DRYING, CALCINING, AND AGGLOMERATION

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Rapid changes have been taking place in recent years over the broad range of processing activity that includes drying, calcination, and agglomeration. Most of these changes are the direct result of escalating fuel costs. It is hoped that in this article there may be a seed or two that will propagate further improvements.

DRYING

Drying is one of the most basic and important processes utilized in the minerals industry, permitting additional processing of material that otherwise would be difficult or even impossible to handle. Numerous drying techniques are available, but continuous rather than batch techniques are most applicable in the minerals industry.

In considering drying processes, several general characteristics are important:

- Free-flowing, fine material will dry quickly.
- Blocky material will dry quickly if all moisture is surface moisture, but will dry more slowly if some moisture is internal and/or chemically bound.
- The drying rate increases as gas velocity increases.
- High temperature differentials speed drying rates.
- A fine, wet cake has very poor drying characteristics, and must be broken to speed drying.

The most commonly used dryers in the minerals industry are: direct-fired, indirect-fired, and steam tube rotary dryers; fluidized bed dryers; spray dryers; flash dryers; conveyor dryers; screw dryers; and drum dryers.

DIRECT-FIRED ROTARY DRYERS

The direct-fired rotary dryer is the type most commonly used in the minerals industry. It is simple in design: basically a revolving horizontal cylindrical shell tilted at a small angle (usually 1.8° to 2.4°, or ⅜ in. to ½ in. per ft) towards the discharge end. The length-to-diameter ratio (L/D) is usually 6:1 to 8:1. The size of this type of dryer, and thus its capacity, is limited only by the constraints of shipping the equipment to the end user. Units up to 18 ft dia x 169 ft long are currently in use. The largest model is located in Indonesia, where it dries 600 stph of wet-feed laterite ore containing 28% water, providing a product containing 16% water.

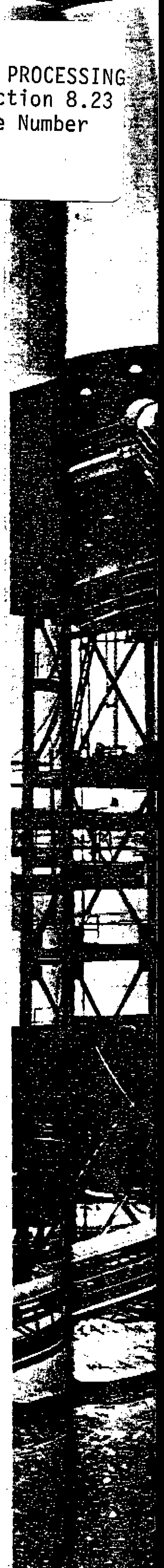
Direct-fired rotary dryers are simple to operate and extremely versatile, operating well on a full size range of materials from 325 mesh to 2.5 in. They also can accommodate many sticky materials and can handle agglomerated wet lumps in sizes up to 12 in. If feed material is fine and free-flowing, speeds up to 9 rpm can be used, but when material is very abrasive, much slower speeds are employed to reduce internal wear. If material is blocky, speeds of 2-3 rpm are most suitable.

Combustion gas makes direct contact with wet material in this type of dryer, which is commonly fired by a combustion chamber generating gas temperatures as high as 2,100°F. If material is not heat-sensitive, the unit can be fired by a burner protruding directly into the dryer. In this case, ignition tiles must be used to support combustion, but higher gas temperatures are obtained. The higher the gas temperature, the greater the capacity of the dryer.

Rotary dryers come in two basic designs: parallel-flow dryers and counterflow (or countercurrent) dryers. Parallel-flow dryers are used in 95% of current applications because they are more fuel-efficient and have greater capacity than counterflow dryers. Heat is applied at the feed end of the unit, and this helps to prevent buildup of wet feed. In general, these units are designed to dry material to not less than 1% moisture content, but drying to well under 1% is possible if the unit is used at less than rated capacity. (Fig. 1).

Counterflow dryers apply heat at the discharge end. As a result, they usually must be refractory-lined for the last 10-15 ft. This heating arrangement yields a bone-dry product and heating of that product if required. Counterflow units also move any airborne fines to the discharge end, where they can be captured in a cyclone and deposited on the same conveyor belt that collects the dryer discharge. (Fig. 2).

Approximate temperature conditions for each type of rotary dryer are as follows, based on a drying gas temperature of 1,800°-2,000°F, feed moisture of 12%, and product



The large copper concentrate dryer *(right)* measures 16 ft dia x 80 ft long. With heat moving in parallel flow to the concentrates, moisture is reduced from 7% to less than 1%.

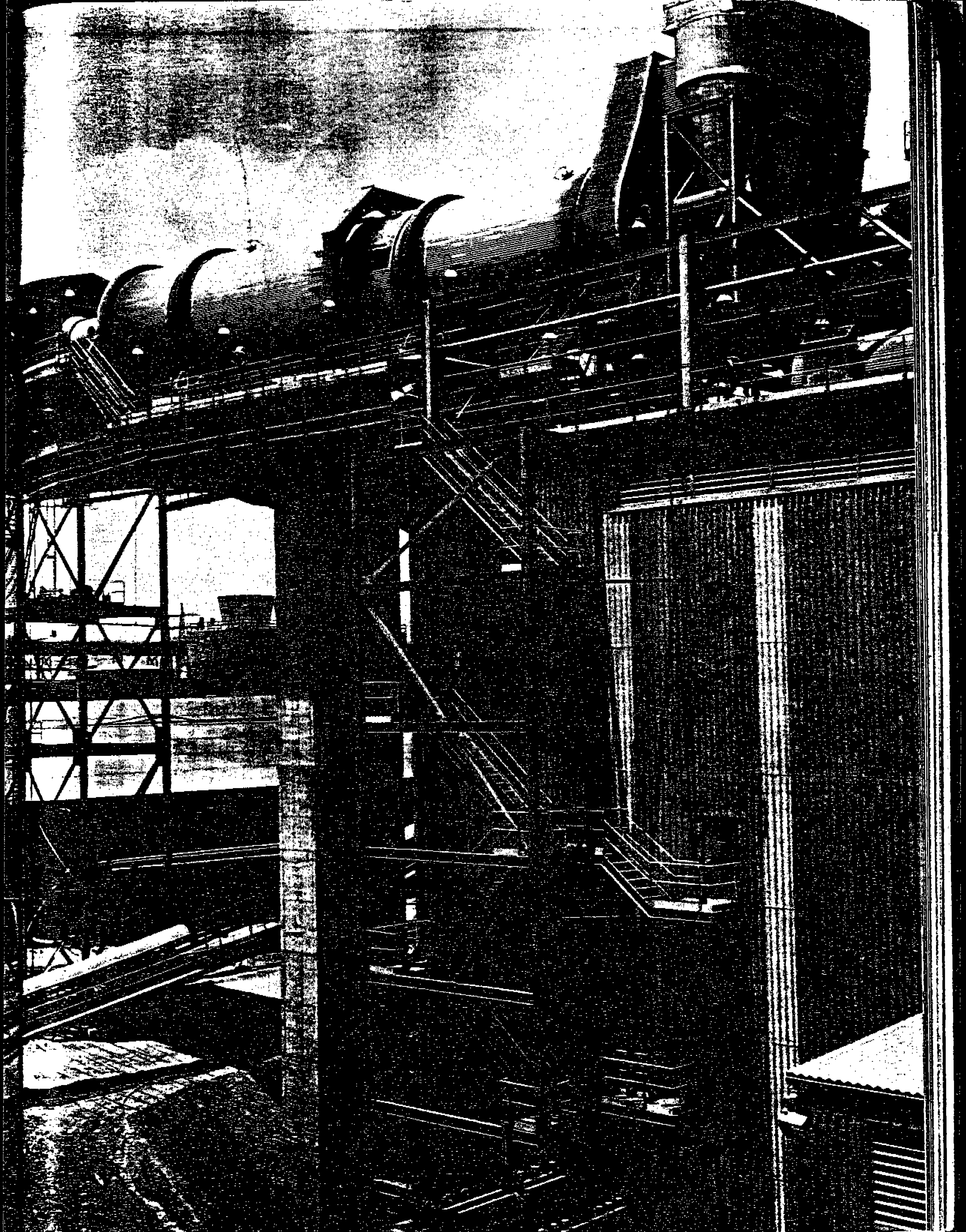
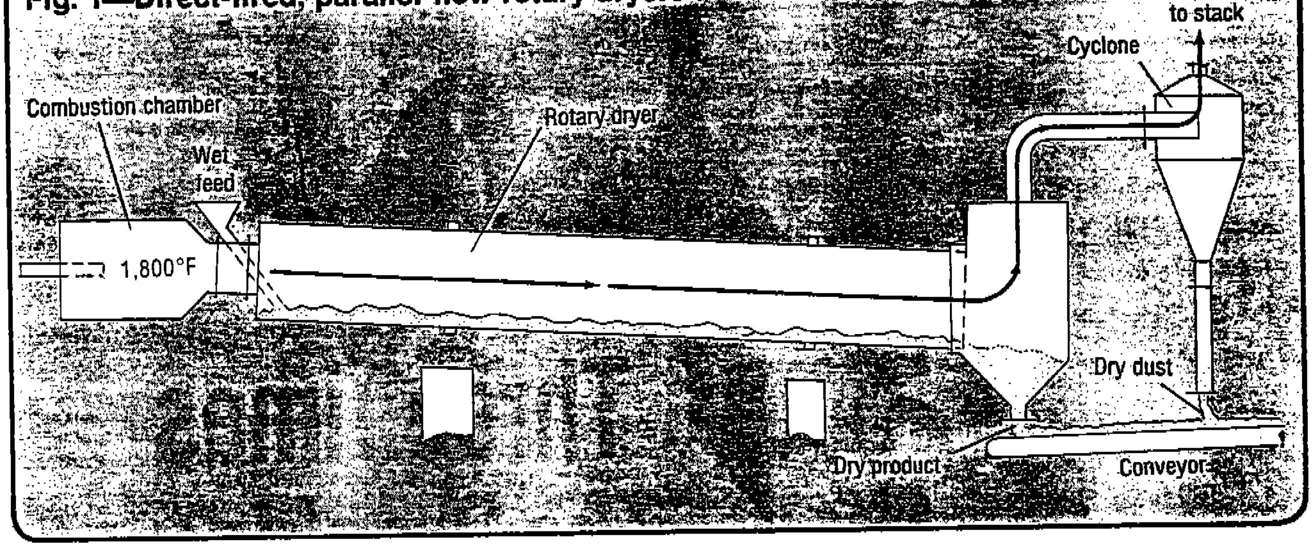


