CHAPTER 8.3

Continuous Drying Technologies

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The drying operation of materials from particulate solids, through slurries and suspensions to continuous sheets, represents an important part of several processes in the chemical and mineral industries. The increasing demand of high productivity at low cost and minimal environmental impact makes it complex to evaluate and choose the best available drying technology for each industrial application.

A combination of heat, gas, and agitation are essential for process drying. The location and level of these key inputs are what distinguish direct from indirect drying systems (Kimball 2001). In the direct drying method (convection drying), the product is brought into direct contact with the drying medium, which may be hot gas or air. Large quantities of gas are necessary for transfer of the required energy. A special case of the direct dryer is the fluid bed dryer, in which the product floats on a cushion of air or gas. The process air is supplied to the bed through a perforated distributor plate and flows through the bed of solids at a velocity sufficient to support the weight of particles. Very high heat and mass transfer values are obtained as a result of the intimate contact with the solids and the relative velocities between individual particles and the fluidizing gas. In the indirect drying method (conduction or contact drying), the wet product is separated from the drying medium. The drying unit can consist of a rotor forming the indirect contact heating surface mounted in a stationary or rotating shell. The indirect method uses saturated or superheated steam, resulting in low energy consumption and minimal environmental impact.

The drying process typically consists of three periods. Figure 1 represents the drying process in an indirect dryer. In the first period, only heating of the wet product takes place. In the second period, the bulk of the water or liquid is evaporated at approximately constant product temperature. Finally, the removal of final moisture results in rising product temperature.

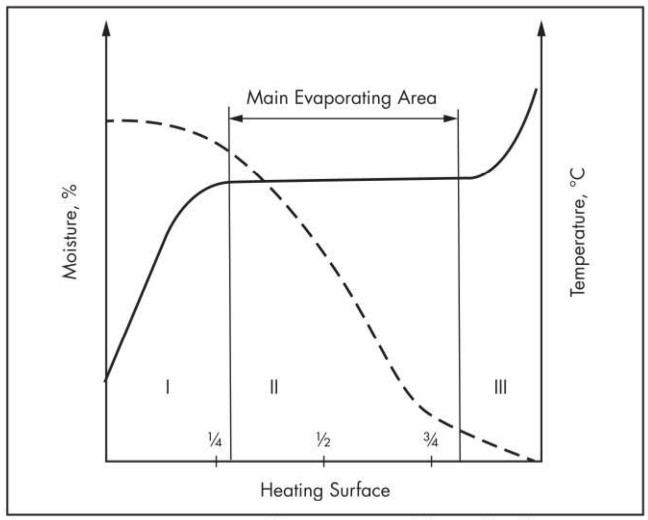

Figure 1 Temperature and moisture profile in the dryer

CLASSIFICATION OF DRYERS

The two most useful classifications of drying equipment are based on how the wet product is related to the drying medium or on the handling characteristics and physical properties of the wet material (Moyers and Baldwin 1999). A classification chart based on heat transfer (direct and indirect) with subclasses of continuous and batch-wise operation was defined by Marshall (1946). Batch operation is most useful for low product feed rates and when the residual time of the product must be controlled and uniform. Batch dryers are omitted in this study because mineral applications with high production rates are considered. Figure 2 shows a simplified chart for most of the dryers with continuous operation that are used in the mineral industry.

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DIRECT DRYERS

Drying in a pneumatic conveying or flash dryer is often done in conjunction with grinding. The material is conveyed in high-temperature, high-velocity gases to a cyclone collector. This type can be used if the product is recirculated to make feed suitable for handling. Currently, the flash dryer performs the important role of effective utilization of off-gases from super heaters and the anode furnaces.

In direct rotary dryers, the material is conveyed and showered by flights inside a rotating cylinder where hot gases flow. The dryer is applicable to dry-product recirculation.

In a spray dryer, the wet feed must be capable of atomization by either a centrifugal disk or a nozzle. It is well suited for large capacities. High temperatures can be used with heat-sensitive materials. However, pressure-nozzle atomizers are subject to erosion.

