbon monoxide, and hydrocarbons. The volumetric composition range is from about 73% to less than 10 ppm. The last four gases are the primary constituents of environmental concern, with the latter two usually of environmental interest only when waste-derived fuel (WDF) is being burned.

In 1982, a Portland Cement Association survey showed that the average SO_2 and NO_x emissions for approximately 50 reporting kilns were 8.41 and 4.62 pounds per ton of clinker respectively. The standard deviation of the survey results for each constituent was nearly equal to the mean value. The frequency distribution revealed a wide range of values.[5] It is impossible, therefore, to characterize the industry for gaseous emissions of SO_2 and NO_x with a single number or narrow numerical range. Each individual pyroprocessing system has its own emission characteristics and the SO_2 and NO_x emissions from proposed or untested pyroprocessing systems are very difficult to predict accurately. Extensive continuous testing of a few cement plants has shown that SO_2 and NO_x emissions from a single source will vary with time over a rather large range for a variety of reasons (e.g., 70–700 lb/h of SO_2). Short-term tests, such as EPA Methods 6 and 7, can lead to very erroneous conclusions regarding SO_2 and NO_x emissions since these methods represent nearly instantaneous process conditions.

Sulfur input to a pyroprocessing system is only from feed and fuel. The relative amounts of sulfur in the feed and fuel, the system design, the chemical form of the input sulfur, and the process conditions, such as the presence of an oxidizing or reducing atmosphere in the kiln, are the variables that determine the quantity of SO_2 emissions at any given time. Oxides of nitrogen result primarily from the combustion of fuel, although nitrogenous constituents in the raw mix may make a contribution to NO_x emissions. The two basic sources of nitrogen oxides from fuel combustion are known as fuel and thermal NO_x. Nitric oxide (NO) predominates among the oxides of nitrogen that are emitted from cement pyroprocessing systems.

The NSPS for cement plants recognize the current uncertainty about SO_2 and NO_x emission rates and the lack of economically feasible control technology through the absence of any emission standards for these pollutants. Regulators, however, often find it necessary to include air pollution permit limitations on SO_2 and NO_x emissions to meet prevention of significant deterioration (PSD) regulatory requirements.

Air Pollution Control Measures

Air pollution control equipment on the kiln system includes reverse air fabric filters and ESPs. Acoustic horns are sometimes used in both devices to assist in cleaning. Table 3 presents typical data.

TABLE 3. Kiln System Dust Collectors

	Reverse Air	Precipitator
acfm	50,000–300,000	50,000–300,000
Fabric type	Fiberglass	N/A
Temperature range, °F	350–500	350–650
A/C ratio	1.5:1 net	SCA: 350–500[a]
Inlet loading, gr/acf	4–18	4–18
Expected outlet emissions, gr/acf	0.02	0.02
Particle size out, μm	>0.5	>0.5

[a]Specific collecting area (ft²/1000 ft³).

Cement kiln systems have highly alkaline internal environments that can absorb up to 95% of potential SO_2 emissions. Exceptions to the generalization are found in systems that have sulfide sulfur (pyrites) in the kiln feed. Without unique design considerations or changes in raw materials, the sulfur absorption rate may be as low as 50%. The cement kiln system itself has been determined to be best available control technology (BACT) for SO_2 emissions. Various reports have appeared in the literature that fabric filters on cement kilns absorb SO_2. Generally, this allegation is not true. There must be an absorbing reagent (e.g., calcium oxide) in the filter cake for SO_2 capture to occur. Without the presence of water, which is undesirable in the operation of a fabric filter, calcium carbonate is not an absorbing reagent. It has been observed that as much as 50% of the SO_2 can be removed from the pyroprocessing system exhaust gases when this gas stream is used in a raw mill for heat recovery and drying. In this case, moisture and calcium carbonate are simultaneously present for sufficient time to accomplish the chemical reaction with SO_2.

Energy-efficient pyroprocessing systems have the potential to emit less SO_2 than inefficient systems because of the lower sulfur input from the fuel. Similarly, raw materials with the lowest content of sulfide sulfur usually result in the lowest SO_2 emissions. Selective quarrying or a change in raw materials can lower the input of sulfur to the pyroprocessing system.

A mechanism for the control of NO_x emissions from cement kilns has not been established, although several possibilities exist. Stable kiln operation, such as is found in a successful precalciner system, appears to reduce cumulative, long-term NO_x emissions. Short-term spikes of NO_x emissions during process upsets are currently unavoidable since a higher than normal input of heat from the combustion source is required to restore the process to equilibrium. Several equipment vendors sell burner configurations for the rotary kiln that are alleged to reduce NO_x. These burners have met with varying degrees of success in reducing NO_x emissions. A form of staged combustion can be used on precalciner kilns to reduce NO_x. Fuel is burned under reducing conditions in the riser duct from the rotary kiln to the calciner to generate carbon monoxide. This carbon monoxide chemically reduces the NO_x generated in the kiln to elemental nitrogen. The oxygen-deficient gases thereby generated are then supplied to the calciner further to reduce

NO_x generation in that low-temperature combustion source. It is theoretically possible to inject ammonia or urea into a preheater tower at a point where gas temperatures are about 1800°F to achieve a beneficial reaction between ammonia and NO_x. To date, this technology has not been demonstrated in the United States. Ammonia injection is not possible in pyroprocessing systems with only a rotary kiln since the point of optimum temperature is not accessible through the kiln shell. Other possibilities for NO_x emissions reduction exist in the recirculation of flue gas as oxygen-deficient primary air in the rotary kiln and alternative or low-nitrogen fuels and/or raw materials.

CLINKER COOLING

Process Description

The clinker produced in a rotary kiln is cooled in a device called a clinker cooler. This process step recoups up to 30% of the heat input to the kiln system, locks in desirable product qualities by freezing mineralogy, and makes it possible to handle the cooled clinker with conventional conveying equipment.