Fig. 1—Direct-fired, parallel-flow rotary dryers



moisture of 1.5% for parallel-flow and 0.2% for counterflow:

	Dried product	Exit gas
Parallel-flow	200°F	350°F
Counterflow	250°F	250°F

In both types of dryers, lifter configuration is very important. In a typical unit, the first 5-10 ft at the feed end contains feed spirals to move the wet material into the dryer and prevent back-spill. These are followed by lifters, of which the first third generally are straight, the second third have a 60° lip, and the final third have a 90° lip. The logic behind this configuration and its many variations is that the material becomes more free-flowing as it dries. In all configurations, lifter height should equal fill height when the dryer is in operation.

The retention time in a rotary dryer ranges from a minimum of six min for fast-drying material to approximately 30 min for slow-drying material. The old USBM formula provides a simple way to calculate retention time (using a factor of 1.5 for lifter effect) as follows:

$$T = \frac{1.77 \times \sqrt{\theta} \times L \times 1.5}{S \times D \times N}$$

where T = retention time in min; θ = the angle of repose of the material—40° for blocky material, 35° for fines; L = length of dryer in ft; D = inside diameter of dryer in ft; S = slope in degrees; and N = speed of shell in rpm.

Rotary dryers are generally sized on the basis of pounds of water evaporated per cubic foot of dryer volume. However, actual drying capacity varies, depending on the quantity of fines in the feed material, which in turn affects gas velocity in the dryer: more fines means higher gas velocity and higher capacity for any given type of material. Generally, if the material is fine enough to be airborne, it will dry in seconds. These effects must be considered when determining the proper size of dryer for a specific operation.

One example of a large direct-fired rotary dryer is the

Fig. 2—Direct-fired, counter-flow rotary dryer

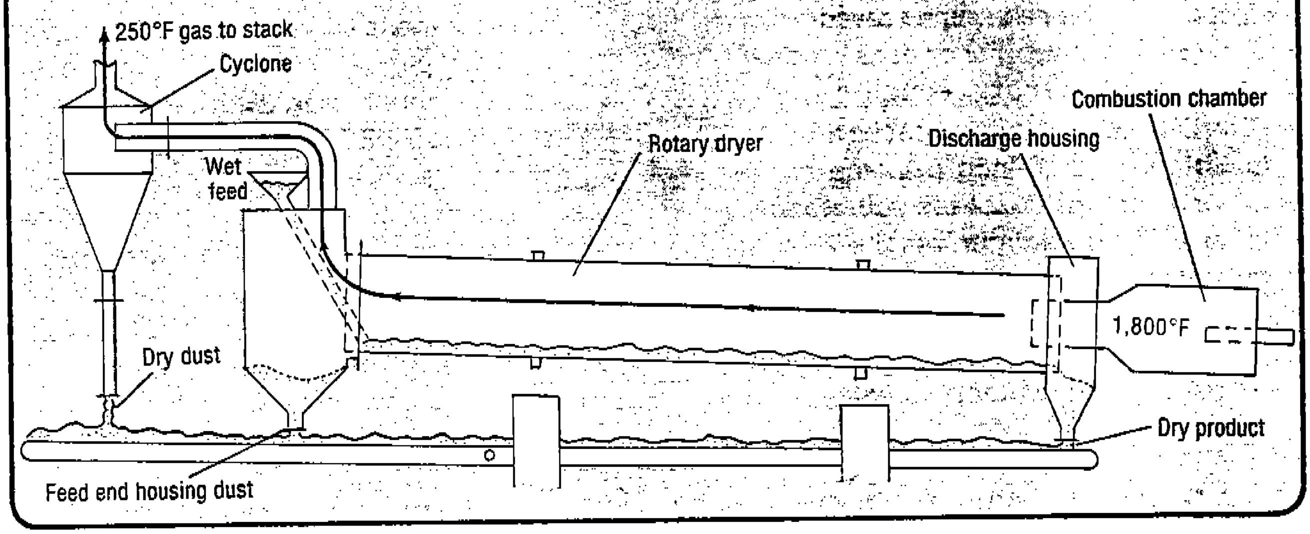


Table 1—Guide to rotary kiln performance and sizing

Material	Free H_2O in feed	Reaction	Fuel rate MM Btu/ton*	L/D	Cu ft/ton* ( ) = Average	°F Exit temperature
Cement Note:	For Cement all production is expressed in bbls—Fuel rates in L.H.V./bbl. All others tons and H.H.V.					
Preheater	0	Calcining to incipient fusion	.495-.550	15-18:1	3.5-4.0	2,000 4 Stage**
Dry	0	a mixture of argillaceous and	.750-.950	24-30:1 (6)	8.5-9.0	1,000-1,100
Wet	35-42%	calcareous materials	.850-1.30	24-28:1 (7)	9.0-9.5	450-600
Limestone	0-3%	$CaCO_3 \xrightarrow{Heat} CaO + CO_2$	6.5-7.5	30-35:1 (35)	35-75 (55)	900-1,200
Dolomite						
Soft burn	0-3%	$CaCO_3 + MgCO_3 \xrightarrow{Heat} CaO + MgO + CO_2$	6.2-7.5	30-35:1 (35)	35-60 (55)	800-1,000
Dead burn	0-3%		7.5-8.5	30-35:1 (35)	45-60 (55)	1,100-1,300
Oyster Shell	6-10%	$CaCO_3 \xrightarrow{Heat} CaO + CO_2$	7.5-9.5	30-40:1 (35)	75-80 (75)	700-800
$Ca(OH)_2$	40%	$Ca(OH)_2 \xrightarrow{Heat} CaO + H_2O$	7.0	20-30:1 (25)	55	550
$CaCO_2$ slge.	35%	$CaCO_3 \xrightarrow{Heat} CaO + CO_2$	8.0-10.0	18-30:1 (30)	100	450-625
Alumina						
Flowery	15%	$Al_2O_3 \bullet 3H_2O \xrightarrow{Heat} Al_2O_3 + H_2O$	4.5-5.3	28-32:1 (30)	30-52 (40)	700
Sandy	15%		4.1-4.8	28-32:1 (30)	27-48 (35)	700
Sinter	40%	$CaO + Na_2O + 3Na_2O_3 \bullet 3Al_2O_3 \bullet 5SiO_2 \longrightarrow Na_2Al_2O_4 + Ca_2SiO_2$	8.0	30:1		400
Ltwt. aggreg.						
38#3/4x3/8	3-7%	(Bloat by slight melt & gas	1.8-2.8	16-25:1 (18)	27-32 (28)	800-1,200
48#3/8x3/16	3-7%	release from within material		16-25:1 (18)	24-28 (25)	800-1,200
(1) 60#3/16x0	3-7%	at approximately same time)		16-25:1 (18)	21-25 (22)	800-1,200
Petrol. coke		Burn off volatiles	(2)1.0-2.0	20:1	20-40 (25)	1,800
Clay	0-24%	Evap. free & comb. H_2O & densify	4.0-6.2	18-26:1 (24)	20-50 (30)	700-1,000
Periclase	50%	$Mg(OH)_2 \xrightarrow{Heat} MgO + H_2O$	10.0-13.0	23-45:1 (30)	80-120 (100)	450-1,000 (4)
Phosphate						
Calcine	0-1%	Calcins $CaCO_3$ & remove follow. kiln	(3)3.92	36:1	50	1,000
Defl'r'te	8-12%	Drive off fluorine	7.0-9.0	22:1	70	1,200-1,400
Nodulize	15-35%	Nodulize	2.7-3.3	22-28:1 (22)	10-16 (15)	
Decarbon	10-15%	Burn off carbonaceous material	1.7-2.0	18-23:1 (20)	10-13 (12)	600-1,100 (5)
Diat. earth	0-5%	Burn off H_2O & carbonaceous material	4.0-4.5	10.5-15:1 (15)	35-40 (37)	1,100-1,600