In a fluid bed, the solids are fluidized in a stationary tank. The bed is either inert or mounted with a dry-solid recirculator. A fluid bed may also have indirect-heat coils to enhance the heat transfer.

INDIRECT DRYERS

An indirect drum dryer may be heated by steam or hot water under atmospheric or vacuum operation with a single, double, or twin drum. Maintenance costs can be high.

A screw-conveyer dryer is applicable to dry-product recirculation. Operation under vacuum is feasible to permit solvent recovery.

A steam-tube rotary dryer operates with rotating tubes and shell. It is also applicable to dry-product recirculation. Operation under slight negative pressure is feasible to permit solvent recovery. Dryer off-gas is directed to a bag filter for dust removal. All dust is returned to the dryer discharge drag conveyor.

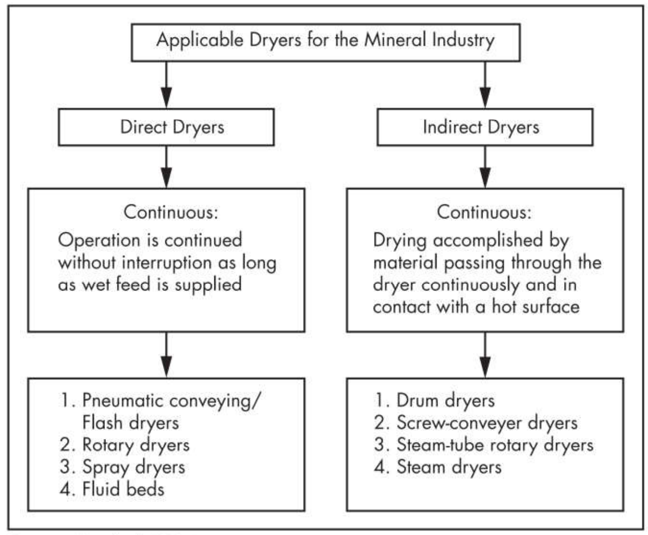
In a steam dryer, the tubes or coils rotate, and the shell or vessel itself is stationary. Operation under vacuum is feasible to permit solvent recovery. Dust leakage is very low because the dryer body is stationary and no difficult sealings are needed. Another advantage with the stationary shell compared to a rotary shell is that the dust can be led directly back to the dryer and the dried product in the vessel. Additionally, the shell has inspection and service doors on the side opposite the product discharge.

To optimize the dryer, one seeks to increase the available heating surface per volume unit of the dryer. Coils offer a higher heating transfer surface compared to shovels, discs, or paddles. Additionally, the coil design is not subject to thermal expansion problems that are common in other types of steam dryers with longitudinal pipes. The configuration of parallel coils also permits an improved flow of product through the total volume of the dryer (Figure 3).

ADVANTAGES OF INDIRECT DRYERS

Indirect dryers offer several advantages over direct dryers (Raouzeos 2003):

- Cross-contamination is avoided because the product does not contact the heat transfer medium.
- Solvent recovery is easy due to the very small amount of non-condensable gas present.
- Extensive dust formation is generally avoided because of the small amount of vapor involved.



Source: Marshall 1946

Figure 2 Classification of dryers applicable to the mineral industry

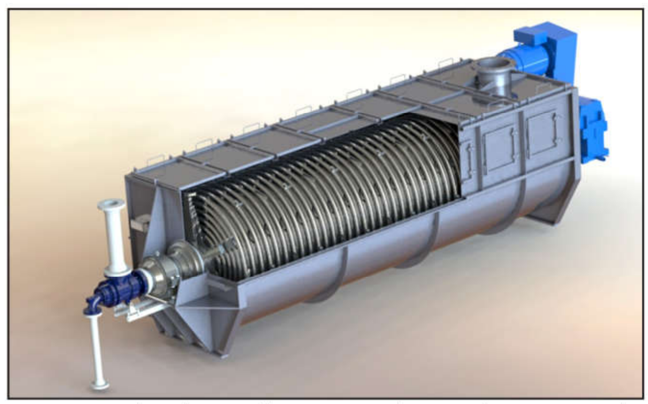


Figure 3 Multicoil, an indirect steam dryer with rotating coils and stationary vessel

