The
ROTARY KILN
HANDBOOK
OPERATION | SIZING & DESIGN | CONSIDERATIONS | MAINTENANCE
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Introduction

FEECO International was founded in 1951 as an engineering and equipment manufacturer. We quickly became known as the material experts, able to solve just about any material processing or handling problem, and now serve nearly every industry, from energy and agriculture, to mining and minerals.

As experts in the field of thermal processing, FEECO has been solving problems through feasibility testing and custom thermal processing equipment since the 1950s. We’ve helped our customers process hundreds of materials into value-added products, eliminating handling and transportation problems, improving product characteristics, and creating marketable products.

For further information on thermal processing with rotary kilns, contact a FEECO expert today.
Intro to ROTARY KILNS
An Intro to Rotary Kilns

Rotary kilns are an advanced thermal processing tool used for processing solid materials at extremely high temperatures in order to cause a chemical reaction or physical change. They are commonly used to carry out processes such as:

- Calcination
- Thermal Desorption
- Organic Combustion
- Sintering/Induration
- Heat Setting
- And more...

While rotary kilns were originally developed for use in the cement industry, due to their flexibility, they can now be found throughout a variety of industries, aiding in both processing commodities, as well as in highly specialized applications. Some of the most common kiln applications in use today include:

- Mineral Roasting
- Proppant Sintering
- Gypsum and Bauxite Calcining
- Waste Incineration
- Desorption of Soil Contaminants
- Upgrading of Phosphate Ores
- Waste Lime Recovery
- Catalyst Activation
- Activated Carbon Production & Re-Activation
- Plastics Processing
- Ceramics Processing

Rotary kilns have become the backbone of many new industrial processes that make the world a more efficient and sustainable place. As new applications for rotary kilns continue to be developed, much experimental work is being done, prompting many questions and the need for further research and development.

This handbook serves to give an overview of rotary kilns and answer some of the commonly asked questions about these versatile thermal processing machines.
ROTARY KILN
OPERATION & PROCESSING

HOW ROTARY KILNS WORK | PROCESSES
How Rotary Kilns Work

Rotary kilns are used to heat solids to the point where a chemical reaction or physical change takes place. They work by holding the material to be processed at a specified temperature for a precise amount of time. Temperatures and retention times are determined through creating temperature profiles, based on thorough chemical and thermal analyses of the material.

A rotary kiln is comprised of a rotating cylinder (called the drum), sized specifically to meet the temperature and retention time requirements of the material to be processed. The kiln is set at a slight angle, in order to allow gravity to assist in moving material through the rotating cylinder.

Rotary kilns can be either of the direct-fired type, or the indirect-fired type (sometimes referred to as a calciner). In a direct-fired kiln, a process gas is fed through the drum, processing the material via direct contact. In an indirect-fired kiln, material is processed in an inert environment, and is heated through contact with the shell of the kiln, which is heated from the outside to maintain an inert environment.

Rotary Kiln Construction

While FEECO rotary kilns are custom designed around the material to be processed, in general, there are some standard components that serve as the basis of a rotary kiln. The diagram shown on the following page illustrates some of the common standard components found on a basic direct-fired kiln. A diagram of an indirect-fired kiln can be seen on the following page.

Drive Assembly

The drive assembly is the component that causes the kiln to rotate. A variety of drive assembly arrangements are available: chain and sprocket, gear drive, friction drive, and direct drive assembly. Unlike most other rotary kiln components, there is not a need for further customization in terms of the mechanical components of the drum; the need for one drive type over another is solely dependent on how much horsepower is required.

Chain & Sprocket: A chain and sprocket arrangement works much like a bicycle; there is a large sprocket wrapping around the rotary drum with a chain on it that goes to the reducer and motor. The spinning motor turns a gear box, which spins a small sprocket that is attached by the chain to the large sprocket wrapping around the rotary drum. Chain and sprocket drive setups are reserved for small rotary kilns, running up to 75 horsepower. This type of arrangement is not suitable for larger kilns running above 75 horsepower, but is ideal for smaller jobs, as it is cost-effective, and easy to run.

Gear Drive: The gear drive is best for heavy-duty applications running above 75 horsepower. Similar to the chain and sprocket drive, instead of a sprocket wrapped around the girth of the drum, this drive has an actual gear around the drum. This gear meshes with a small gear drive, which rotates it. This type of drive is more costly, but operates and wears better in heavy-duty applications.

Friction Drive: Friction drive assemblies are reserved for small applications requiring low horsepower. This
is commonly seen with drums around 6' and under. With a friction drive, two of the four trunnion wheels are connected by one shaft and driven by a shaft mounted reducer and motor arrangement.

**Direct Drive:** Direct drive assemblies are used in small to medium sized drums, with motors up to 75 horsepower. In this design, a shaft is mounted to a solid, discharge end plate at the outlet of the kiln. The motor and reducer are either directly connected to this shaft with a coupling, or a shaft mount arrangement.

**Riding Rings**
The riding rings provide a surface for the kiln load to be distributed.

- **Thrust Rollers**
  Thrust rollers prevent the drum from drifting or moving horizontally by pushing against the riding rings.

- **Trunnion Wheels**
  The trunnion wheels act as the cradle for the rotating drum shell. They ensure smooth and concentric rotation during operation. They also act as a wear piece, because they are easier and less costly to replace than the riding ring itself. The wheels are mounted to steel support bases with sealed roller bearings. Support rollers bear the weight of the drum.

- **Discharge Breeching**
The discharge breeching serves two purposes: one purpose is to provide a place for product to exit the
kiln, so it can move on to subsequent processing; the second purpose is to mount the kiln burner in a counter-current system.

**Product Discharge**
The product discharge area is where product exits the kiln. Typically, the product will then move on to cooling or subsequent processing if needed.

**Exhaust Gas System**
The exhaust gas system is typically much larger when working with a direct-fired kiln. Here, exhaust gases and any small particulates exit the system and typically go through exhaust gas treatment to remove contaminants before being discharged into the environment. The exhaust gas system on a kiln often requires an afterburner and heat exchanger or quench tower to cool the gases before they enter the bag filter.