(1) Not recommended for rotary kiln. Use fluidized bed. This for fines only.
(2) Burner capacity should be 6.0 MM Btu/ton for start-up.
(3) Feed taken at 60% $CaCO_3$ with balance phosphate.
(4) High exit gas with no chain.
(5) Lifters in feed end will give 600-700° temperature.
(6) Typical sizes: 13 x 15(120) x 500—15 x 17(120) x 520—16 x 17 ft 6 in(120) x 560—19 x 21(120) x 630—Use 6-in refractory up to 14 ft or 15 ft dia.
(7) Typical sizes: 12 ft 6 in x 14 ft 6 in(150) x 500—14 x 16(150) x 525—15 x 16 ft 6 in(150) x 540—13 x 15(150) x 500—17 ft 6 in x 19 ft 6 in(150) x 580—Use 6-in refractory up to 14 ft or 15 ft dia.
*Short tons.
**Temperature of gas from kiln. Gas from preheater about 700°F.

16-ft-dia x 80-ft-long parallel-flow copper concentrate dryer pictured at the beginning of this article. This unit is rated to dry 110 stph of feed containing 7% water to a product containing less than 1% water. A unique feature of the dryer is a set of internal chains hung in a garland pattern, designed to knock loose wet and sticky copper concentrate from the dryer walls. Another technique is to place knockers on the outside shell, somewhat less effective but often causing sufficient vibration to free "hung" material.

Other large units include: 1) three 15 x 160-ft parallel-flow dryers, each rated at 473 stph wet bauxite feed containing 15% water and 414 stph product containing 3% water; 2) three 14 x 112-ft Parallel-flow units drying nickeliferous laterite ore in Australia from 25% water to 2% water (140 stph product each); and 3) a second laterite ore dryer in Indonesia that measures 16 ft 5 in. x 169 ft. and handles 430 stph of 28% wet feed yielding a product with 16% moisture content.

INDIRECT-FIRED ROTARY DRYER

The indirect-fired rotary dryer is used when a material cannot be in contact with hot combustion gas. There are a number of designs that are all inefficient because heat must be transferred to the material inside the dryer by conduction through the dryer walls. In the simplest design, a furnace built around the dryer supplies the heat. As with all rotary dryers, the rotating unit is set on a gentle slope towards the discharge end, and it is properly sealed and vented.

STEAM TUBE ROTARY DRYER

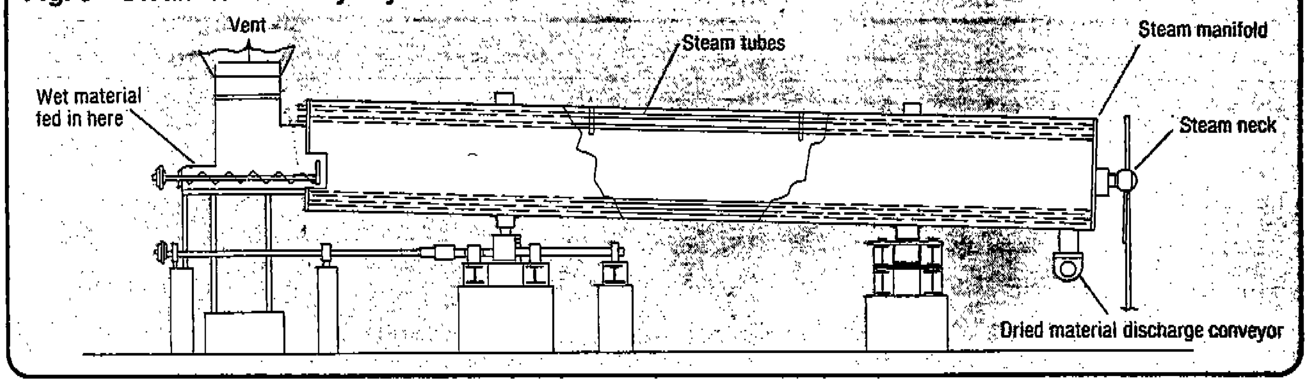
The steam tube dryer is really a variation on the indirect-fired rotary dryer, except that heat is supplied by steam introduced into tubes surrounding the inside periphery of the dryer, which are set one, two, or three tubes deep. The steam is supplied through a universal joint and steam manifold at one end of the rotating unit. (Fig. 3).

This type of dryer is used on: 1) heat-sensitive material that cannot tolerate overheating, 2) material that cannot tolerate contact with combustion gas, and 3) very dusty materials when dusting must be minimized. It cannot be used to dry material that sticks to the hot tubes. In general, steam tube dryers are suited to the drying of granular or powdery materials.

FLUIDIZED BED DRYERS

Fluidized bed dryers can be used to dry fine material consisting of particles that can be suspended in an upward flow of gas. The material is supported on a perforated grid, through which hot gas flows from an underlying plenum chamber. When gas is uniformly introduced through the grid, the bed fluidizes and acts like a liquid. In general,

Fig. 3—Steam tube rotary dryer



plenum temperature ranges from 1,200° to 1,800°F, and discharging material-exit gas temperature ranges from 180° to 250°F. Residence time varies from 5 to 30 min (Fig. 4).

The fluidized bed is fuel-efficient and can achieve fuel consumption as low as 1,500 Btu per lb of water evaporated. Capital and maintenance costs are low. However, feed size is usually limited to material less than 3/4 in., and the larger material must have a low specific gravity, such as Florida phosphate (pebble and concentrate). Fluidized beds also dry titanium dioxide, alumina trihydrate, zirconium silicate, lithium salt, ilmenite concentrate, zircon sand, and other chemicals and nonmetallics.

The plenum chamber in this type of dryer is typically supplied with hot gas from a separate heating device, but the unit itself can be fitted with coils using hot oil or steam as a heat source. If a little air is then introduced for fluidization, the unit becomes a semi-indirect dryer with characteristics much like a steam tube dryer, but the unit remains stationary (Fig. 5).

Spray nozzles are sometimes used to feed appropriate materials into a fluidized bed dryer, in which case the unit becomes a modified type of spray dryer, with the added advantage of residence time for material conditioning.

OTHER DRYERS

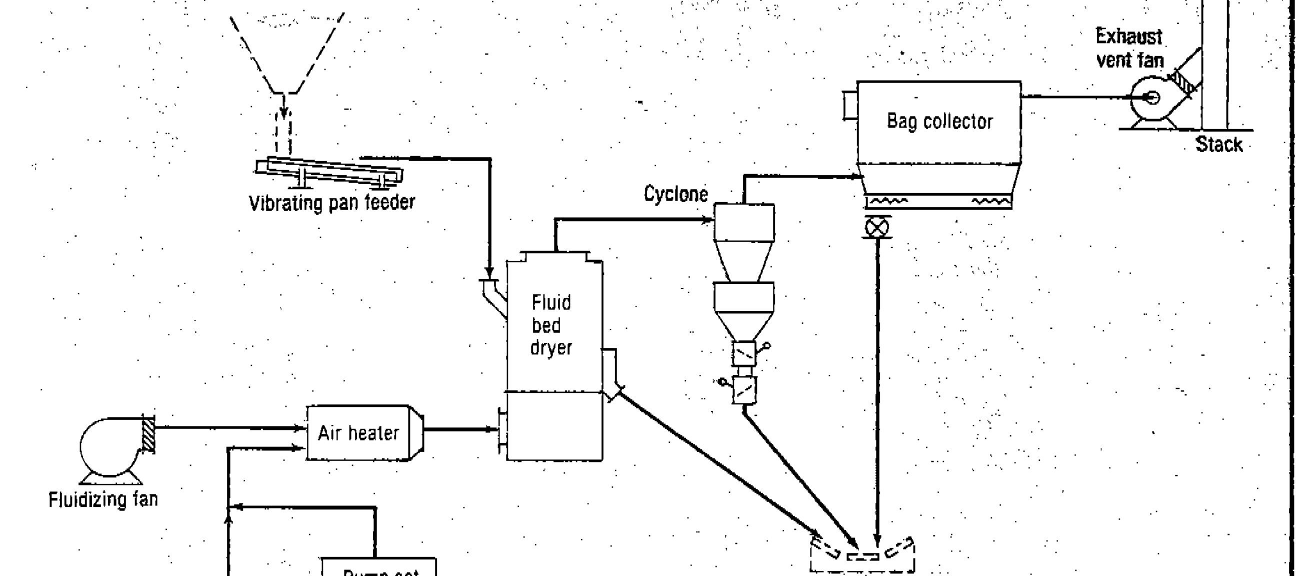
Spray dryers are simple, relatively inexpensive and extremely efficient. In general, feed must be wet enough to spray, and thus solutions, thin slurries, or pumpable pastes are possible candidates for this device (Fig. 6).