The more common types of clinker coolers are (1) reciprocating grate, (2) planetary, and (3) rotary. In these coolers, depicted in Figure 8, the clinker is cooled from about 2000°F to 350°F by ambient air that passes through the clinker and into the rotary kiln, where it nourishes the combustion of fuel. In the reciprocating grate cooler, lower clinker discharge temperatures are achieved by passing additional airstreams through the clinker. This air cannot be utilized in the kiln for efficient combustion so it is vented to the atmosphere, used for drying coal or raw materials, or used as a source of heated combustion air in a precalciner. Water sprays are sometimes used to lower clinker discharge temperatures from planetary and rotary coolers.

The reciprocating grate cooler consists of a horizontal box of rectangular cross section that houses horizontal rows of fixed and movable grate plates that bisect the cross section. A grate plate has holes for passage of air and is about 1 foot square. A row may consist of 6 to 12 grate plates, depending on the cooler capacity. The clinker cooler is normally oriented so that the clinker continues its flow parallel to the longitudinal axis of the kiln as it is passed along the top of the grates. The reciprocating movement of every second row of grates forces the clinker through the cooler. The ambient air is forced through the grates and the bed of clinker from the chamber below by a series of fans along the length of the cooler.

Planetary coolers are attached to the kiln shell and rotate with it. Typically, 10 coolers are attached to a single rotary kiln. The clinker drops into the coolers through holes in the kiln shell and is cooled by ambient air that is drawn into the kiln through the cooler tubes. The rotation of the tubes and the internal lifting mechanisms create a cascading of the clinker through the cooling air. The inclination of the kiln and planetary tubes ensures transport of the clinker toward the outlet of the tubes.

A rotary cooler is an independently rotating tube that receives hot clinker by gravity from the rotary kiln discharge point. The clinker is cooled in essentially the same manner as in a planetary cooler with ambient air being drawn through cascading streams of clinker.

Planetary and rotary coolers are vented exclusively into the kiln with an amount of air equal to the combustion air requirements, thereby eliminating the need for a cooler excess air vent. The induced-draft fan for the kiln creates a suction of a few tenths of an inch of pressure, water gauge, at the cooler inlet, which is sufficient to supply the required combustion air.

The reciprocating grate cooler will deliver an identical amount of combustion air to the kiln as the other coolers; however, since this cooler provides for better cooling of the clinker as a result of more airflow, an excess airstream is created. This gas stream must be cleaned of clinker dust before it is vented to the atmosphere.

Air Emissions Characterization

The collected dust from clinker coolers is fairly coarse, with only about 0–15% of it finer than 10 μm. This abrasive dust consists solely of cement minerals and is returned to the process.

The quantity of air used for cooling is about 1 to 2 pounds per pound of clinker, depending on the efficiency of cooling and the desired temperature of the clinker and vent gas. If some of the gases are used for the drying of coal or for other purposes, then the volume of gas to be cleaned at the cooler vent may be reduced by 10–100%.

The dust content of the cooler exhaust gases is affected by the granular distribution of the clinker, the degree of burning of the clinker, the bulk density of the clinker (i.e., liter weight), and the flow rate of the cooling air. Frequently, a clinker breaker (i.e., hammermill) is located at the discharge of the cooler and may increase the dust burden.

If applicable, NSPS set an allowable mass emission limit of 0.050 kg of particulates per metric ton (0.10 lb/ton) of kiln feed (dry basis) from the cooler vent stack. An opacity limit of 10% also applies to the cooler stack. If the cooler gases are used for drying in the raw mill, the same mass emission and opacity limits apply to the raw mill vent.

Air Pollution Control Measures

Upsets in the kiln can rapidly increase the vent gas temperature to 1000°F and the dust load to 13–50 gr/ft^3. In older plants, there may be bypass arrangements to vent these gases directly to the atmosphere until the upset is over. These particulate emission excursions are not permitted in newer plants. Gas temperatures are controlled to protect the dust collector through the use of tempering bleed air, water