**Refractory**
Refractory serves the purpose of insulating and protecting the shell of the drum from the high temperatures within, and also minimizing heat loss. Many types of refractory are available, and refractory layers can be customized to suit the unique application. Refractory is discussed further in depth on page 17.
Burner
The burner of a rotary kiln supplies the energy required by the process. Instead of utilizing a combustion chamber, typically the burner on a kiln is mounted on the discharge end housing.

Burners can be designed to accommodate a variety of fuel sources, from natural gas, to propane, diesel, and other common fuel sources. Choosing the appropriate burner for a rotary kiln is integral to ensuring efficient processing.

Raw Material Feed
The raw material feed, or feed chute, is where feedstock enters the drum. This is typically carried out using a feed screw or chute and is often made from a more heat-resistant alloy. This area must be designed to be robust and to lessen the opportunity for build-up to occur.

Air Seal
The seal connects the stationary breeching to the rotating drum, and helps to prevent the escape of process gas from the system, as well as prevents air from leaking in. Holding the appropriate temperature within a rotary kiln is what allows the desired chemical reaction to occur. Sustaining that temperature, however, can be difficult if the right seal is not chosen. Various seal options exist. For more information on choosing the right seal, see page 16.

Shell
Direct-fired kilns are typically made out of carbon steel. Indirect-fired kilns, however, must be more resistant to high temperatures, and are therefore made out of a more heat-resistant alloy.

Rotary Kiln Processes
Because rotary kilns simply serve as a vessel to cause a chemical reaction or phase change, as mentioned, there are many types of processes that they can be used for. Below is an overview of some of the processes that are commonly carried out in a rotary kiln and how they work.

Calcination
The calcination process requires heating a material to a high temperature with the intent of chemical dissociation (chemical separation). Calcination is commonly used in the creation of inorganic materials. One of the most common examples of this process is the dissociation of calcium carbonate to create calcium oxide and carbon dioxide.

The calcination process can also be used in the removal of bound moisture, such as that which is chemically attached in Borax.

Thermal Desorption
Thermal desorption uses heat to drive off a volatile component, such as a pesticide, that has mixed with an inorganic mineral like sand. It is important to remember that this is not incineration, which may produce harmful pollutants and would require a more extreme exhaust treatment system; instead, it is a separation process that uses the different reaction temperatures of absorbent minerals and chemicals. The organic chemical (e.g. pesticide) is vaporized at the increased temperature, causing a separation.
without combustion. An indirect rotary kiln is best for this application, because the volatile chemicals may be combustible. The indirect kiln would supply the heat for desorption, without the material coming into direct contact with the flame.

**Organic Combustion**

Organic combustion is the thermal treatment process of organic waste. This combustion process leaves behind ash that has considerably less mass and volume. The most common use for this rotary kiln process would be in waste treatment plants with the intent of reducing the volume of waste for depositing in landfills. Direct-fired rotary kilns are the most common style for this application, because air is required to combust the organics.

**Sintering/Induration**

Sintering, or glassification, is the process of heating the raw materials to a point just before melting. The objective of this process is to use the high internal temperature of the rotary kiln to increase the strength of the material. The most common use of this process is in the creation of manufactured proppants, where the sand or ceramic material needs to have high strength.

**Heat Setting**

This is a process of bonding a heat resistant core mineral with another, less heat resistant coating material. Much like other coating processes, there is a core material and a coating material (usually mixed with a binding agent). The difference between this process and a non-heated coating process is that a rotary kiln heats the coating material to just below its liquefaction point. At this heated state, the material can coat the heat resistant core evenly and, since this is a chemical phase change, more securely than a traditional coating process. A common application of this process would be in the manufacturing of roofing granules, where a mineral such as granite is coated with a colored pigment, producing a durable and aesthetically pleasing granule.
SIZING & DESIGN

SIZING & DESIGN | CUSTOMIZATION | THERMAL TESTING
Rotary Kiln
Sizing & Design

Every material is different in terms of how it will behave in the kiln and at what temperatures different reactions will occur. When designing a process around a rotary kiln, as well as in the design of the kiln itself, the material must undergo thorough chemical and thermal analyses. Various material characteristics will play a part in how the material will perform in the kiln, and subsequently, how the kiln will need to be designed around the material to accomplish the process goal. For example, will the material melt, vaporize, or combust at certain temperatures? Much of this data can be gathered through testing (discussed on page 19). The following provides an overview of some of the common material characteristics that can influence the design of the kiln.

Characteristics that Affect Rotary Kiln Design

Particle Size Distribution & Bulk Density
The particle size distribution and bulk density of a material will influence the sizing of some kiln components. For example, a material with a high bulk density will likely require more horsepower, and therefore a more robust drive system. Additionally, a material that has been agglomerated into pellets (or has a larger particle size distribution) will not require as large of a kiln diameter as fines would. This is because when processing fines, a lower air velocity must be used to minimize entrainment. When processing pellets, however, a higher air velocity can be utilized, and therefore, the kiln does not need to be as large.

Abrasiveness & Corrosiveness
While the abrasiveness or corrosiveness of a material may not have a direct effect on the sizing aspects of the kiln, it does influence the materials of construction. Working with abrasive or corrosive materials may require parts, or all, of the kiln to be lined or constructed with a corrosion/abrasion-resistant refractory.

Specific Heat
The specific heat of a material is another central factor in the design of a rotary kiln. Specific heat is how resistant a material is to heating. By definition, it is how much energy (i.e. calories) it takes to raise 1 gram of material by 1 degree Celsius. Some materials, such as water, have a very high specific heat, meaning it takes a significant amount of energy to raise the temperature. Other materials, such as metals, have a much lower specific heat, meaning it takes much less energy to cause a change in temperature.

Heat of Reaction
In many kiln applications, heat is required in order for a reaction to occur. For example, in the calcination of limestone to lime, energy is required to dissociate CaCO₃ into CaO and CO₂. In addition to energy, an elevated temperature is required for most reactions to occur; the dissociation of limestone will not happen at a temperature below 900° C.