Flash dryers transport a wet pulverized solid for a few seconds in a hot gas stream and are among the most efficient of all dryers. They require a fine feed material with a maximum size of 3/8-in. if the specific gravity of the feed is low. Since time of contact is so short, heat-sensitive materials such as coal can be dried. If materials are adversely affected by combustion gas, then air passed through a steam heater can be used as the heating medium (Fig. 7).

If the feed is not free-flowing, it is sometimes possible to integrate a hammermill into the gas circuit to reduce feed size to small particles. Cake-like feeds can also be reduced to dryer-size material by mixing them with dried product; this mixture will then convey and dry properly when fed to a cage mill through which hot gas flows.

Conveyor dryers carry wet feed loaded onto a belt or vibrating conveyor into and through a heating chamber. Air may or may not pass through the material on the conveyor,

Fig. 4—Typical flow diagram of a fluidized bed dryer system



depending on dryer design.

Screw conveyor dryers have hollow shafts and flights through which a heated fluid or gas flows. The trough which carries the material is similarly heated. Generally, this dryer is suitable for free-flowing material, and it has the advantage of conveying as it dries. It is well suited as a supplement to an existing dryer.

Drum dryers are suitable for drying liquid material, solution, slurry, or paste, and do so by heating liquids to their boiling points. The drum rotates slowly and is heated on the inside. It either revolves through a trough of the liquid, or the liquid is sprayed onto the drum. The dried material on the drum is scraped off before a new coating of wet material is applied.

FUTURE DEVELOPMENTS

Most dryers—especially those that put combustion gas in direct contact with the wet material—operate best with liquid or gaseous fuels. However, because of high oil and gas prices, dryers will increasingly utilize coal whenever possible. The direct-fired rotary lends itself most easily to the use of coal. Some work is already being done on other types of dryers in an effort to adapt them for solid fuel use. Gasifiers for producing low-quality gas from coal have been available for many years, but they are expensive.

Another trend is the development of more fuel-efficient drying systems, which unfortunately will come at the expense of convenience and ease of operation. Better fuel economy will be obtained by using those dryers with the lowest exit gas temperatures, such as fluidized beds, flash dryers, and spray dryers. All are quite efficient, but they can be further improved.

CALCINING

Calcining as it relates to minerals processing can be defined as: "The application of heat to a material in a confined vessel usually on a continuous basis to effect a desired chemical and/or physical change." Materials that are commonly calcined include: cement raw materials, limestone, dolomite, oyster shell, calcium hydroxide, calcium carbonate sludge, alumina, lightweight aggregate, petroleum coke, clay, magnesite, manganese carbonate, phosphate, diatomaceous earth, bauxite, laterite, copper concentrate, ilmenite, zircon, and iron ore.

There are many ways to effect calcination, and the method chosen for any given application is a function of the size of the raw material, its resistance to attrition, the temperature required, corrosive characteristics, sticky phases, and any special chemical and physical characteristics. Calcination usually takes place at temperatures in the range of 1,800°-2,200°F, but it may proceed at temperatures as low as 400°F or as high as 3,200°F.

There are certain standard calcining processes used in the minerals industry that are well known to most design and operating engineers. However, there are several new concepts and systems of equipment that have only recently become available, most of which are attractive because they use less fuel to produce a desired product. Some of the technology is so new it has not yet been used in the mining industry, and it must be tested in pilot equipment currently available in certain laboratories. All of this technology has excellent potential, and less expensive methods of calcination will come from these new concepts.

The following text describes new and older calcination equipment and systems in some detail.

Fig. 5—Fluidized bed dryer with steam coils

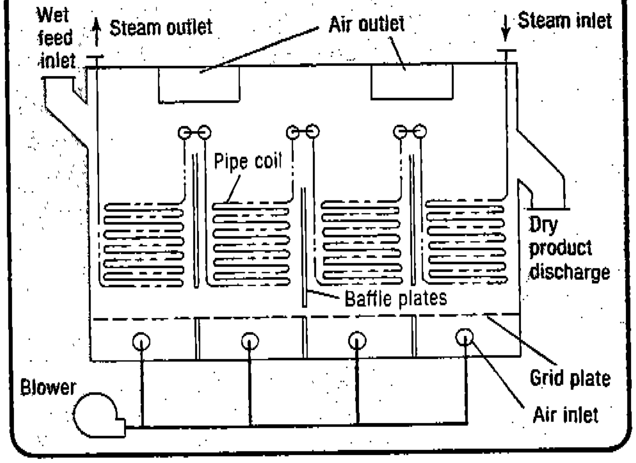


Fig. 6—Spray dryer

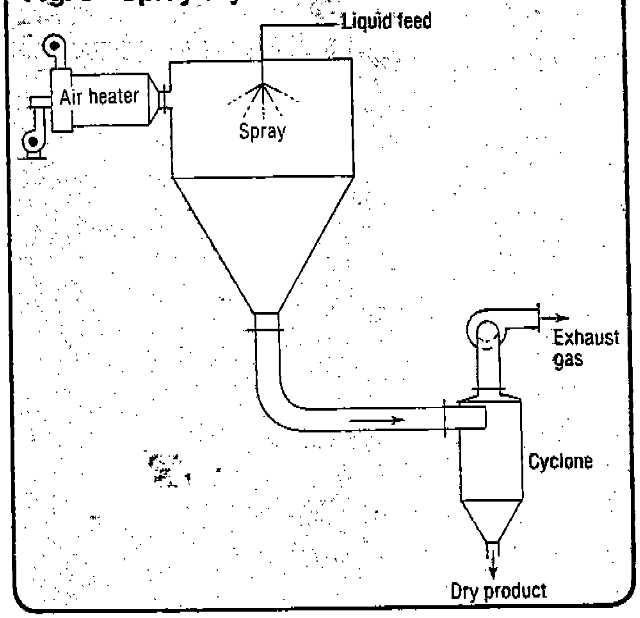


Fig. 7—Flash dryer

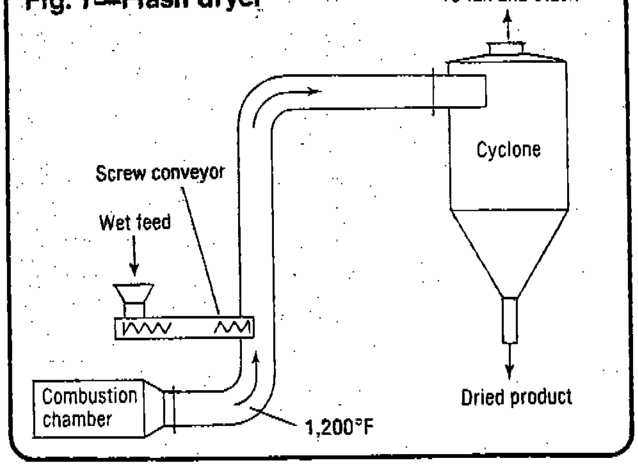


Table 2—Drying rates when using direct-fired rotary dryers drying to about 1½% with 1,800°F combustion chamber gas

Material	Feed size	Pounds H_2O evaporated per cubic foot dryer volume
Pebble phosphate	⅜ in. x 100 mesh	8-12
Phosphate concentrate	10 x 100 mesh	10-15
Limestone	1½ x ¾ in.	3-4
Bauxite	2 x ½ in.	3.5-5
Copper concentrate	10 x 325 mesh	2
Zinc concentrate	10 x 325 mesh	2
Sand	4 x 100 mesh	6-10
Lateritic nickel ore	2½ x ½ in.	4-5
Iron ore	Fines	5
Iron ore	¾ x ¼ in.	4
Trona ore	Fines	2.5-3