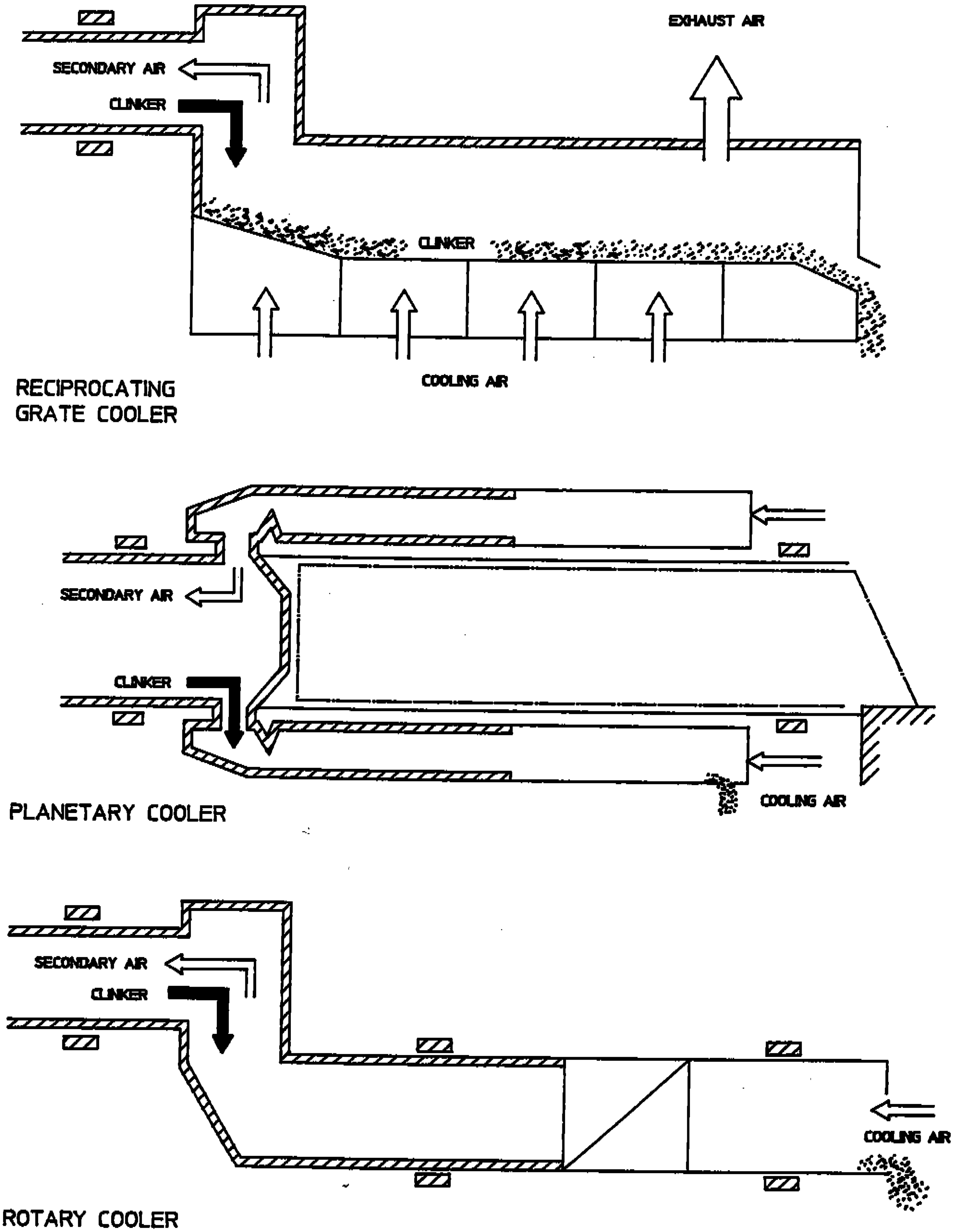

FIGURE 8. Types of Clinker Coolers

TABLE 4. Fabric Filters on Clinker Coolers

	Pulsed Plenum/Pulse Jet	Reverse Air	Precipitator
acfm	20,000–100,000	20,000–100,000	20,000–100,000
Fabric type	Nomex, polyester	Nomex, fiberglass	N/A
Temperature range, °F	<425, 275	<500	350–600
A/C ratio	5:1 net	2:1 net	SCA: 350–500
Inlet loading, gr/acf	5–10	5–10	5–10
Expected outlet emissions, gr/acf	0.02	0.02	0.02
Particle size, μm	>0.5	>0.5	>0.5

sprays, or an air-to-air heat exchanger. Alternatively, a gravel bed filter, which can tolerate the high temperatures, can be used. All of these methods have costs and limitations and there is no clear universal solution. In a few plants with air-to-air heat exchangers, the cooled air is recirculated to the cooler, thereby eliminating the need for a clinker cooler vent stack.

The dust collectors used on reciprocating grate clinker coolers are most often fabric filters, but ESPs and gravel bed filters are also used. Sometimes these collectors are preceded by a mechanical cyclone or multiclone dust collector. Typical fabric filters on clinker coolers are pulse jets or pulsed plenums in the newer plants and reverse air types in the older plants. In the older plants, the cooler dust collector may be a smaller version of the kiln fabric filter. Table 4 presents typical data.

Gravel bed filters are somewhat unique to the cement industry and may not be described elsewhere in this manual. The gravel bed is contained in several cylindrical compartments and consists of quartz granules of about 2–5 mm in diameter lying on a wire mesh. The dirty gases pass through the bed of quartz. The circuitous path of the gas through the bed causes the dust to drop out of the gas stream and remain in the bed. The beds are individually cleaned at regular intervals by reverse airflow and agitation of the gravel with an internal rake system. The advantage of a gravel bed filter is its ability to tolerate high-temperature excursions without permanent damage. The gravel bed filter is somewhat sensitive to flow volume changes that tend to result in particulate emissions that are higher than normal. Normal particulate emissions from a gravel bed filter are comparable to other dust collection devices on clinker coolers.[6]

CLINKER STORAGE

Process Description

To allow for necessary operational flexibility, a cement plant usually is able to store from 5% to 25% of its annual clinker production capacity. The storage requirement largely depends on market conditions.

The material-handling equipment used to transport clinker from the clinker coolers to storage and then to the finish mill department is similar to that used to transport raw materials. Belt conveyors, screw conveyors, deep bucket conveyors, and bucket elevators are popular. Where possible, drag chains are used because they are less sensitive to abrasion and high temperatures during upset conditions. Gravity drops and transfer points in the conveying and storage systems are normally enclosed and connected to dust collectors.

Older plants were typically designed to store clinker in partially enclosed buildings and storage halls or in outside piles. Newer and modernized plants store at least some clinker in fully enclosed structures or cylindrical, vertical silos, but may also use the other types of storage facilities.

Air Emissions Characterization

Dust in the clinker has a tendency to become airborne during handling. The character of the dust varies by plant and existing process conditions. Dust caught in the clinker cooler exhaust dust collector is usually returned to the clinker stream and can result in reentrainment of this material in air during subsequent handling. Usually, clinker dust is a small proportion of clinker production and is relatively coarse, but some kilns normally produce dusty clinker. During process upsets when the kiln falls below clinkering temperatures and runs "raw," material that is discharged from the kiln is said to be "unburned" (i.e., not fused into clinker) and very dusty.

Air Pollution Control Measures

The air pollution control measures and equipment used in clinker handling systems are similar to those described for raw milling.