The temperature and energy required for a reaction can be found in published data or by running a DTA test (described on page 13).
Thermal Conductivity

Similar to specific heat, the thermal conductivity of a material also plays a part in the design of a rotary kiln. How a material transfers heat will have a direct effect on how the material behaves in the rotary kiln: will it transfer its heat easily, causing even heat distribution and low retention time, or will it hold onto its heat, causing cold pockets of material, longer retention time, and possibly the need for additional accessories like dams or bed disturbers?

Temperature Profiles

A Thermal Gravimetric Analysis, or TGA, can be performed on a material to determine changes in mass as a function of temperature. A TGA describes the temperature ranges at which mass loss occurs. This is critical in determining the required temperature profile in a kiln. As an example, free water will show primary removal at around 212°F, where tightly bound chemical water may show a mass loss upwards of 500°F.
A TGA also helps show where a reaction begins, and ends, as often, the curve on a TGA starts at a specific temperature, but does not complete until a much higher temperature. Overall, a TGA helps determine the temperature profiles that will be required in a rotary kiln by showing at what temperature reactions are occurring. Additionally, while the intent of a process may be to convert a material in a specific way, a TGA will reveal reactions that might occur between the start and end point, helping to indicate where unpredicted reactions may occur.

A **Differential Scanning Calorimeter (DSC)** or Differential Thermal Analysis (DTA) is also useful at this stage, as it shows the amount of heat required to perform the reactions and to heat the material to the final temperature.

**Chemical Composition**
Knowing the chemical composition of a material is a
valuable asset in rotary kiln design for several reasons. One important reason is that many materials will combust inside the rotary kiln at high temperatures, creating more heat than was put into the rotary kiln. In cases such as these, the rotary kiln will need to be designed to withstand those excess amounts of heat. In other cases, materials may need a particular chemical atmosphere for a reaction to occur—for example, an atmosphere devoid of oxygen, or rich in carbon dioxide. Still another reason to understand the chemical makeup of a material, and how those chemicals react together at certain temperatures, is to predict what exhaust gases will be generated and subsequently, what type of exhaust gas treatment will be necessary.

**Sizing**

After the material has been thermally and chemically analyzed, sizing can begin. Sizing is a complex process not easily explained in brief; the process of sizing a rotary kiln is one that combines engineering principles with the thermal and chemical analyses, along with experience, to design a kiln that meets its intended processing goal.

The size of a rotary kiln is not only a function of capacity, but also of the amount of heat that can be generated inside the rotary kiln from the volatizing and/or combustion of the material. The diameter and length of the rotary kiln are calculated based on the maximum feed rate, the required retention time, and what the bed profile (how full of material the rotary kiln is) will need to look like. In the FEECO design process, once we have engineered a rough design of the rotary kiln, we use several computer programs to help predict and model how the material will behave in the rotary kiln we have designed. We review the combined analyses, and if our design does not meet the appropriate criteria, we adjust accordingly.

Once we have our preliminary rotary kiln size, we can start to think about the details of the rotary kiln internals, such as if there will be a need for a dam, or what type of refractory will best suit the process.

FEECO encourages that each material go through a research and development process at our on-site, concept testing facility. The information gained through FEECO’s proven testing procedures allows us to design the most efficient and beneficial thermal processing system for our customer’s material requirements. Testing is discussed in-depth on page 19.

**Increasing Efficiency through Customization**

Rotary kilns are extremely customizable, and can be configured to fit nearly any process needs. There are various ways to customize a kiln in order to attain the most efficient processing possible. Below are some of the common customizations used to maximize the performance of a rotary kiln.

**Dams**

For various reasons, it is often desirable to increase retention time or bed depth in the rotary kiln. This is done by adding what is called a “dam.” A dam in a rotary kiln works much like a dam in a river; material builds up behind the dam, forcing retention time and bed depth to increase. Material then spills over
the dam, and discharges from the rotary kiln. Since most kilns utilize a counter current air-flow, end dams are the most commonly used (see illustration above). End dams efficiently hold the material where the air is warmest (at the discharge end in a counter current kiln). Internal dams can also be used if a discharge end dam is not sufficient.

**Flights**

Flights are most commonly seen in rotary dryers. They are, however, sometimes utilized in low temperature kilns in order to shower the material and increase heat transfer efficiency.

**Bed Disturbers**

Indirect rotary kilns create heat transfer by conduction through the shell of the rotary kiln, rather than by means of contact with a process gas. Because all of this heat transfer is occurring through the shell, it is essential that the bed rolls rather than slides in order to expose fresh material, allowing for even heat distribution throughout the bed of material. This will assure that the transfer of heat is as efficient as possible. For this reason, when processing material in an indirect-fired kiln, it is often desirable to employ a bed disturber. Bed disturbers are also commonly used in a direct-fired kiln for the same reason; the bed disturber helps to prevent the bed from sliding, as well as promotes more uniform heating.

A bed disturber, often custom designed to create maximum, material-specific efficiency, is essentially anything affixed to the inside of the rotary kiln that helps to mix the bed of material. Ideally, the bed should tumble, turning over and minimizing dead spots, or temperature variations within the bed.

Dams are put in place when retention time needs to be increased using the same size rotary kiln. Dams allow the loading to be increased, which increases retention time and bed depth by forcing the material to build up in the rotary kiln.
Unfortunately, not all materials tumble well, which results in a slipping bed with poor mixing and large temperature variation. Bed disturbers can be attached to the interior of the rotary kiln in order to disturb the bed and turn it over. However, what seems like a simple task can get complicated quickly, as thermal stresses must be accounted for.

A common bed disturber used in an indirectly heated kiln is a bar that runs the length of the interior of the rotary kiln. Material pushes up against the bar, building up and rolling over it, so material that was on the top of the bed now gets redistributed to the bottom of the bed. The disadvantage to using a bar bed disturber is that they can sometimes bend and break with the thermal stresses of the rotary kiln. A rotary kiln naturally has gradients of temperature, usually cooler on the ends of the rotary kiln, and hotter in the middle. This gradation in temperature causes differential thermal expansion on the rotary kiln shell. Because of this, the bar, welded to the shell, is pulled in different directions, which can cause the weld to break. When this kind of thermal expansion is at work, it is usually best to look at alternative bed disturbers.