	Instrument Identification		
	1st Letter	2nd Letter	3rd Letter
A	Analysis	Alarm	Alarm
B			
C		Controller	Controller
D		Differential	
E		Primary Element	
F	Flow Rate		
G			
H	Hand (Manual)		High
I		Indicate	Indicate
J			
K			
L	Level	Light(Pilot)	Low
M			
N			
O	Oxygen		
P	Pressure(Vacuum)		
Q		Totalize	
R		Recorder	
S	Speed	Switch	Switch
T	Temperature	Transmitter	Transmitter
U	Multivariable		
V			
W	Weight		
X			
Y		Relay or Compute	Relay or Compute
Z	Position	Drive or Actuator	Drive or Actuator

Fig. 8—Instrumentation and flow diagram for a typical kiln system

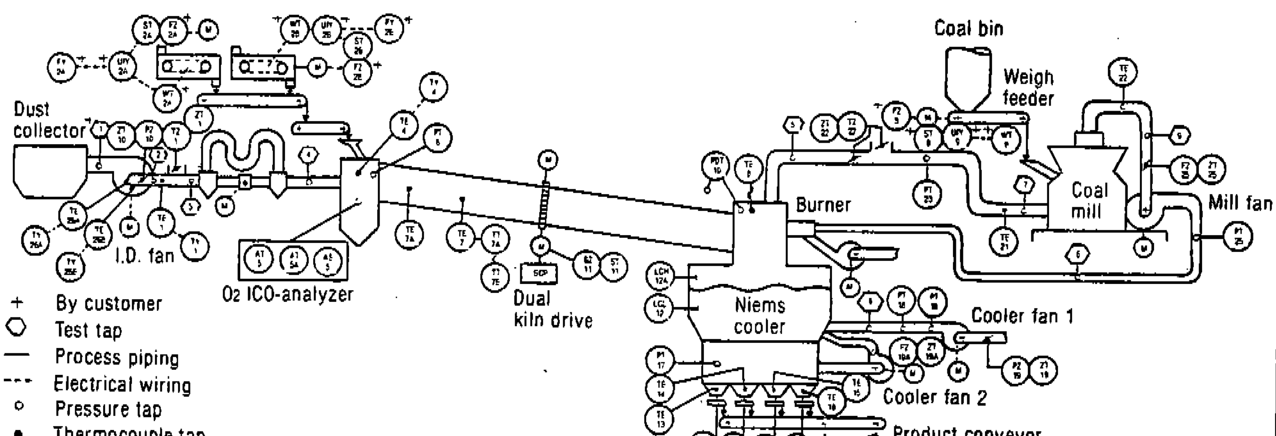
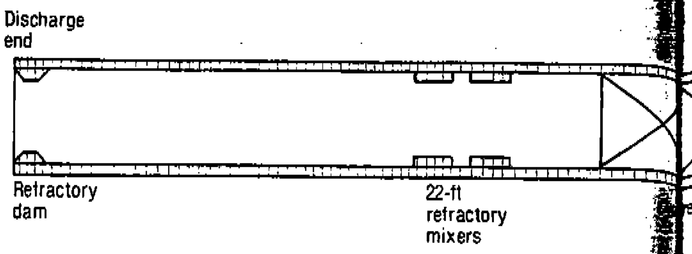


Fig. 9—Locations for heat exchanging internals



EQUIPMENT PARAMETERS

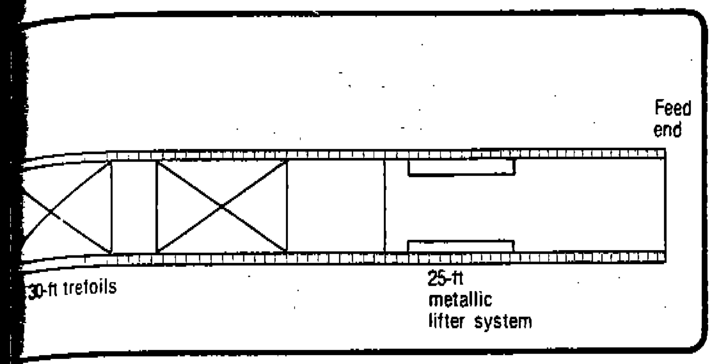
Calcination equipment should be chosen to yield the desired product at minimum fuel costs. Minimum fuel costs will be realized when:

- Exit gas temperatures from the equipment system are low. (500°F would be low for most processes.)
- Heat losses through the skin of the equipment are low. This can be accomplished with thick refractory materials and new, special insulating materials.
- Cooling of the product recovers and returns to the system the highest possible percentage of heat. (Approximately 95% is the maximum possible return.)
- Combustion of the fuel liberates all of the heat where it is needed. Excess air must be present only in sufficient quantity to permit complete combustion, usually no more than 5-10%.

PRINCIPLES OF A ROTARY KILN

The most commonly used calcining equipment, and easily the most versatile, is the rotary kiln (Fig. 8). Its wide use is due to its simplicity of construction and operation. Table 1 lists performance and sizing characteristics for the most important applications of the rotary kiln. The chart outlines the basic chemical reaction for each given material, feed moisture content, the usual fuel consumption range, the L/D or length-to-diameter ratio with diameter taken inside the refractory, the volume of the vessel required per ton per day of product, and the usual exit gas temperature.

The rotary kiln system is highly adaptable and may be



used to calcine a wide variety of materials with feed sizes ranging from 200 mesh to 2½-in. However, for optimum performance, the maximum-minimum size of material in the kiln at any one time should not exceed a ratio of 2:1. Kilns operate most efficiently on feeds larger than ¼-in.

Rotary kilns are inherently wasteful of fuel. Fortunately, there are a number of things that can be done to improve fuel economy:

- The use of thick refractory, backed by special insulating materials, will greatly reduce heat loss through the skin of the rotating vessel. Fuel savings average 5-10%.
- The use of a wind shield to create a quiescent atmosphere around the kiln will also save fuel. In areas where winds are regularly strong, this device can reduce kiln skin losses by one-half.

The use of heat-exchanging internals (Figs. 9 and 10) yields several benefits:

- Refractory dams at the discharge end of the kiln back up the material and create a soaking pit, which enables the chemical reaction to continue with no further introduction of heat.
- Refractory mixers, placed up-slope of the burning zone, improve overall kiln performance by agitating the load and bringing fines to the surface for calcination. These fines are produced by attrition of material as the kiln rotates, and normally become buried in the load. As a result, they will not "see" heat and will not calcine unless brought to the surface by the 9-in.-high mixers.
- Trefoils are refractory configurations that divide the kiln into three parts, and thereby increase gas velocity and expose more material to hot gases and hot refractory. The net result is a doubling of heat transfer in the area where they are used. However, existing kilns can seldom handle the additional weight.
- Metallic lifters are used in the colder parts of the kiln, and will triple or quadruple heat transfer in the area where they are employed. They can substantially increase kiln capacity and reduce unit fuel consumption with only a minor increase in the power requirements for kiln drive. However, feed material must be coherent, or dusting will be excessive.

Internals generally may be used in new or existing installations, but their use in any specific situation depends on the physical characteristics of the feed material between ambient and elevated temperatures.

KILN SYSTEMS

The basic rotary kiln may be modified and supplemented with additional devices to handle a broader range of materials and effect additional chemical reactions, frequently with greater fuel efficiency. For example, the kiln can be used to reduce iron ore, titanium minerals, or nickel ores, if coal is charged directly to the feed or added to the kiln by coal scoops mounted at various locations on the kiln periphery.