- These dryers can be of closed design, thus containing toxic vapors and/or providing better control of explosive hazards.
- The *thermal efficiency*, defined as heat required per unit mass of evaporated liquid, is high.
- The final product has a higher bulk density than when the same product is dried in a spray dryer.
- Indirect dryers can be designed as pressure- and shock-resistant vessels.
- They usually require less erection space.

PRELIMINARY SELECTION OF THE DRYER

The preliminary selection of a drying system is determined by several factors (Moyers and Baldwin 1999):

- Product properties
  - Physical characteristics when wet and dry: pasty, sticky, or not sticky.
  - Particle size distribution: Small particle sizes result in better dryer efficiency and hence smaller dryer units (indirect dryers).

- Corrosiveness: In material selection, high-grade steel is required.
- Abrasiveness: In material selection, high-grade steel is required.
- Toxicity: A closed drying system and recovery/capture of moisture/off-gas may be required.
- Flammability: Fire and explosion protection devices should be considered. Indirect dryers are superior due to lower off-gas quantity.

• Drying characteristics of the material
  - Moisture type: Water or solvents.
  - Initial and final moisture content: High initial moisture may require drying in two steps, a combination of direct and indirect dryers. Indirect dryers are superior to achieve low final moisture content ≤0.1%.
  - Permissible drying temperature: Direct drying or indirect heating by hot water, for example.
  - Probable drying time: If a specific drying/product retention time is required, direct dryers (batch) are the most reliable.

• Flow of material
  - Capacity to be handled: Degree of material flowability is important.
  - Continuous or batch operation: Depends on product quantity and/or high-cost product.
  - Process before and after drying: Consider the need for dewatering/crushing of feed to smaller particles prior to feed inlet of the dryer unit, and cooling of the product below maximum operational temperature to the downstream conveying system.

• Product qualities
  - Gentle handling of product surface: Product testing is required.
  - Shrinkage: Dependent on product property; product testing is required.
  - Contamination
  - Uniformity of final moisture content: Dependent on product property and particle sizes.
  - Decomposition of product: Segregation of smaller/bigger particles is minimized by use of paddle dryers (direct dryers).
  - Overdrying: Indirect continuous dryer systems are not to be oversized due to the risk of overheating the product.
  - State of subdivision.
  - Product temperature: Heat sensitive or not.
  - Bulk density: Important due to dimensioning of installed power and drive systems.

• Recovery problems
  - Dust recovery: Heat tracing of off-gas system to avoid product buildup/blocking of filter bags.
  - Solvent recovery: Consider drying under vacuum.
  - Energy recovery: Indirect steam dryers are superior due to recovery of condensate energy to the steam boiler feed water tank.

• Facilities available at site
  - Space: Direct dryers require more space due to bigger dryer units and off-gas systems.
  - Temperature, humidity, and cleanliness of air: Site conditions are important in selecting an off-gas system and cooling/heating system on drive units.
  - Available fuels, drying medium (steam, cooling water, etc.).
  - Available electrical power.
  - Permissible noise, vibration, dust, or heat losses.
  - Source of wet feed: Stable and continuous feed is required for indirect dryers.
  - Exhaust-gas outlets: Direct dryer units have excessive off-gas quantities compared to indirect dryers.

• Investment cost: Consider spare parts needed over the lifetime of the dryer.

• Operational cost
  - Spare parts needed over the lifetime of the dryer.
  - Energy recovery of heating medium off-line. Indirect dryers are more energy-efficient due to recovery of condensate energy to the steam boiler feed water tank.
  - Availability of dryer: The dryer should be proven for at least 90% availability.
  - Maintenance: Easy access for maintenance and available service partner for dryer equipment.