Flights, or lifters can also be used as a bed disturber. In this case, flights are welded with one weld point each to the inside of the rotary kiln. This method of disturbing the bed is designed to accept the different thermal expansion stressors, making it ideal for drums with temperature gradations.

Seals
Almost all rotary kilns run at a negative pressure, meaning gas doesn’t leak out, but rather, air leaks in.

Diagram: The illustration above shows the gradations that can occur in a bed of material that is poorly rotated (top). The addition of a bed disturber helps to rotate the bed, ensuring even distribution of heat throughout the bed (bottom).
Because rotary kilns are always running at a higher temperature than ambient, any ambient air leaking into the rotary kiln will cause the temperature inside of the rotary kiln to drop. Not only will this result in an unnecessary amount of energy being used and wasted, but if the leak is severe enough, it could also potentially disrupt the process. This is why it is crucial to have a quality seal.

Sealing the ends of a rotary kiln can be a difficult task, because of the fact that you’re trying to seal something moving to something stationary. The stationary part, referred to as the breeching, is typically where leakage will occur. One option is a leaf seal. Leaf seals are the standard seal used on both rotary kilns and rotary dryers.

How Leaf Seals Work: Leaf seals are similar to a fanned out deck of cards. The “cards,” or leaves, are made out of spring steel. These fanned out leaves are bolted to the breeching, and the springy leaves are forced to push against the seal/wear plate of the rotating kiln, naturally keeping pressure on the rotary kiln to create a good seal.

The purged double leaf seal is a variation of the leaf seal, and is typically used in situations where maintaining the atmosphere inside the rotary kiln is extremely critical. For example, in cases where the atmosphere inside the rotary kiln cannot tolerate oxygen from ambient air leakage, a leaf seal may not be sufficient, and a purged double leaf seal would provide a better seal.

The purged double leaf seal is made up of two components. The first is two sets of seals, which consist of two layers of “leaves” on top of each other. The second component is an inert purge gas, such as nitrogen, which is introduced between the two sets of seals. This purge gas pushes outward to ambient, so that there is a flow of gas going out, and therefore, no oxygen can flow in.

Refractory
Arguably one of the most critical components of a direct-fired rotary kiln, the refractory is what protects the shell from the high temperatures within, and maintains heat retention. A quality refractory is of the utmost importance, and many options are available, depending on the needs of the rotary kiln. Refractory is specific to direct-fired kilns; the addition of refractory to an indirect-fired kiln would decrease efficiency, because it would add another layer for heat to pass through before it could reach the material.

Typically, there are two kinds of refractories for lining a rotary kiln: castable, and brick. Each kind of refractory has its advantages and disadvantages. The choice of refractory is dependent on the rotary kiln temperature,
material chemistry, and how abrasive the material is. Castable and brick refractory are comparably priced for similar refractory compositions. However, the installation cost for brick is higher, since it is more labor intensive. Brick is usually used for abrasive materials, because it is more wear resistant.

**Working vs. Insulating Layer**

The way in which refractory is layered is also customizable. When higher efficiency is desired, or very high temperatures are involved, often it is desirable to use multiple layers of refractory: a “working” layer, and an insulating layer. The working layer is what is in direct contact with the material being processed. Because of this, this working layer is a dense lining that can withstand the high temperatures within the rotary kiln and the constant abrasion from the material. However, when it comes to refractory, the denser it is, the less insulating capabilities it has. This means that even though there may be a tough, durable, thick working layer in place, the heat can easily pass through to the shell of the rotary kiln. For this reason, an insulating layer is needed beneath the working layer (See figures at right). The insulating layer does just that; it insulates the shell of the rotary kiln so the high temperatures cannot reach the shell and damage it.

Typically the working layer and the insulating layer are made of the same form of material (i.e., brick or castable), with varying chemistries. The working layer tends to be a higher density, stronger material that is more conductive. The insulating layer does not need these qualities, and tends to be softer, lighter, and less conductive, therefore more insulating. These two layers often vary in thicknesses, and these are

**Diagram:** The illustrations above show castable and brick types of refractory with both working and insulating layers. The castable illustration also shows optional ceramic fiber backing.
determined from the needs of the rotary kiln and what material is being processed. In some unique cases, where processing temperatures are low, or efficiency is of less concern, it is only necessary to use one working layer. For these reasons, refractory in a rotary kiln is often a very custom part of the design.

When insulation is extremely critical, an optional third layer of ceramic fiber backing can be used (as seen in the castable illustration on the previous page). Though there are various kinds of this backing, this thin, but very efficient layer is similar to fiberglass insulation found in a house, but it is much more compressed.

**Thermal Testing**

Testing plays an integral part in the development of many industrial processes, and is especially critical in the thermal processing industry when working with kilns. Testing gathers important process data, and lays the groundwork for developing a safe, efficient, and effective process that meets the desired processing capacity and product quality.

**Why Use Testing?**

Testing is useful in a multitude of processes. Commonly tested processes include:

- Thermal Desorption of Organic/Hazardous Wastes
- Sintering/Induration
- Heat Setting
- Organic Combustion
- Metal Recovery
- Calcination
- Mineral Processing
- Reduction Roasting

There are many reasons why it may be desirable to conduct testing with a rotary kiln. Some of the most common reasons include:

**To Size and Design a Commercial Size Kiln**

Perhaps the most common reason for thermal testing with a kiln is to gather the data necessary to size and
design a commercial size kiln for an intended application. In this setting, the desired set of product specifications have typically been determined, but the customer needs to know what the kiln and surrounding process looks like to reach those parameters.

To Aid in Product Development
Often times, a customer is looking to develop a new or enhanced product. This is commonly seen in the proppant industry, where ceramic proppants are processed in a rotary kiln to develop the ideal characteristics needed for the hydraulic fracturing process.

Testing can be carried out on small samples of material and used for field trials to evaluate the product properties.