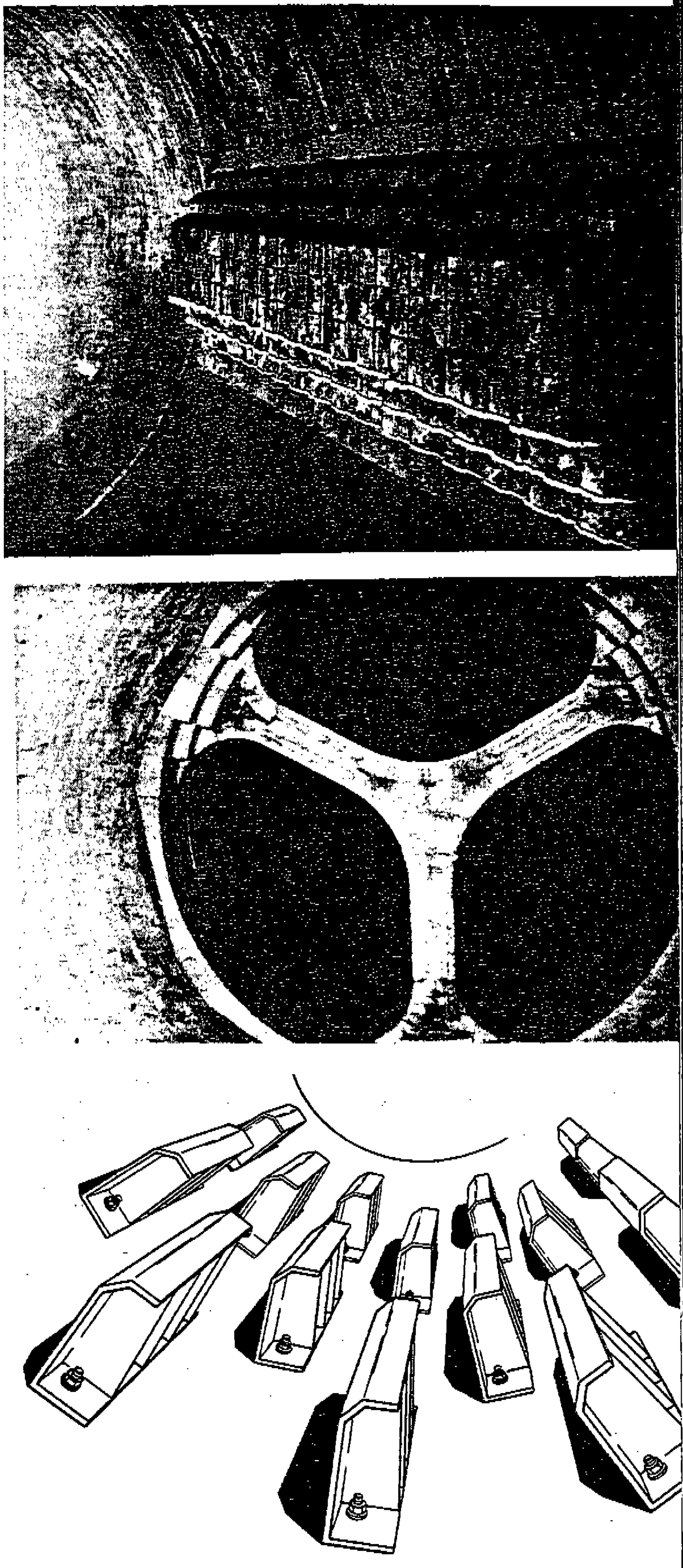


Fig. 10—A variety of useful heat exchanging internal mechanisms can be designed into rotary kilns, including refractory mixers *(top)*, trefoils *(center)*, and metallic lifters *(bottom)*.

This will generate a reducing flame at the discharge end of the kiln and a reducing atmosphere throughout the unit, thus permitting the reduction process to take place. Fans may also be mounted on the kiln periphery to introduce tertiary air, which facilitates the reactions.

When used with boring bars, rotary kilns will calcine manganese carbonate ores to manganese oxide nodules suitable for furnace use. The kiln first calcines and then nodulizes the manganese carbonate feed. A plant is currently under construction that will produce nodules at the rate of 1,100 stpd.

The use of various types of preheaters can substantially increase the fuel efficiency of kiln systems. Suspension preheaters consist of a series of vertical cyclones, which can be used to preheat feed material finer than 10 mesh and non-sticky below 1,400°F, prior to its introduction into the kiln. A further refinement would include a flash furnace-calciner, which consists of a cyclone with burners that "pre-works" the feed material, thus allowing additional production from the kiln. Material must not be sticky at flash furnace temperatures. In both devices, hot gas flows counter to the feed and gives up its heat to the material (Fig. 11).

Another fuel-efficient system that is suitable for fragile materials uses a preheater grate for preheating material prior to introduction into the kiln (Fig. 12). Such a system requires a blocky feed (e.g., 3/8 x 2 in.), so that hot gas may be freely drawn down through a porous bed of material resting on the grate. As the hot gas flows through the bed, heat is transferred from gas to material. The grate travels very slowly toward the kiln, and after thorough preheating, the material is discharged into the rotary kiln for final heat processing. This system very successfully indurates iron ore pellets. The pellets are partially heat-hardened on the grate, and then finish-hardened in the kiln.

A contact-type preheater may be used on blocky feeds with good strength, and is regularly used in the calcination of limestones. However, the system is adaptable to other materials with similar feed size that are strong through 1,500°F, have few fines, and are non-sticky at preheat temperatures. In this system, the feed enters the top of an elevated storage bin on the way to the preheater. It slowly passes down through the preheater, aided by hydraulic plungers, while hot gas from the kiln is drawn through the slowly moving bed. Heat transfer is excellent in the preheating phase, and after several hours, the material enters the rotary kiln for a short period to finish the calcination process. A contact cooler removes 95% of the heat in the calcined material, and returns it to the system (Fig. 13).

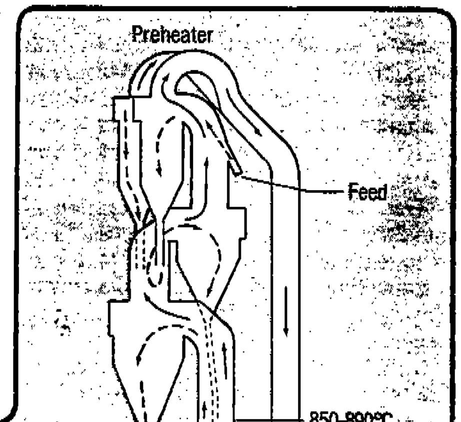
OTHER CALCINING SYSTEMS

Fine-sized material that is 100% minus 20 mesh or finer may be processed in a flash calcining system. The "basic" system consists of a suspension preheater, flash calciner, and suspension deheater, but if additional retention time is required, a fluidized bed can be added (Fig. 14). Both systems are simple and very fuel efficient, but both represent new technology that needs further laboratory testwork to determine overall applicability.

Multiple-hearth furnaces are used on relatively fine material that does not require extremely high temperatures. They may also be used for reduction work. The device consists of a series of furnace floors mounted in a vertical stack. Feed material enters at the top floor and slowly moves down through the stack, swept by rabble arms, which move material from point of entry on each hearth to point of discharge. Hot gas flows upward from hearth to hearth as material flows down, thus effecting an efficient heat exchange.

Material too fragile for tumbling may be calcined in a rotary hearth furnace equipped with a preheater and a cooler. This device consists of a refractory-lined, slowly rotating hearth, with multiple burners located above the point of entry for feed material. Only a small quantity of material enters the top of the hearth to form a thin layer, typically 1½ times the maximum particle size (usually 1.5 in.) in depth. Speed of rotation is roughly 1 rph, and the entire rotating hearth uses a water seal to maintain its atmosphere. The rotary hearth must be operated in conjunction with a contact-type preheater (as in Fig. 13) and a post-hearth cooler for heat recovery, in order to obtain good fuel economy.

Shaft kilns have been used to calcine limestone since the



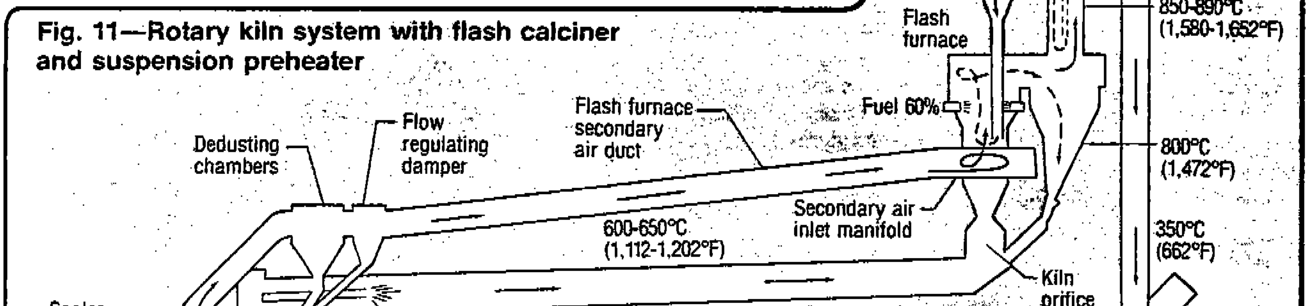
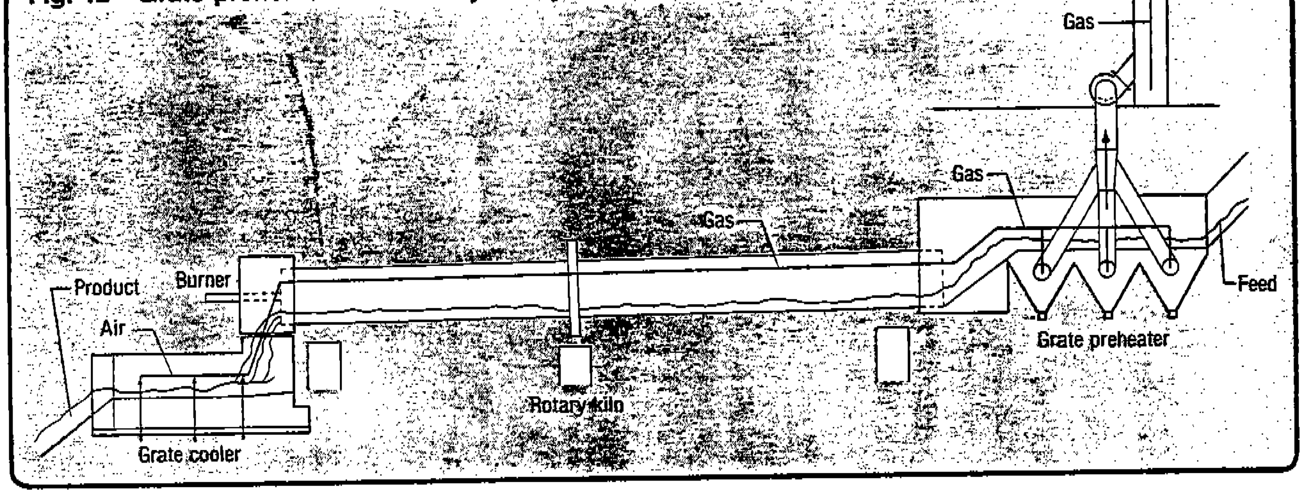