• Environmental impact/emission: Less off-gas quantity on indirect dryers; selection of reliable off-gas system and material in filter bags.

These factors are helpful in the preliminary screening of the applicable dryer for a given application. The next step in the selection process is to obtain data from the equipment manufacturer to perform an adequate pre-selection. A comparison of drying systems is presented in Table 1 (Riekkola-Vanhanen 1999).

The main reasons for selecting a steam dryer instead of a conventional rotary dryer are the relatively simple off-gas system and its insensitivity to material variations (moisture, composition, and quantity) and the small space required (Gernerth and Willbrandt 1996). This means that the investment and operation costs are low.

Also, because the drying process is a high-energy-consuming stage in a production line, the obvious choice is an indirect dryer if a steam boiler is available. Using steam as heating medium allows recovery of the energy in the condensate from the dryer by return to the steam boilers' feed water tank. Compared to direct dryers, the heating medium off-gas around 60°–90°C is normally not usable for energy recovery.

Table 1 Comparison of drying systems

Criteria	Spray Dryer	Rotary Dryer	Steam Dryer	Flash Dryer	Fluid Bed Dryer
Investment cost	– –	+ +	+ + +	+	– –
Operating cost	– – –	+	+ + +	–	– –
Gas flow	– – –		+ + +	– –	–
Fugitive emission control	–	–	+ + +	–	–
Operational flexibility	–	+ +	+ + +	–	– –
Material handling	+	–	–	–	–
Future expansion	– –	+	+ + +	–	–
Environmental compliance	– –	–	+ + +	–	– –
Process sophistication	+	+	+ +	+	+
Process maturity	++	+ + +	+ + +	+ + +	+ +
Generality	+	+ + +	+ +	+ +	+

Source: Riekkola-Vanhanen 1999

+ Represents degree of advantage; – represents degree of disadvantage; blank represents neutral.

A steam boiler may not be available or feasible at the particular site, and therefore the option will be electric-heated air or air heated by excess energy from other processes on-site; hence direct dryers are a solution.

The selection of a dryer should be based on drying tests to determine the optimum operating conditions forming the basis for quotations from vendors. From the drying tests and quotations, the final selection can be made.

INDIRECT DRYING SYSTEM EXAMPLE

The following example is for a Multicoil indirect dryer unit with rotating coils and stationary vessel (Figure 3). Several of these dryer units are currently operating in copper smelters in Sweden, Germany, Spain, Canada, Mexico, Zambia, Australia, and India.

Typical Steam Dryer Plant Setup

Consider a Multicoil copper concentrate dryer plant with a drying capacity of 200 t/h (metric tons per hour) of wet product and 22 t/h of evaporated water at a steam pressure of 19 barg (bar gauge). Typical figures are 11% initial moisture content in the concentrate to 0.2% after drying, and the use of air as sweep gas at a rate of 1.5 kg air/kg evaporated water. Two dryers in parallel are used due to the high-capacity requirements. Each dryer is designed for a wet product capacity of 100 t/h and 11 t/h of evaporated water. This will result in a higher flexibility and reduce the risks associated with maintenance and eventual unexpected shutdowns. Two dryers in parallel offer the possibility to run the drying unit under partial load conditions when maintenance is carried out.

Heat Transfer Coefficient

An overall heat transfer coefficient K (W/m^2/°C) in a dryer is mandatory to determine scale-up of an industrial dryer size for a specific application.

An average heat transfer coefficient for the product could be determined by testing a product sample in a laboratory dryer. The test dryer should have a similar design to industrial units; however, a 3-m^2 heating surface is sufficient. A typical test is performed under medium operational steam pressure, 10 barg.

The dryer test starts with a product sample, for example, 150 kg, and with measured initial water content (WC). During the test, the following parameters are measured every 10 minutes:

- Product moisture, % WC
- Product temperature, °C (Cold product temperature is recorded at the start of the test.)
- Coil surface temperature, °C
- Off-gas temperature, °C

The energy consumed is calculated using the recorded temperatures for heating dry product and water, and including the total energy of the measured evaporated quantity of water at the end of the test.