To Confirm Viability of an Intended Process
Testing is also useful in determining if a particular process holds potential for a commercial-scale operation. Customers come to FEEOC with an idea and a sample of material, and trials are run to determine if the process is technically and economically viable.

While this is seen throughout a variety of industries, one common example is in the reclamation of valuable materials, such as the recovery of metals from wastes. Many waste materials have previously been landfilled even though they contained a valuable component, because the component was not accessible or recoverable in its current form. Advanced thermal processing techniques have opened the door to the recovery of these valuable components. In cases such as these, a company may test a material to see if the valuable component could be recovered from the waste material in an economically viable way.

To Test Variable Process Conditions
Another common reason for thermal testing is to research and develop different processing conditions. Many customers may have an existing thermal system, but are looking to adjust the process, or feel that their current process could be improved upon. Testing allows them to try out various process conditions in a test setting, without disrupting production in their existing commercial kiln.

How Testing Works
Testing is commonly conducted first at batch scale, and then at pilot scale.

Batch/Feasibility Testing
Batch testing, also referred to as feasibility testing, is a cost-effective way to test small sample sizes and gather initial process data, such as time and temperature profiles. Batch test work also helps to define the process parameters needed for continuous pilot-scale testing.

Pilot Testing
Pilot test work is done on a much larger scale than batch testing, allowing for a continuous process, including exhaust gas treatment, to be tested, and commercial process conditions to be simulated.

During both batch and pilot testing, solid samples can be regularly withdrawn in order to determine the material chemistry and physical properties of the material at various intervals. Material characteristics
such as those listed below are commonly analyzed to ensure a product is meeting desired specifications:

- Flowability
- Compression Strength
- Bulk Density
- Crush Strength
- Chemical Analysis
- Gas Sampling & Monitoring

Gathered process data can then be used to produce the desired product specifications and aid in process scale-up. These data points may include:

- Residence time
- Kiln slope
- Temperature requirements
- Kiln speed
- Emissions
- Feed Rate

**Available Testing Equipment**

Direct-fired and indirect-fired kilns can be tested in the FEECO Innovation Center, at both batch and pilot scale. Co-current and counter current air-flow configurations can also be tested, with a variety of optional equipment available to accommodate the process. Optional testing equipment in the FEECO Innovation Center includes:

- Kiln combustion chamber
- Thermal oxidizer
- Baghouse
- Wet scrubber
- Removable flights, dams, and bed disturbers

**Automation**

The FEECO Innovation Center offers an extensive programmable logic control system. We have partnered with Rockwell Automation to bring our customers the best in process automation, both as part of testing in our Innovation Center, and as part of a system purchase.

Our system allows for a variety of data points to be tracked and adjusted from a single interface, in real time. This includes:

- Horsepower
- Amps
- Feed rate
- Hertz
- Temperature
- Flow Rates
- Torque
- Gas Sampling & Analysis

In addition, data points can be selected, trended, and reported on, allowing users to select only the data they need, from the exact time frame they need.
CONSIDERATIONS
DIRECT VS. INDIRECT | AIR FLOW | MOISTURE REDUCTION
Direct vs. Indirect

When designing a thermal processing operation, confusion often results on whether a direct-fired or indirect-fired kiln is the better option. And while there can be some overlap in applications, in general, each type of kiln is better suited for different processes. Below is a brief overview on these two types of kilns.

Direct-Fired Kilns

As mentioned, direct-fired rotary kilns rely on direct contact between the process gas and the material in order to heat the material to the specified temperature. Direct-fired kilns can be either of the co-current design, or counter current design, referring to the direction that the process gas flows through the drum in relation to the material (more information on air flow can be found on the following page).

Direct-fired rotary kilns are most often the equipment of choice in thermal processing, because they are more efficient than their indirect counterparts. There can be disadvantages to a direct-fired kiln, however. For example, because a process gas is used to treat the material, direct-fired kilns subsequently produce more off-gases that will require treatment.

Additionally, some materials must be processed in an inert environment, so as not to be exposed to oxygen or nitrogen. In applications such as this, a direct-fired kiln would not be an option. Materials that are commonly processed in a direct-fired kiln include:

- Proppants
- Minerals
- Specialty Ceramics and Clays
- Limestone
- Cement
- Iron Ore

Indirect-Fired Kilns

Conversely, indirect-fired kilns can process material in an inert environment, where the material never comes into contact with the process gas. Here, the kiln is
heated from the outside, using a heat shroud, and the material is heated via contact with the hot kiln shell. While this method is significantly less efficient than a direct-fired kiln, it is necessary in some processes that require a more tightly controlled environment. This might include instances where an undesirable oxide compound will form in the presence of oxygen at high temperatures. Similarly, some materials may form an undesirable compound with nitrogen at high temperatures. In situations such as these, the use of an indirect-fired kiln provides the necessary inert environment for effective processing.

Indirect kilns also allow for precise temperature control along the length of the kiln. This is advantageous in settings where a material will need to be brought up to temperature, and then held there for a specific amount of time as it moves through the kiln.

Indirect fired rotary kilns can also be beneficial when the material to be processed consists of finely divided solids. In a direct-fired rotary kiln, the heat source is hot gas (products of combustion and air), which flows with an inherent velocity. These gases can carry particles through form drag. The degree of entrainment depends on a variety of factors, such as gas velocity, gas density, particle density, and shape. Due to entrainment potential, direct-fired rotary kilns processing fine materials require the design to be centered on permissible gas velocities as opposed to heat transfer requirements. Examples of fine materials commonly processed in an indirect-fired kiln include:

- Carbon Black
- Chemical Precipitates
- Filter Cakes
- Finely Ground Solids

Because the heat is being transferred through the shell, an indirect rotary kiln is not lined, in order to maximize the heat transfer through the shell. Therefore, an indirect rotary kiln is usually made out of a temperature resistant alloy, instead of carbon steel.