The free fall of clinker onto storage piles usually creates visible, fugitive particulate emissions. This dust generation can be reduced by discharging the clinker to piles through a simple device known as a rock ladder or by using variable-height, automatic, stacker belt conveyor systems.

Fugitive dust emissions from open storage piles are mitigated by rain and snow, which cause a crust to form on the piles. Wind breaks and pile covers (e.g., tarpaulins) have also been used to minimize fugitive clinker dust with mixed success. Clinker in open piles is usually reclaimed with mobile equipment, such as front-end loaders. Clinker in storage halls is frequently handled with overhead bucket cranes. Some fugitive clinker dust from operations around open storage piles is usually observed and very difficult to control.

FINISH MILLING

Process Description

The final step in the manufacture of portland cement is the grinding of portland cement clinker to a fine powder. Up to 5% by weight of gypsum and/or natural anhydrite is added to the clinker during grinding to control the setting time of the cement. In the industry, this step is called finish grinding or finish milling and is accomplished in the finish mill department. Small amounts of various other chemicals may be added to the cement during finish grinding to function as processing additions (e.g., grinding aids) or to impart special properties to the cement or resulting concrete (e.g., flowability, air entrainment). Small amounts of water are often sprayed into a cement finish mill to aid in cooling the mill and the cement. Other specification and nonspecification cements with unique properties and constituents can be prepared in the finish mill department. For example, pozzolans or blast furnace slag can be mixed with portland cement clinker and gypsum during the finish grinding process to produce blended cements. In the United States, the most often produced speciality cement derived from portland cement clinker is masonry cement. Typically, a masonry cement is composed of equal portions of portland cement clinker and limestone to which 2–4% by weight of gypsum is added. In addition, chemicals that impart the properties of air entrainment, plasticity, and water repellency to a mortar are added. Each manufacturer of masonry cement has a proprietary formula for its product.

Finish milling is almost exclusively accomplished in ball or tube mills. These mills are rotating, horizontal steel cylinders containing slightly less than half their volume in steel alloy balls, which are called grinding media. These balls can range in size from 4 inches to ½ inch in diameter. Clinkers and gypsum are fed into one end of the mill (feed end) and partially ground portland cement exits from the other end (discharge end). A finish mill might be divided into two or more internal compartments in which the grinding media are segregated by size. The larger balls are at the feed end of the mill. The compartments of the mills are formed by slotted division heads that cover the entire cross section of the mill. The slots are small enough to retain the grinding media in the proper compartment, but large enough to allow the partially ground cement to flow toward the discharge end. At the discharge end of the mill, there is a similar slotted barrier called a discharge grate, which serves to keep the balls in the mill while allowing partially ground cement to exit. A given particle of cement remains in the mill for three to seven minutes. The ends (heads) and sides (shells) of the mills are lined with replaceable alloy steel plates or castings that undergo the wear and abrasion of the grinding process. Mill shell linings are sometimes designed so that the balls are segregated by size during mill operation, thereby eliminating the need for division heads.

Cement is usually ground in a closed circuit with an air separator. This continuously operating device is used to separate particles of cement of acceptable size in the material discharged from the mill from those particles that have not been fully ground. The large particles (i.e., tailings) are returned to the mill and reintroduced to the feed end along with new feed. A figure that is 100 times the ratio of the weight of the returned tailings to the weight of new feed is called the circulating load and is expressed in percent. Circulating loads in the range of 200–500% are typical, but higher and lower circulating loads are found in acceptable mill circuits. Air separators are mechanical devices that use centrifugal force, gravity, and an ascending air current to separate the cement particles. Older air separators have a poor separation efficiency. Equipment manufacturers recently developed high-efficiency separators that are included in most new finish mill projects and are popular retrofit items because of the increased efficiency, lower operating costs, and sometimes improved product performance.

Another device of increasing popularity in the finish mill department is the roll crusher. This device accomplishes the initial size reduction of the clinker and the gypsum outside of and prior to the ball mill. The efficiency and/or the productive capacity of a given ball mill is thereby increased at potentially lower grinding temperatures.

For a variety of reasons, cement customers usually demand cement that is at temperatures of less than 100–150°F when delivered. Cement grinding temperatures can reach 350°F. Water-supplied cement coolers (i.e., heat exchangers) are often installed in the material flow path following the finish mill to reduce the cement temperatures prior to product storage. The high-efficiency separator circuits, with their associated high volumes of mill vent air, provide better cooling of the cement than conventional mill circuits. No air pollution problems are associated with the closed heat exchangers.

Figure 9 is a process flow sheet for a finish mill circuit that includes a roll crusher and a high-efficiency air separator. Figure 10 shows a two-compartment ball mill in finish mill service as viewed from the feed end of the mill.

Air Emissions Characterization

Particulate emissions from mill vents, air separator vents, and material-handling system vents constitute the air pollution concerns in the finish mill department.

About 30–40% of the particles of ordinary Type I portland cement are finer than 10 μm. For Type III, high-early-