Next, the logarithmic mean temperature difference (LMTD) is calculated. The LMTD is a logarithmic average of the temperature difference between the hot and cold feeds at each end of the heat exchanger:

$$\text{LMTD} = \frac{\Delta T_A - \Delta T_B}{\ln\left(\frac{\Delta T_A}{\Delta T_B}\right)}$$

The actual temperatures (T) are related to inlet (A) and outlet (B) ends of the dryer unit.

Finally, the heat transfer coefficient K (W/m^2/°C) is calculated based on known heat-exchanger surface, energy consumed, and a calculated logarithmic average of the temperature difference between hot and cold feeds. For minerals (copper concentrate), a typical K value is 160 W/m^2/°C in a Multicoil steam dryer.

Cost

The cost of a dryer depends on its size, production capacity and material, and current metal prices. A complete drying unit system includes the dryer, bag-filter and exhaust fan with drive motors, air-lock feeders for product inlet and outlet, condensate tank and pump, back-mixing system, local control panel, transport, engineering and project management, installation, commissioning and training, and so on, which define the total price of the package. The major players in the mineral market operate with prices within the same order of magnitude (Moyers and Baldwin 1999). The price of the drying equipment is small compared to the total investment cost of smelter construction; nevertheless, the functionality of the drying unit is essential to the production chain. If the dryer shuts down, the whole process comes to a complete stop.

The purchaser must also estimate the total cost during the life span of the dryer's operation by looking at the spare-parts cost and the approximately availability of the dryer (planned maintenance and unexpected shutdowns). This information can be difficult to find, unless the manufacturer provides reliable data from reference customers.

The availability of an indirect dryer for nonabrasive products is between 96% and 98%, with an average of only one to two days per year of unexpected stops for maintenance. The high efficiency, safety, and cleanliness characteristics of this technology are widely proven (Riekkola-Vanhanen 1999).

Materials of Construction

The dryer parts in contact with the concentrate are made of different materials, such as Super Duplex, depending on the corrosiveness of the concentrate. The shell or vessel is normally made of stainless-steel 316L and carbon steel. For all parts in contact with the concentrate and exhaust gas, the material of construction is a combination of Duplex (SAF2205) and 316L. Carbon steel is used for parts that are not in contact with the concentrate.

INDIRECT DRYER OPERATION AND PITFALLS

The following sections describe the most typical operational pitfalls and how to avoid dryer malfunctions by controls and proposed auxiliary equipment.

Product Overheating

Product overheating is due to improper management of steam pressure. Overheating causes an unnecessary increase in energy consumption and reduced capacity and may, in some cases, lead to a release of noxious gases in the vessel. Monitoring product temperature, which autoregulates the steam pressure, helps to avoid this phenomenon.

Overfilling

Overfilling the dryer could induce increased wear and erosion of the heating surfaces due to higher stresses. This is controlled by monitoring the amps on the rotor drive.