Fig. 11—Rotary kiln system with flash calciner and suspension preheater

Fig. 12—Grate preheater followed by rotary kiln and cooler



days of ancient Egypt. The original shaft kilns could only burn fist-size lumps of limestone, but today's kilns will accept stone as small as 3/4 in. Calcination is quite complete (1½% LOI) and fuel use is remarkably low.

Shaft kilns are essentially tall, thin, refractory-lined vessels with feed introduced at the top, fuel at the midpoint, and cooled product leaving at the bottom. If required feed rate is less than 500 tpd, these efficient calciners should be considered for materials other than limestone, as long as feed size is greater than 3/4 in. and is otherwise suitable for use in a shaft kiln. The device generally uses either gas or oil, but it may also be loaded with coke for use as fuel, or as a reductant. Industry is familiar with the use of a shaft furnace for the production of iron: commonly called a blast furnace. In this use, the shaft acts as a very suitable preheater and smelter for iron ore, fluxes, and coke.

FLUIDIZED BEDS

The fluidized bed represents another efficient method of calcination. Capital cost is low, and operating and fuel costs

Fig. 13—Contact type preheater followed by rotary kiln and contact cooler

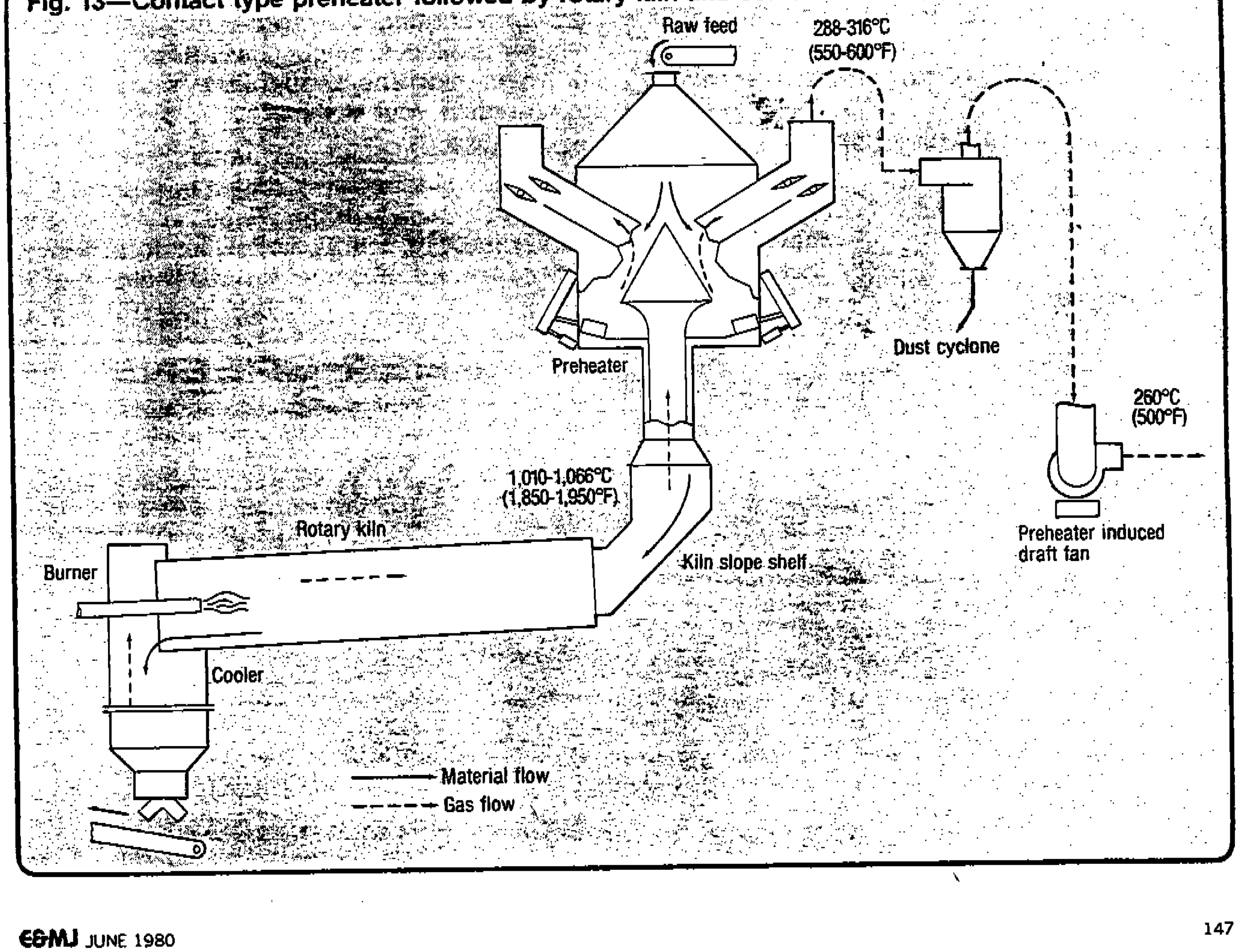
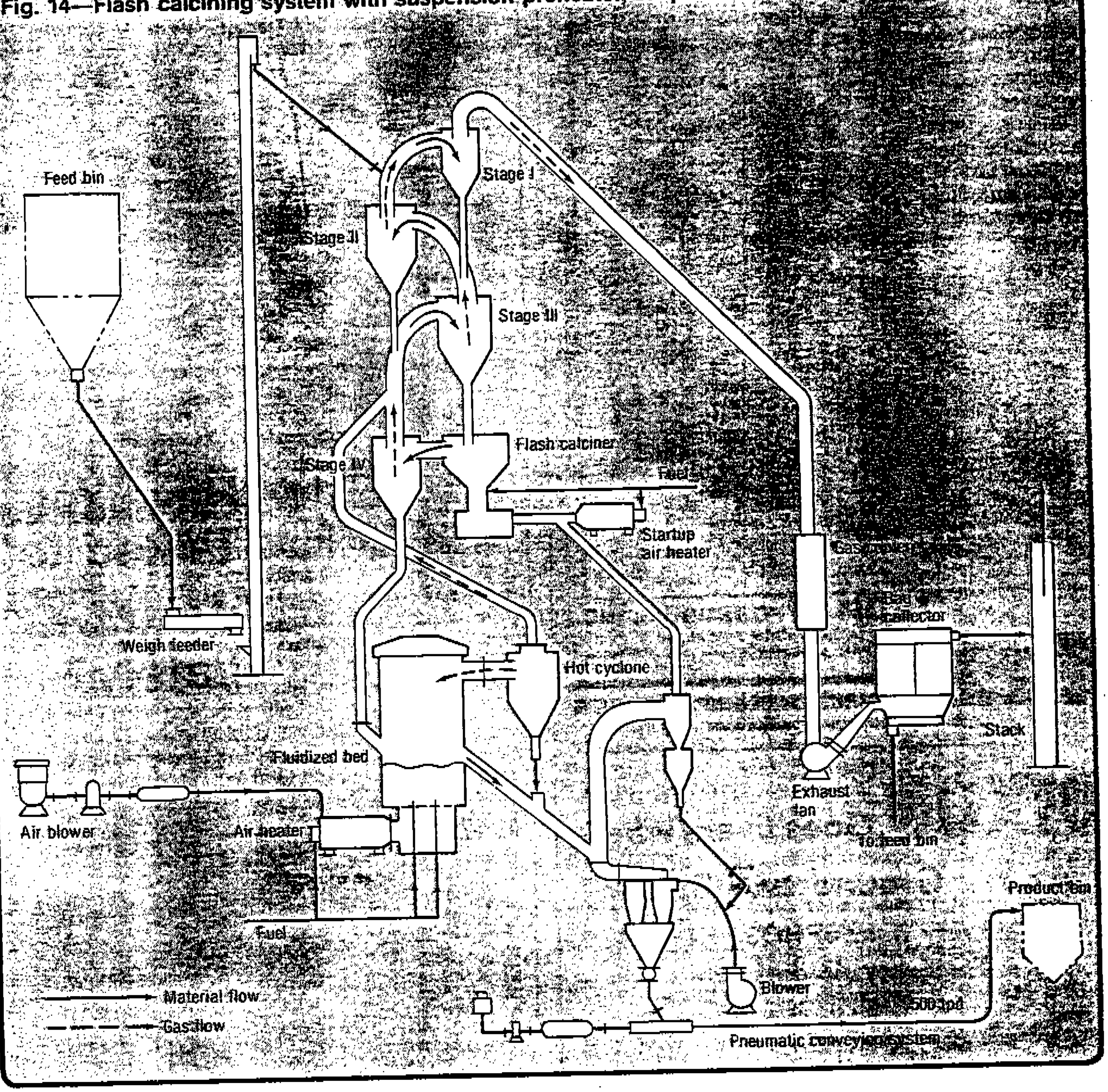