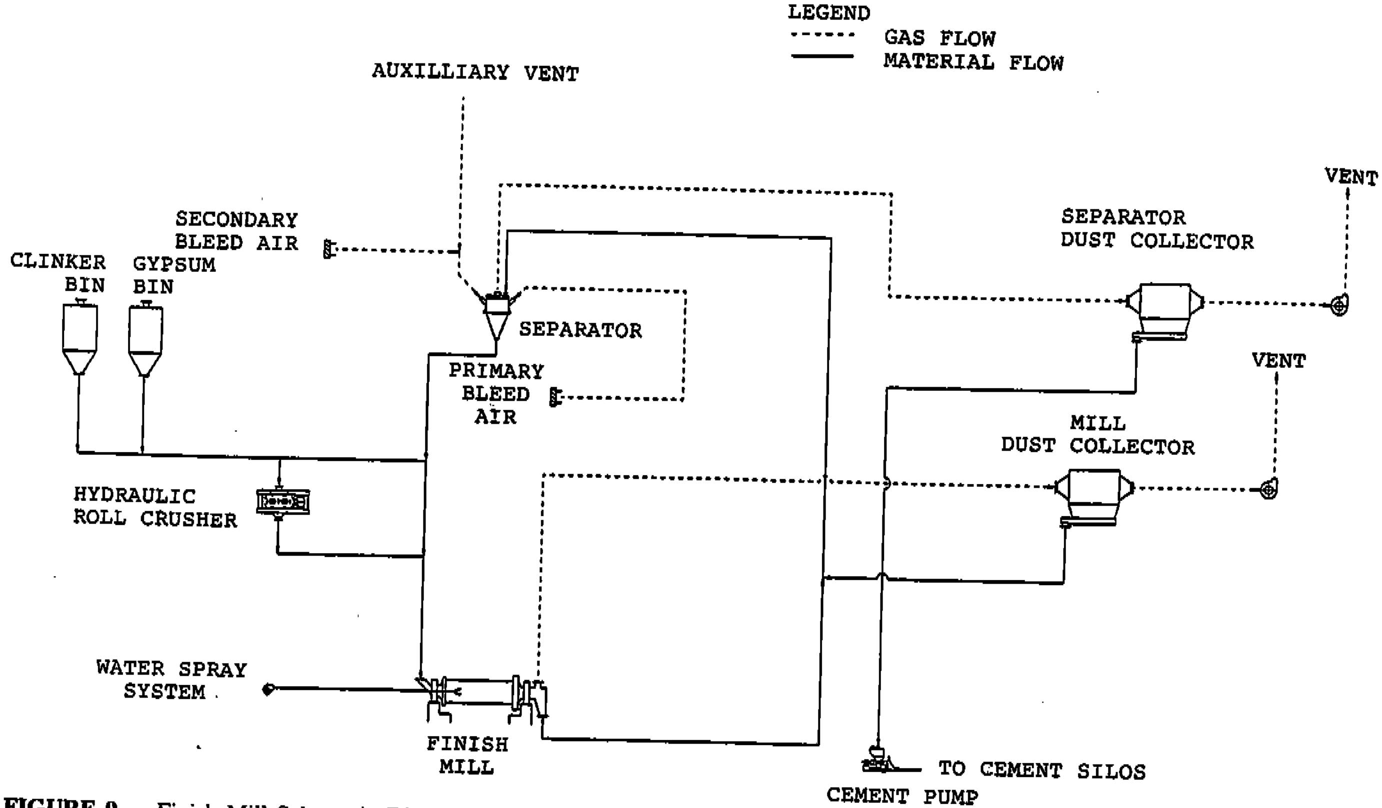

FIGURE 9. Finish Mill Schematic Diagram

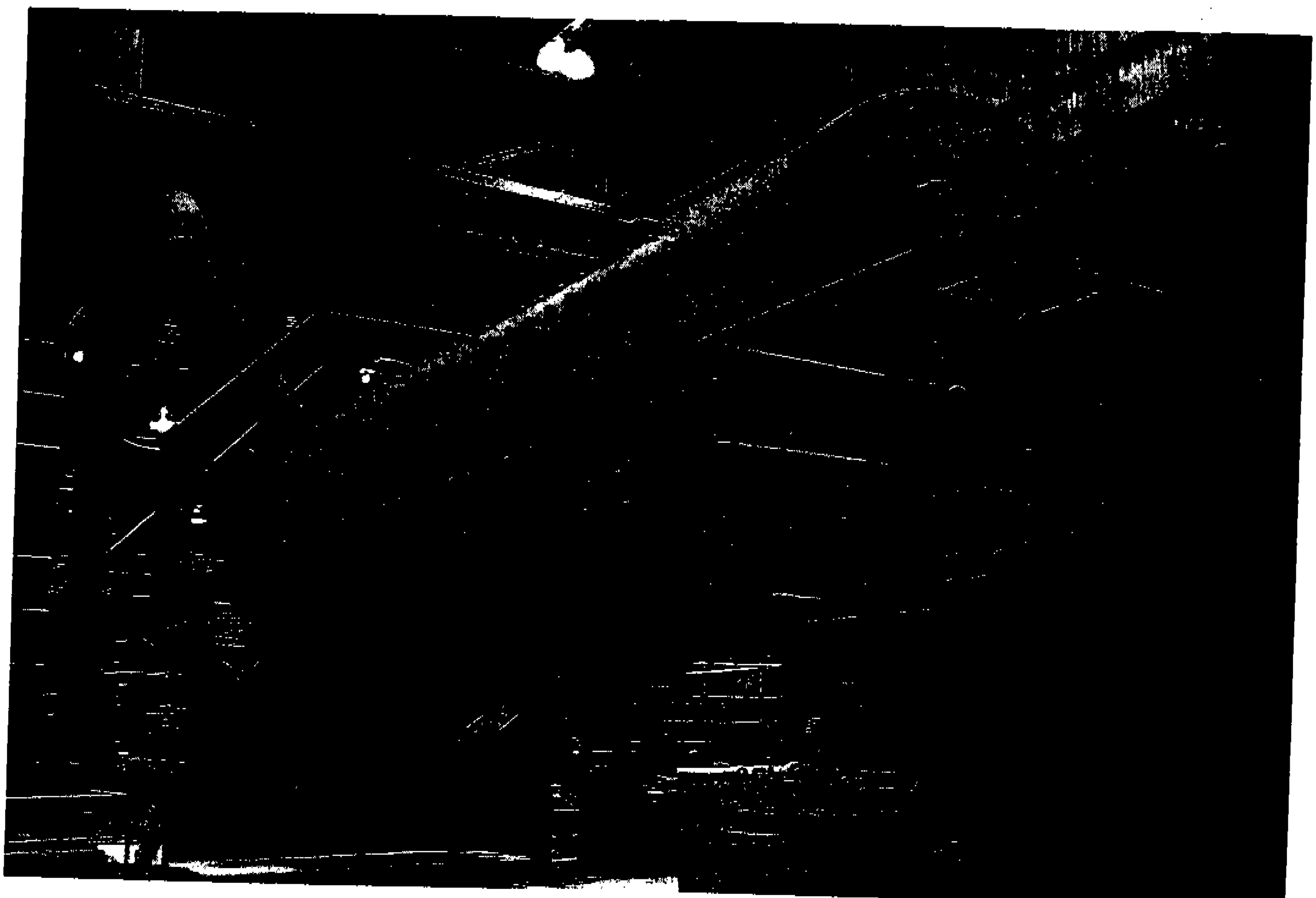

FIGURE 10. Finish Mill

TABLE 5. Fabric Filters for Finish Mill Systems

	Reverse Air/Shaker	Pulse Jet	Pulsed Plenum
acfm	10,000–30,000	10,000–30,000	10,000–30,000
Fabric type	Polyester	Polyester	Polyester
Temperature range, °F	<275	<275	<275
A/C ratio	2.5:1	4:1	5:1
Inlet loading, gr/acf	5–20	5–100	5–100
Expected outlet emissions, gr/acf	0.02	0.02	0.02
Particle size out, μm	>0.5	>0.5	>0.5

strength portland cement, the percentage of particles finer than 10 μm increases to the 45–65% range. Typically, about 90% of portland cement will pass a 325-mesh (44-μm) sieve. The potential air pollution problems associated with the manufacture, handling, and transportation of portland cement have their origin in the number of very fine particles in the product.

Air Pollution Control Measures

Emissions from finish mills are adequately controlled by fabric filters. The fabric filters most often found on new or upgraded plants are the pulse-jet and pulsed-plenum types. Reverse air/shaker fabric filters are typically found in older plants. In almost all cases, pulse-jet or pulsed-plenum fabric filters are installed in conjunction with high-efficiency separators. Tables 5 and 6 present typical details.

The cement dust caught in a fabric filter is returned to the process. In colder weather, the water that is used for internal mill cooling can produce a steam plume at the mill baghouse vent. This condensate plume is sometimes confused with excessive particulate emissions, but it will dissipate within a few feet of the vent opening. Fabric filters on finish mill systems that use cooling water must be well insulated to prevent condensation within the baghouse and subsequent blinding of the bags.

PACKING AND LOADING

Process Description

Portland cement is pneumatically conveyed from the finish mill department to large, vertical, cylindrical concrete storage silos in the packhouse or shipping department. Mechanical transfer systems, such as bucket elevators, belt conveyors, screw conveyors, and air slide conveyors, supplement the pneumatic system.

The number and capacity of the storage silos depend on the capacity of the plant, the number (i.e., types) of cements in the product mix, the marketing strategy of the company, and the weather-driven shipping pattern.

Portland cement is withdrawn from the storage silos by a variety of feeding devices and conveyed to loading stations in the plant or directly to transport vehicles using the same kinds of material-transfer systems that were used to put the cement into the silos. Most of the portland cement is shipped from the plant in bulk by rail or truck transport. Those plants located adjacent to water transportation routes usually serve some customers or distribution terminals by barge or ship.