While direct-fired kilns offer maximum efficiency, they are not always appropriate for the intended process. In settings such as these, an indirect-fired kiln would offer the best processing solution. In some process situations, a combination of a direct and indirect rotary kiln is required; the direct-fired rotary kiln is used to burn off the organic fraction of the material being processed, and further polishing of the resultant ash material is conducted in a specialty indirect kiln.

### Options in Air Flow

As mentioned, direct rotary kilns are available in two types of air flow configurations: co-current and counter current. Both options have been developed through extensive research and development in order to maximize the thermal efficiency of the process. Most rotary kilns are of the counter current configuration, because this option is much more energy efficient. However, in some instances, the co-current configuration is more appropriate. Additionally, indirect kilns use a different air flow altogether: cross-flow. This is because combustion gases are not flowing through the kiln, but rather, are perpendicular to the material.
During the design process of a direct-fired kiln, the selection of which air flow configuration (co-current or counter current) will best suit the application is based on the material’s properties, as well as overall process requirements. Because of this, it is important to understand how each air flow option functions to fully understand the benefits each has to offer.

### Co-Current

Co-current air flow, which is also referred to as parallel flow, is when the products of combustion flow in the same direction as the material. This immediately puts the coldest material in contact with the hottest gas in the kiln, resulting in a rapid initial temperature change.

Co-current kilns work best with materials that don’t need a gradual temperature increase for a controlled transformation. An organic combustion process commonly uses this air flow configuration, because it does not require a very specific end product. In this example, a waste material (e.g. spent catalyst) containing both organic and inorganic material is introduced into the kiln. These materials can come into immediate contact with the high heat and the volatile components will be vaporized soon after feeding. The organic material is burned off with the high heat and what is left is a dry ash.

### Counter Current

Counter current air flow is when the air flows in the opposite direction of the material flow. In this design, the material is heated gradually while traveling through the kiln. Here, material comes in contact with the hottest products of combustion just before discharge. The main benefit to this air flow
configuration is the thermal efficiency; with the burner being mounted at the end of the thermal processing cycle, less heat is required, resulting in decreased fuel consumption. This is illustrated in the tables on the previous page.

The co-current configuration needs a much higher initial temperature in order to heat the process material from its initial temperature and get the desired phase or chemical change. In contrast, in a counter current configuration, the material and the process gas temperature are directly correlated. For the example in the chart, the air flow (process gas) temperature only needs to be slightly higher than the required temperature for the material transformation. The result is a lower exhaust gas temperature and lower operating costs.

Additionally, the counter current design is commonly used for a more controlled physical or chemical change, where the material temperature needs to be gradually increased to achieve the desired end result. Sintering is a common process that utilizes the counter current air flow to maintain a controlled phase change. The gradual, yet extreme heating process allows for a material such as a proppant, to transform into a much harder material.

**Cross-Flow**

As mentioned, the cross-flow configuration is specific to indirect kilns. In co-current or counter current flow, the gas and solid streams flow parallel to each other. In a cross-flow configuration, however, the gas and solid streams are perpendicular to one another.

One advantage of cross-flow heat transfer is that the solids can be held at a constant temperature for an extended time. This is very difficult to achieve in a co-current or counter current kiln.

Understanding how each air flow system works is one of the many considerations in designing the most efficient and effective rotary kiln for the job. Each air flow configuration has its unique and varying benefits for material transformation.
Moisture Reduction:  
Dryer or Kiln?

Although rotary kilns are designed to be used for driving a chemical reaction, an issue that often comes up in the processing of a material is when to remove the excess moisture from the feedstock.

Many times, there is surface moisture that needs to be removed from the material before it is processed in a rotary kiln, and one is faced with a decision: buy another piece of equipment, or use the rotary kiln to do the work. There are costs and benefits to each approach.

While rotary kilns have the ability to remove moisture from a material, this tends to be a less efficient process. In a rotary kiln, material is typically not showered like in a rotary dryer, but rather, slides along the interior of the rotary kiln. This results in lower heat transfer between the material and the gas. Because of this, drying material in a rotary kiln takes much longer than in a rotary dryer.

The alternative to drying material in a rotary kiln is to add a rotary dryer into the process prior to the material going into the rotary kiln. Taking this approach would efficiently dry the material before it enters the rotary kiln, leaving the rotary kiln the sole job of converting the material. With a rotary dryer, flights lift the material and drop it through the stream of hot gas, creating a showering effect called the curtain. This showering effect allows for a maximum heat transfer between the material and the gas, drying the material in an efficient manner.
INSTALL & MAINTENANCE

INSTALLATION | DAMAGE PREVENTION
Ensuring A Smooth Kiln Installation

A rotary kiln is a major investment and integral part of many industrial processing systems. And while a significant amount of time and research is put into finding the right rotary kiln manufacturer, and engineering a solution that blends seamlessly into your process, the work continues after the purchase.

The install of your new rotary kiln requires just as much planning and attention to ensure proper installation, optimal performance, and equipment longevity.

Why Proper Rotary Kiln Installation is Important

A properly installed rotary kiln is the first step in prolonging equipment life and reducing potential downtime and maintenance. Problems that begin at install can quickly result in serious damage and downtime. A poorly installed rotary kiln can result in a variety of problems, including:

- Damage to wheels/tires from poor alignment
- Damage to drum shell because it was handled improperly
- Re-work needed and/or voided warranties because critical hold points/inspections were not done

However, there are a few simple steps you can take that will help to achieve a smooth and successful install, avoiding the problems mentioned above.

Key Steps for a Smooth Installation

Have a Service Technician On-Site

Having a service technician from the manufacturer on-site for installation offers many benefits. The service technician is well trained in the exact specifications needed for efficient installment and operation of your equipment. They know what to look for and any potential places for error to occur. Service technicians can oversee installation, assuring that things are done right, and no warranties are voided in the process.

In addition, service technicians are a valuable source of knowledge for answering installation and operation questions on the spot. Furthermore, they can train maintenance personnel on the ins and outs associated with the equipment during their time on-site.

Plan Ahead

Contacting the equipment manufacturer well ahead of the installation date to begin planning is vital to carrying out a seamless rotary kiln installation.