Fig. 14—Flash calcining system with suspension preheater, suspension deheater, and fluidized bed



are also low if the system is properly designed to minimize heat losses. Material temperature up to 2,600°F are possible.

Any material that can be fluidized may be a candidate for this type of heat treatment, and such material is generally sized less than ½ in. A quick laboratory test will demonstrate whether or not a given material properly fluidizes. The test consists of putting a small amount of the material in a very small, cold tube with a porous bottom, and then passing a known quantity of air over the material.

The feed material rests on a grid containing a large number of tuveres or nozzles to evenly disperse hot gas from an outside heater through the material (Fig. 14). This process will create temperatures up to 2,000°F in the bed material. Alternatively, burners may protrude through the grid and into the material, or coal may be mixed with the bed and used as fuel. If burning is done directly in the bed, temperatures above 1,400°F must be maintained to support combustion.

In a fluidized bed, the temperature of material and gas equalizes very quickly, and thus gas leaves the bed at the same temperature as the material. Heat must be recovered from this hot gas to make the system economic. One way to accomplish this is to use multiple grids: a preheating grid above the calcining grid to utilize the hot gas escaping from the calcining grid, and a cooling grid below the calcining grid to return heat to the calcining grid (Fig. 15). A second technique is to use a gas-to-gas heat exchanger above a single-grid fluidized bed to return heat to the combustion gas.

RELATIVE FUEL EFFICIENCY

The relative fuel efficiency of the various systems described above, in order from the least fuel efficient to the most fuel efficient, is as follows: 1) rotary kiln with no heat-exchanging internals; 2) rotary kiln with heat-exchanging internals; 3) rotary kiln with grate preheater; 4) rotary kiln with contact preheater; 5) multiple-grid fluidized bed; 6) multiple-hearth furnace; 7) rotary kiln with suspension preheater; 8) rotary kiln with suspension preheater and flash calciner; 9) suspension preheater, flash calciner, fluidized bed, and suspension deheater; 10) suspension preheater, flash calciner, and suspension deheater; and 11) shaft kiln, the most fuel-efficient calcining system of them all.

SYSTEM REVIEW

Although fuel consumption is of prime importance, the selection of a calcining system is a function of performance, capital cost, maintenance cost, and ease of operation. These additional factors relate to the specific material being heat treated, and must be assessed after an examination of the material. There are a number of well-proven systems for calcining any material, but recently developed systems are designed with fuel savings in mind. A careful examination of the calcination problem and suitable testing of the material can lead to the use of the most fuel-efficient calcining system.

AGGLOMERATION

Agglomeration can be performed on a variety of materials, but, perhaps the most prominent is iron ore, which is agglomerated primarily to improve permeability in the blast furnace by decreasing the amount of fines charged to the shaft. The reduction of fines also reduces the dust load blown out of the blast furnace.

The four most important agglomeration processes are nodulizing, briquetting, sintering, and pelletizing. Nodules are produced in rotary kilns by introducing a fine feed material at the charge end. The nodule is formed by the rolling action of the kiln and by heat induced at the discharge end, which heats the material to incipient fusion. Heat requirements are high, nodules are not always uniform, and the method is seldom used in current practice.

Cold briquetting is also of relatively minor importance currently, but the process is finding more application as fuel costs escalate for hot agglomeration. Cold briquettes usually do not have sufficient strength to supply a high percentage of the blast furnace charge. Past practice has been to limit them to 10-15% of the ferrous burden.

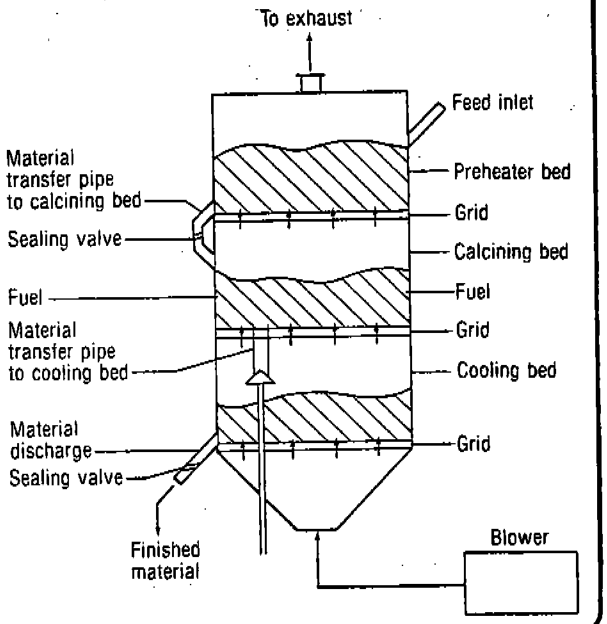
Hot briquettes do have suitable strength for furnace use. In this process, the fine material (minus ¼ in.) is heated to between 1,600° and 1,900°F and then briquetted in double-roll briquetting presses. Binders usually are not required. In-plant fines and steel turnings are often hot briquetted, and the HIB and FIOR direct reduction processes require briquetting. The hot briquetting process warrants attention due to its success to date.

In the sintering process, the raw feed is mixed with about 5% coke breeze or anthracite in a mixing drum. Flux is usually added. This feed then goes to a balling drum and is subsequently evenly distributed on a grate. The sinter mix is ignited at the feed end by means of an ignition furnace. Air is drawn through the bed, maintaining combustion until the burn-through point is reached at the discharge end of the sinter strand. For good fuel economy, the discharged sinter should be cooled and the air used to initiate combustion in the ignition furnace.

PELLETIZING

Use of pellets in the steel industry has grown phenomenally over the past 20 years, a gain that has been made at the expense of lump ores. The three most important induration systems are the shaft furnace, the straight grate, and the grate kiln.

Fig 15—Three-grid fluidized bed (top grid for preheating, middle grid for calcining, bottom grid for cooling)



The following fuel consumptions are reported using magnetite concentrates by the *Mining Engineers Handbook, 1973*: shaft furnace, 450,000-600,000 Btu per lt; straight grate, 550,000-700,000 Btu per lt; grate kiln, 575,000-750,000 Btu per lt. The handbook also reports that these figures are higher by 150,000 to 350,000 Btu per lt for hematite concentrates or natural ore.

In shaft furnaces, there are roughly three zones, a top zone for drying, a middle zone for indurating, and a bottom zone for cooling. Such furnaces are suitable only for magnetite pellets. Hematite pellets require more heat and are apt to hang up and stick due to the extra fuel required.

In straight grates, a moving grate is entirely covered by a housing, and four general zones are created through the use of ducting and baffles: a drying zone at the feed end, an induration zone, a heat recuperation zone, and a cooling zone. Straight grates lend themselves to the entire range of pellets, from magnetite through hematite, including mixtures.

The grate kiln system consists of a moving grate that preheats the pellets using hot gas from a kiln that follows. Induration is completed in the rotary kiln. Heat is recovered and returned to the system in a cooler after the kiln. The grate kiln system is widely used and is competitive with the straight grate system. Like the grate system, it lends itself to use with the entire range of green pellets, from magnetite through hematite, including mixtures.

In the past, the three indurating systems discussed above have depended on the use of oil or gas. Some comment on the use of coal in these systems may be of interest.

The shaft kiln does not lend itself to the use of coal. If a suitable method is found, it will probably involve external combustion chambers.

Dravo Corp. has developed a system adapting the straight grate system to coal, using two external combustion chambers, one on either side of the grate. The system is designed to permit coal ash to be withdrawn from the bottom of the combustion chambers.

The grate kiln system is most readily adaptable to the use of coal, and with suitable coals, can be truly direct-fired.