Portland cement is also shipped in multiwall paper bags with a capacity of 94 pounds. These bags are filled on automatic or semiautomatic packing machines. During filling, each bag is vented to allow the escape of displaced air. The filled bags are then manually or mechanically palletized for shipment. A few customers may still require loads of unpalletized bags of cement.

Masonry cement is almost totally shipped in multiwall paper bags. Bag weights range from 70 to 80 pounds, depending on the type of masonry cement in the bag. The packing, palletizing, and dust suppression operations are identical to those used for portland cement.

There are remote distribution terminals associated with some cement plants. Bulk or packaged cement is shipped from the plant to the terminal for storage and subsequent timely distribution to customers. Shipments to terminals are most often accomplished by rail or barge, although trucks and ships are sometimes used. The handling and loading of bulk portland cement at distribution terminals are carried out by the same kinds of pneumatic and mechanical conveying systems as are used at the plant.

TABLE 6. Fabric Filters for High-Efficiency Separators

	Pulse Jet	Pulsed Plenum
acfm	40,000–60,000	40,000–60,000
Fabric type	Polyester	Polyester
Temperature range, °F	<275	<275
A/C ratio	4:1	5:1
Inlet loading, gr/acf	150–300	150–300
Expected outlet emissions, gr/acf	0.02	0.02
Particle size out, μm	>0.5	>0.5

Air Emissions Characterization

Particulate emissions from the silo openings, cement-handling equipment, bulk and package loading operations and the fabric filters constitute the air pollution problems in the shipping department.

Air Pollution Control Measures

Active and passive fabric filters are used to remove dust from the exhaust airstreams from the silos and transport systems. The cement dust is returned to the product.

The dust generated during the loading of trucks, railcars, barges, and ships is controlled by venting the transport vessel to a fabric filter. The collected dust is returned to the shipment of cement. Flexible loading spouts with concentric pipes are among the devices that are successfully used for dust-free loading. In a loading spout, the cement flows to the transport vessel by gravity through a central pipe, while exhaust air is drawn through an annular space.

Dust is controlled at distribution terminals through the venting of silos, bins, and transfer points to fabric filters. The captured cement dust is returned to the product.

The typical fabric filters used in the packing and loading departments of newer plants are of the pulse-jet type. Reverse-air or shaker-type fabric filters are found in older plants. Occasionally, a cartridge-type fabric filter will be employed. Table 7 presents typical data.