Ideally, the equipment purchaser, manufacturer, and installation contractor should be in contact with one another prior to installation so that everyone knows what needs to happen before install day arrives. This will help to ensure that on-site service technicians and supporting manpower will have everything they need on-site, and won’t waste valuable time waiting on things that could have been prepared for. The items listed below are all things that should be considered during the planning stages of installation:

Appropriate equipment staging: In cases where the kiln is a replacement and will need to be fit into place, ensuring all ancillary equipment, such as feed chutes
and/or discharge chutes are in place and pre-posed will prevent wasted time during install. This is less of a concern when putting together a new process where equipment will be fit around the kiln, but can still be prepared for.

**Materials & Equipment:** Having the right materials and equipment on hand can mean the difference between a smooth install and days wasted.

Materials such as grout needed for pouring under bases, or shimming materials used in the alignment process should all be purchased and prepped for install. It’s worth mentioning also, that the proper tools and equipment should be on-site as well. While most install contractors will have the right tools and equipment at their disposal, the importance of having them on-site and ready for use cannot be emphasized enough. This too, will prevent wasted time waiting for the proper tools or equipment to arrive. An inadequate crane, for example, could mean that technicians have to wait for a new crane to arrive and be mobilized before work can begin.

**Pre-Alignment:** The installing contractor should install and pre-align the drum bases prior to kiln installation. Having the drum bases installed and pre-aligned will allow technicians to begin their work right away on installation day, instead of waiting a day or two for the pre-alignment to be completed.

All of the items above can be planned for by a simple conference between the equipment purchaser, installing contractor, and original manufacturer. Planning for these items will help to ensure that no time is wasted on installation day and progress moves according to plan.

**Use a Laser Tracking System for Optimal Alignment**

Properly aligning the kiln bases and shell is an important part of installation, and can set the tone for operational efficiency and equipment longevity. Rotary drum misalignment is one of the most common causes of drum damage and premature equipment failure, making proper alignment during install key to operational success. One way to ensure proper alignment is achieved is through the use of a laser tracking system.

While traditional alignment techniques can offer a reliable alignment option, they leave much room for error. New laser tracking systems, however, provide a more efficient, and accurate solution to alignment needs, offering fast, precise alignment. In a typical setting, laser alignment can get the bases to within +/- 0.005 in.

Additionally, while traditional alignment methods rely on manual measurements and mathematical equations to determine and execute proper alignment, advanced laser tracking systems eliminate the opportunity for human error by utilizing a laser beam to measure 3D coordinates, and recording and analyzing data on a software program, resulting in faster alignment and extreme precision.

The proper installment of a rotary kiln is key to process efficiency, prolonging equipment life, and avoiding unnecessary downtime and maintenance. Adequate
planning for installation, such as having the appropriate materials, manpower, and equipment on hand, will go a long way in assuring a smooth rotary kiln installation. Additionally, the use of a laser tracking system, as well as having a service technician on-site will aid in achieving the most accurate and efficient install possible.

**Damage Prevention**

Rotary kilns are a valuable component in many industrial process systems. Protecting them is of the utmost importance in maintaining process efficiency, prolonging equipment life, and avoiding costly repairs. If properly maintained and serviced, a high quality rotary kiln should yield very little downtime.

Due to the high heat and process reaction that occurs within a rotary kiln, there are certain wear points to monitor. The main focus points are:

- Refractory degradation or damage
- Burner maintenance or upgrade
- Worn out breeching seals
- Drum misalignment

**Refractory Degradation or Damage**

A rotary kiln relies on its refractory liner in order to operate efficiently and maintain the desired temperature within. Refractory is also what protects the shell of the kiln from the high temperatures within.

Unfortunately, refractory liners will begin to degrade over time, causing a loss in kiln efficiency. Also in some cases, an object, such as hard material build-up, may find its way into the kiln and cause damage to the refractory. The damage may seem minimal, but can cause a material trap or cold spot, resulting in process inconsistencies. Furthermore, since the refractory is meant to absorb the heat before it can come into contact with the drum shell, any thin or damaged areas may result in heat distortion. A distorted drum shell can cause serious damage to several components and will need to be replaced as opposed to repaired. Because of the significant role that the refractory plays in protecting the kiln, routine inspections should be scheduled with a service technician.

The biggest source of refractory failure is what is called cycling. Cycling is the heating up and cooling down of a rotary kiln. Each time the rotary kiln is heated, the refractory expands with the drum. As the rotary kiln is cooled, the refractory also retracts. If a kiln is constantly being turned on and shut down, the refractory can easily get stressed, causing cracks. Cracks can also occur from heating or cooling the kiln too quickly. It is important to try to reduce cycling as much as possible, keeping shut downs to a minimum.

Another source of refractory failure is chemical incompatibility. Refractory is not designed to be able to withstand certain chemicals. A big offender of this is chlorides. Chlorides can aggressively attack refractory, causing excessive wear because of their corrosive nature. When these chemicals are identified up front, refractory can be designed to handle such aggressive corrosion. Similarly, this failure can also happen when a rotary kiln is used for something the refractory was not designed for. Sometimes there are unknown components in a material, and when a feedstock is changed, these unknown components can attack
the refractory, again, causing excessive wear.

Aside from regular inspections by a service technician, one easy way to help extend the life of your rotary kiln is to check for hotspots regularly. This can be done by picking a spot on the rotary kiln shell, and holding a temperature gun in place. As the rotary kiln rotates, that spot should be the same temperature for the entire circumference of the shell. There would be trouble if the temperature reading was 400°, 400°, 700°, 400°.

A hotspot on the shell of the rotary kiln indicates a failure in refractory. Left unnoticed, this could lead to severe damage to the rotary kiln shell. In addition to circumference temperature being the same in a given location, there should be a gradual shift in temperatures from one end of the kiln to the other, not a drastic change, which could indicate a problem.

**Burner Maintenance or Replacement**
While you may have selected a high quality, reliable burner, it is still possible for issues to occur. Parts such as the burner nozzle, burner cone, and burner sensors may need to be replaced for the kiln to continue operating as designed. In the case of an older rotary kiln, it may be beneficial to upgrade the burner. Burner technology is constantly progressing and a new burner may result in greater energy efficiency and material output, making for a cost effective upgrade.