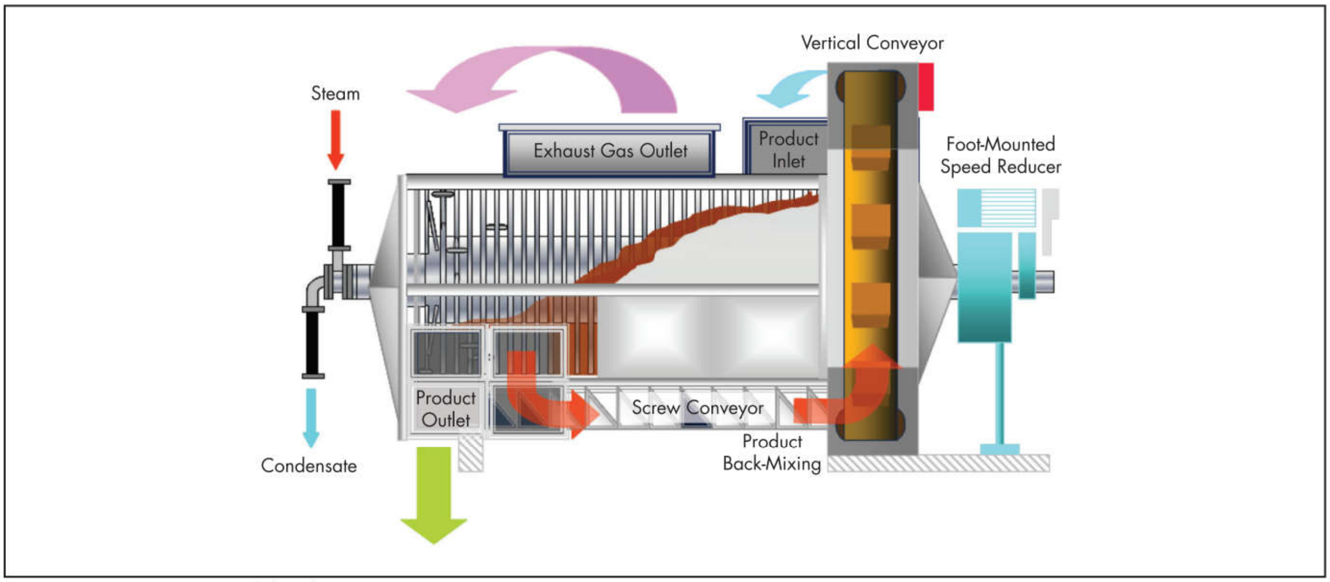


Figure 4 Drying unit with back-mixing system

Product Handling at Inlet Using a Back-Mixing System

The purpose of the back-mixing system is to mix wet and dried product in the inlet section of the dryer to avoid fouling the heating coils and to achieve better flowability of the wet feed (Figure 4). A pasty or sticky feed may plug between coils or stick to the heating surface in the inlet section. This will reduce the flow area and lower the heat transfer ratio in the dryer. When product sticks to the heated coils, the product layer will reduce the heat transfer and result in loss of production.

Because the product flow through the dryer is forced by slow rotation of the dryer rotor and gravity, it is critical that the product does not choke the inlet sections of the dryer or build up product layers on the heating surface. Acceptable flowability and no-stick performance will be achieved by reducing the average moisture level of the wet feed by introducing a parallel feed of dried product at the dryer inlet. The dryer rotor itself acts as a mixing device for wet and dried product.

A back-mixing system should be considered if the moisture content of the dryer feed is in the range of 11%–12% (wet basis) over longer periods. The back-mixing system is not necessary if the moisture content of the dryer feed is in the range of 8% to 9% (wet basis) during the main period of operation.

A back-mixing system may increase the interval between major maintenance of the rotor by 30%–50% and results in a longer rotor lifetime. An additional feature is that back-mixing enables proper operation at lower steam pressure, giving improved flexibility at partial load.

Maintenance

The maintenance of the dryer should be user-friendly. Operators should have easy access from the outside to all parts of the rotor or heat exchange unit. This allows a predictable maintenance routine that can be scheduled and conducted without unnecessarily long discontinuation of the operation. Some dryers have inspection doors available during operation. In this type of design, the rotor does not need to cool down before maintenance and/or repair work can take place. Steam leakages can be easily detected, and general maintenance and/or repair work requires a very short time.

CONCLUSION

This chapter provides an overview of the drying technologies available based on different drying methods. To facilitate the selection of a drying system for an application, the advantages and disadvantages are summarized with respect to issues such as investment, operating cost, maintenance, product capacity, product handling, and environmental impact. The final choice of dryer should be based on drying tests to determine the optimum operating conditions forming the basis for quotations from vendors. From the drying tests and vendors' quotations, the optimal selection can be made.

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PART 9

Disposal