SUPPLEMENTAL FUELS AND RAW MATERIALS

The recycling of wastes in portland cement kilns as fuel and raw material substitutes is a reliable and proven technology. This technology offers a cost-effective, safe, and environmentally sound method of resource recovery for some hazardous and nonhazardous waste materials. Following appropriate preparation, the energy and chemical values of selected wastes can be beneficially recovered, thereby enabling a portland cement manufacturer to operate more competitively.

The energy-bearing, ignitable wastes that are currently used in the portland cement industry as fossil fuel substitutes are primarily waste oils and spent organic solvents, sludges, and solids from the paint and coatings, auto and truck assembly, and petroleum industries. Smaller amounts of other waste streams are also being successfully recycled into cement kilns as fuel substitutes. Some waste streams require pretreatment so that they can be effectively introduced into the kiln. For example, liquids with high or variable chlorine levels are blended to a somewhat consistent chlorine concentration to minimize the impact on kiln operations. Sludges are liquefied, solidified, or encapsulated to provide better material-handling properties. Solids may be ground to facilitate blending and sampling. Materials such as petroleum coke and sawdust can be handled with the same equipment as coal and are readily consumed in a cement kiln. Other high-energy waste streams, such as rubber tires, can present materials-handling problems that are overcome with new or modified fuel-delivery equipment.

The cement-making process offers many unique opportunities for the utilization of nonhazardous wastes. Silicon, aluminum, and iron are needed to react chemically with the calcium in the cement raw mix. Such materials as spent cracking catalyst, diatomaceous earth filter material, foundry sand, and contaminated soils have high concentrations of these elements and are used to replace the conventional siliceous, argillaceous, and ferriferous components of the raw mix.

The greatest economic and societal benefits from utilizing wastes in cement manufacturing are derived from the replacement of fossil fuel. Coal provides about three fourths of the thermal energy for manufacturing cement in the United States. If the domestic cement industry had replaced only 10% of its conventional fuels with waste substitutes in 1987, 40 trillion Btu of nonrenewable energy would have been conserved.

Older, less fuel-efficient cement plants often derive the greatest benefit from waste fuel substitution because of an improved competitive position. These older facilities successfully compete with more modern facilities as a result of lower operating costs and improved cash flow.

Cement plants are often located near industrial and metropolitan areas. As these same areas produce most of the waste materials, transportation of the waste can be mini-

TABLE 7. Fabric Filters in Packing and Loading Departments

	Pulse Jet	Reverse Air/Shaker	Cartridge
acfm	3,000–10,000	3,000–10,000	2,000–10,000
Fabric type	Polyester	Polyester	Paper, polyester
Temperature range, °F	<275	<275	<275
A/C ratio	6:1	2.5:1	<2:1
Inlet loading, gr/acf	5–40	5–40	5–40
Expected outlet emissions, gr/acf	0.02	0.02	0.02
Particle size out, μm	>0.5	>0.5	>0.5

mized by recycling appropriate materials into cement kilns rather than transporting them to a remote disposal facility.

Cement kilns have several important advantages that contribute to the effective destruction of waste materials. The gas residence time in the burning zone of the kiln is in excess of 3000°F for a period of approximately three seconds. Temperatures in excess of 2000°F exist for as long as six seconds. Test burns repeatedly demonstrate destruction and removal efficiencies (DREs) of 99.99 to 99.9999% for the most stable organic compounds. The alkaline environment of a portland cement kiln can absorb the hydrogen chloride that may result from the combustion of chlorinated hydrocarbons. Ash resulting from incombustible material, such as metals in the waste, either becomes chemically incorporated in the clinker crystal matrix or is caught with the CKD in the air pollution control device prior to the kiln stack. The more volatile metals, such as lead, primarily migrate to the CKD, while refractory metals, such as chromium, are mostly found in the clinker. Since cement raw materials come from the earth's crust, these and other naturally occurring trace metals are normally found in cement and CKD. The use of waste fuels and waste raw materials usually increases the heavy metal content of cement and CKD only by small and insignificant increments. No significant increases in metals emissions from cement kilns have been observed during numerous test burns.

The CKD is not a listed or a characteristic hazardous waste under 40 CFR 261. In no instance has there been a report of CKD associated with the burning of WDF failing the EP toxicity or TCLP tests for the eight specified metals.

The most significant operating problems with WDF are associated with its chlorine content. Excessive chlorine levels can contribute to material buildups within a kiln system (e.g., kiln rings), deterioration of ESP performance, and excessive corrosion. The cement manufacturer quickly learns the maximum chlorine level that a pyroprocessing system will tolerate and limits chlorine input to below that amount. Each system has a different chlorine tolerance, but chlorine in WDF is usually held to below 5% by weight in the absence of permit limits. The chemical and physical specifications for portland cement also make it necessary for a cement manufacturer carefully to control the performance of the pyroprocessing system during waste-fuel firing and to monitor the input of several trace elements that can be found in WDFs or raw materials. Regulations for the burning of WDF in cement kilns were promulgated under RCRA by the EPA on February 21, 1991. The air emissions of pollutants of concern (i.e., carbon monoxide, hydrocarbons, hydrogen chloride, and heavy metals) during waste burning for energy recovery are regulated.

PROCESS AND QUALITY CONTROL

Modern cement plants are exclusively controlled by digital computers from central control rooms. Process variables in all manufacturing departments are continuously monitored. Control actions are usually initiated by the process control computer, but manual intervention is possible during process upsets, equipment malfunctions, or emergency conditions. Older cement plants use analog control systems in either central control rooms or departmental control stations.

Modern cement plants are usually equipped with continuous opacity monitors on the kiln and clinker cooler stacks. At some plants, gaseous emissions of oxygen, carbon monoxide, nitrogen oxides, and sulfur dioxide from the kiln stacks are also continuously monitored. In the past few years, these monitoring devices have become more reliable and less maintenance intensive. Nevertheless, equipment redundancy may be required if there are to be minimal data gaps in a compliance monitoring scheme. The location for these devices in the plant is often hot and dirty, thereby complicating the monitoring task.