**Worn out Breeching Seals**
The main function of the breeching seals on a rotary kiln, no matter the style, is to prevent outside air from entering the kiln. FEECO kilns are specifically designed to funnel exhaust air along with dust to a controlled area. Similarly, the design is configured to discharge the maximum amount of process material, while still maintaining the desired internal temperature. This also means keeping cool, ambient air from entering the drum; breeching seals prevent outside air from mixing with the controlled combustion air inside of the kiln. Worn out seals can alter this precise system, resulting in poor dust control and varying kiln temperatures.
This can lead to added plant clean-up and process inconsistencies.

**Drum Misalignment**
Similar in all rotary drum equipment, proper alignment preserves all components from premature wear. Major damage to the inlet or discharge breechings from a misaligned drum can result in extensive downtime. Also, a drum that is out of alignment can accelerate wear on the tires, trunnion wheels, and thrust rollers, all of which are a necessity for rotary kiln operation.

Misalignment can occur naturally over time, or as a result of improper installation. No matter how the misalignment happened, it should be re-aligned before operation continues in order to prevent further damage.

**General Kiln Maintenance**
Since a rotary kiln is, in many ways, similar to other rotary drum equipment, many of the same preventive maintenance procedures apply, and should be routinely performed by the on-site maintenance staff. This includes:

- Lubricating bearings
- Changing gear box oil
- Rechecking/Defining backlash

More extensive maintenance should be done with the assistance of a service technician on-site. Depending on the manufacturer you work with, a variety of field services will likely be available to help keep your rotary kiln operating efficiently. This could include:

- Annual inspections
- Tire and wheel grinding
- Gear replacements
- Spare part installations
- Routine maintenance checks
- 24-hour emergency services
- Training programs
CONCLUSION

CHOOSING A MANUFACTURER
What to Look for When Choosing a **Rotary Kiln Manufacturer**

Rotary kilns are a significant investment in any thermal processing operation, requiring precision engineering and quality fabrication, and finding a manufacturer that can meet your unique needs can be a challenge. What follows is a guide covering some of the key factors to consider when selecting a rotary kiln manufacturer.

**Process Development Capabilities**
Finding a manufacturer that can work with you to develop a process that meets your specific process and product goals is critical, because in many cases, the application is custom. It is for this reason that it is important to find a company that will work with you every step of the way during product and process development. These steps include:

- Running pilot tests on your material to gather valuable data and develop a process that produces the exact product you’re looking for.
- Providing scalability options to help develop the process to produce the quantity and quality required for full-scale production.

**Advanced Thermal Processing Knowledge**
Rotary kilns are powerful systems, requiring a precise balance of several dynamics to produce the desired product results. Selecting a manufacturer that is well-versed in advanced thermal processing knowledge and experience will ensure the best results.

Furthermore, without the proper engineering and design, rotary kilns do have the potential to be dangerous. Confidence in the thermal processing knowledge of the manufacturer is a must so that you can be confident that the process and the equipment will not only operate efficiently for years, but will also remain safe for continued production.

**Proven Rotary Kiln Design**
A rotary kiln manufacturer with proven equipment is essential when selecting a company to design and build your rotary kiln. The difference between proven and unproven design may not be obvious at first, but there are things you can look for to help validate their claims. One aspect to look for is a service division; this usually means that the manufacturer’s equipment has been around long enough to require replacement of old worn-out components. Additionally, asking for case studies or project profiles can give you an idea of projects they’ve been successful with, as well as the types of applications they’ve worked with previously.

**High Quality Fabrication**
Quality materials and fabrication standards are crucial for a long lasting rotary kiln. Any shortcuts taken during engineering or fabrication will resonate throughout the life of the kiln, causing unnecessary downtime, process inefficiencies, and likely costly repairs.

**Ongoing Support**
When choosing your rotary kiln manufacturer, it is important that the company provides the necessary support for the purchased equipment in a variety of areas, including:
• Installation & Start-up
• Training (operation and routine maintenance)
• Spare Parts

A rotary kiln manufacturer should be experienced in servicing their equipment, offering a variety of services to keep your rotary kiln operating efficiently for years to come. The ability to have the original equipment manufacturer perform these services offers an advantage over kiln service companies; the original equipment manufacturer is most familiar with the operation of your unique kiln and overall system, and how it should best be maintained.

To ensure maximum efficiency and potential from your rotary kiln investment, select a company that will provide a high quality rotary kiln. Thermal processing knowledge, concept testing, innovative design, and high quality manufacturing all play a vital role in the production of a premium piece of equipment.

FEECO is a leader in custom thermal processing systems. We can help you develop a process around your unique project goals in our batch and pilot testing facility. We can then use the gathered data to scale up the process to full-scale production, and manufacture a custom rotary kiln to suit your exact processing needs. We also offer a highly skilled service department to assist in everything from start-up and install, to routine maintenance and repairs.
WHY CHOOSE FEECO

The FEECO Commitment to Quality

With 65+ years of experience, FEECO International has provided full-scale process solutions for thousands of satisfied customers (including some of the world’s largest corporations, engineering firms, and start-ups). Cited in over 250 US patents, the name FEECO has become synonymous with innovation and the reimagining of efficiency. As the leading manufacturer of processing and handling equipment in North America, no company in the world can move or enhance a concept from process development to production like FEECO International, Inc.

The choice to work with FEECO means a well-rounded commitment to quality. From initial feasibility testing, to engineering a solution to meet your unique process needs, and manufacturing dependable equipment, we bring our passion for quality into everything we do. In fact, many of the world’s top companies depend on FEECO to bring them the best in industrial processing solutions and equipment time and time again.

You can rest assured that FEECO’s commitment to quality doesn’t end after the sale; the FEECO Service Team is ready to help with installation, start-up, and training services, as well as spare parts, routine maintenance, and even emergency services.
For more information on rotary kilns, material testing, custom equipment, or for help with your thermal process or problem material, contact FEECO International today!

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