The portland cement process involves rather complex chemistry and close process control. Plant laboratories are staffed around the clock. Frequent chemical and physical tests are made on raw materials, raw mix, clinker, and cement. The procedures may range from elementary wet chemistry to more sophisticated testing by X-ray fluorescence. Some of the newest cement plants are equipped with automatic sampling and analytical systems. The operation of the pyroprocessing system receives particularly close attention since product quality is largely determined in the kiln. If proper process conditions and kiln temperatures are not maintained, the complex chemical reactions that take place in the kiln are incomplete and the clinker is unacceptable.

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FIBERGLASS OPERATIONS

Aaron J. Teller and Joseph Y. Hsieh

The production of fiberglass consists of two different forms of product—continuous-filament fiberglass or textile products and fiberglass blown wool or insulation products.

The general-purpose textile fiberglass, which is moisture and alkali resistant with good electrical and physical properties, is also called E- (electrical) Glass. The major applications of the general-purpose textile fiberglass are in the production of fireproof cloth, fiberglass-reinforced plastics (FRP), and composites. The insulation product lends itself for the application of thermal and acoustical insulation because the small cell of air entrained in the wool or blanket prevents the movement of the air and sound wave. The manufacturing process consists of (Figure 1): materials blending and transport, melting and refining, and fiberforming and textile operation.

As in the manufacturing of glass, the major air emission problem where acid-gas recovery in addition to particulate is required is related to the melting and refining furnace operation. The fiberforming and textile operations produce, primarily, particulate emissions and some volatile organic compounds (VOCs). The textile product manufacture presents a more complex emissions control problem than does insulation manufacture because of the presence of boron and fluorine in the most flexible E-Glass product.

PROCESS DESCRIPTION

The composition of textile and insulation fiberglass, although varied as a function of the producer, has the general composition[1] shown in Table 1.

The raw materials are unloaded from freight cars or trucks and transported to specific silos in the batch house. The materials are then withdrawn to automatic weight machines and blended. The mix is transported by air conveying to the holding vessel at the melter and then fed as a batch to the furnace or melter.

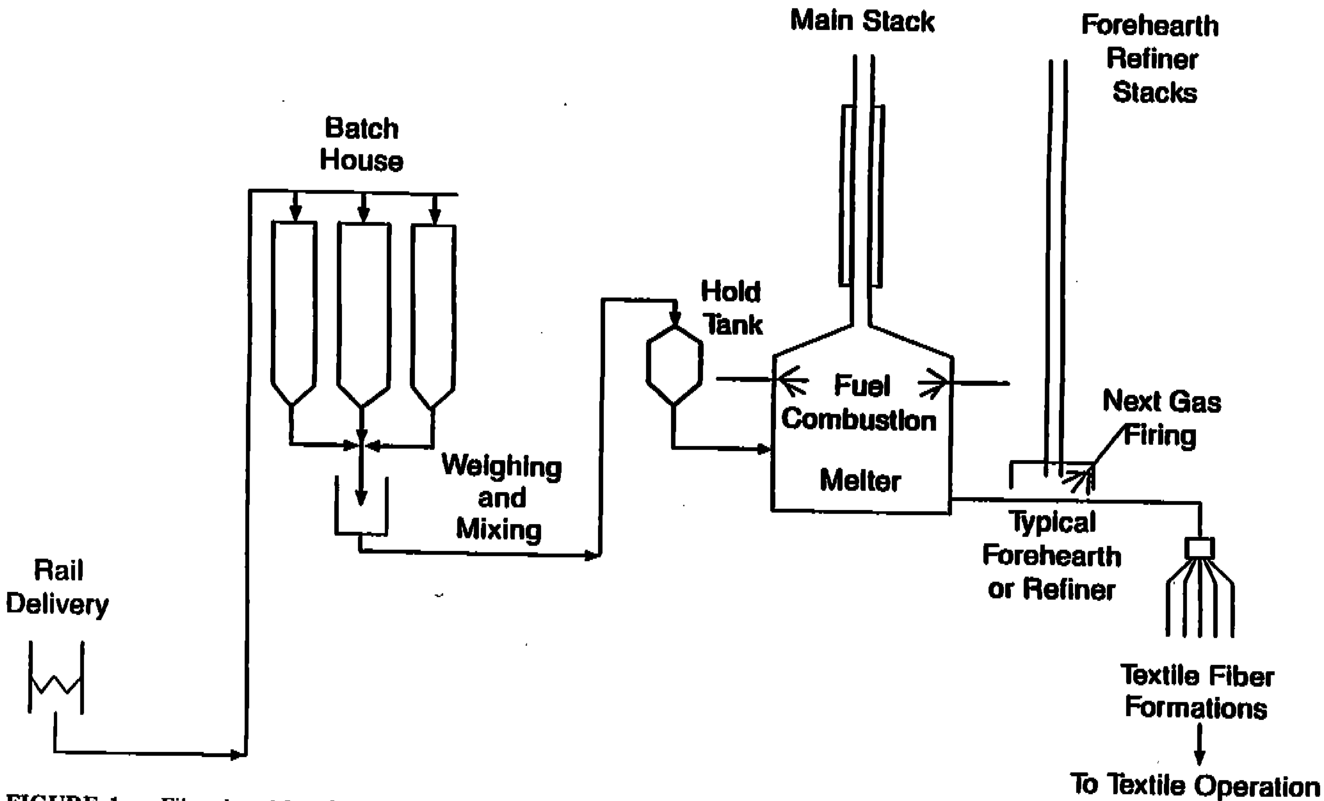

FIGURE 1. Fiberglass Manufacturing Process