A bulk solids dryer removes moisture from the material to be dried by heating the material to induce evaporation. One way to classify dryers is by the method the dryer uses to transfer heat to the material. Three heat-transfer methods used by bulk solids dryers are: direct contact, indirect contact, and a combination of the two.

Direct-contact drying. A direct-contact dryer (also called a convection dryer) transfers heat to the material to be dried by direct contact between the material and heated air (or sometimes an inert gas, such as nitrogen). As the heated air contacts the material, the air cools down and the material heats up, causing moisture to evaporate from the material into the airstream.

The amount of heat transferred is determined by the airflow rate and the temperature drop (ΔT) between the heated inlet air and the dryer’s outlet air. The larger the ΔT, the lower the airflow rate needed for heat transfer, and the smaller the air-handling equipment (including blower, fan, heater, cyclone, dust collector, scrubber, and heat exchanger) required for the drying circuit. A larger ΔT will also improve the dryer’s thermal efficiency (measured in Btus per pound of moisture evaporated) because less thermal energy in the exhaust air will leave the dryer.

Examples of direct-contact dryers include the spray dryer, flash dryer, rotary dryer, belt dryer, hopper dryer, and fluid-bed dryer. An illustration of a direct-contact, fluid-bed dryer is shown in Figure 1.

Indirect-contact drying. An indirect-contact dryer (also called a contact dryer or conduction dryer), transfers heat by conduction across a metal wall that separates the heat source from the material to be dried. The heat source is a heat-transfer fluid (typically condensing steam, hot water, or hot oil) flowing through metal conduits that are in contact with the material. Heat-transfer fluid temperatures typically range from 150 to 600°F, which heats the material up to the boiling point of the moisture to be evaporated.

The dryer uses air as a “sweep gas” to remove the vaporized moisture from the drying chamber, but the air isn’t the heat source. The amount of airflow required is usually determined by how close the outlet air temperature is to the air’s dew point. As with direct-contact drying, reduced airflow results in higher thermal efficiency for the indirect-contact dryer and smaller air-handling equipment for the dryer’s exhaust system.

Examples of indirect-contact dryers include the scraper drum dryer, paddle dryer, disc dryer, hollow-screw dryer, and steam-tube rotary dryer. An illustration of an indirect-contact, steam-tube rotary dryer is shown in Figure 2.

Combination drying. A combination dryer employs both convection and conduction for heat transfer. An example of a combination dryer is the fluid-bed dryer with in-bed heating coils (plates or tubes containing heat-transfer fluid immersed in the fluidized material bed), as shown in Figure 3.

Drying temperature-sensitive materials

Both the fluid-bed dryer with in-bed heating coils in Figure 3 and the steam-tube rotary dryer in Figure 2 are commonly used to dry temperature-sensitive materials. In
this column, I’ll describe how each dryer type operates and compare the pros and cons of each with respect to a number of drying parameters. When drying temperature-sensitive materials, the temperature of the heat-transfer fluid circulating in an indirect-contact dryer will have an upper limit. If this maximum temperature is below the boiling point of the moisture to be evaporated, an indirect-contact dryer may not be suitable for the application unless the dryer operates under vacuum conditions.

Fluid-bed dryer with in-bed heating coils

A fluid-bed dryer is essentially a rectangular box with a perforated plate called an air distributor separating an inlet air plenum below from a drying chamber above (Figure 3). The inlet air plenum can be divided into separate zones (for heating and cooling) using vertical baffles. Similarly, the drying chamber can be divided into zones using vertical overflow weirs or vertical underflow baffles.

In operation, heated inlet air (or other gas) flows upward through the distributor plate, fluidizing a bed of material in the drying chamber and providing the heat for moisture evaporation. Fluidization ensures that the material mixes completely, with no stagnant areas. The fluidized material behaves similar to a pot of boiling water. The material seeks its own level just as a fluid does, with the bed height in any given zone determined by the height of that zone’s overflow weir. After passing through the material bed, the drying air carries away the evaporated moisture through an air outlet at the top of the drying chamber. The chamber is designed to disengage the material from the exhaust airstream, which reduces the amount of fines carryover into the system’s cyclone or other dust collector. The dried material then flows over the final zone’s overflow weir and discharges to the downstream process.

If the feed material is sticky due to surface moisture, the first bed zone below the feed entry point typically has a deep bed height and doesn’t contain heating coils. Instead, the first zone is divided from the second zone by an underflow baffle, as shown in Figure 4. The second bed zone contains tubular heating coils that are designed to maximize material flow around and through the bank of heating elements. The baffle doesn’t extend all the way down to the air distributor, which allows partially dried material to circulate from the second zone back to the first. This warm, semi-dried, fluidized material mixes with the sticky feed particles and prevents the feed material from impinging onto the air distributor and possibly plugging the air holes. This essentially allows for indirect-contact heating in the first zone without immersing heating coils directly into that zone. Enough moisture evaporates from the material in the first zone to eliminate the stickiness from the particles before they reach the heating coils in the second zone.

Since material can flow freely beneath the baffle between the two zones, the height of the second zone’s overflow weir will determine the height for both the first and second zones. The material overflowing the weir enters the segregated third bed zone, in which banks of plate-shaped heating coils continue the indirect-contact heating but minimize material backmixing. This provides “quasi plug flow” in this zone to minimize material residence time distribution. The height of the overflow weir at the end of the third zone ensures that the fluidized material bed covers the heating coils and sets the material residence time for diffusion rate-controlled drying to occur.

Steam-tube rotary dryer

A conventional steam-tube rotary dryer consists of a horizontal, cylindrical drying vessel with two to four concentric rows of longitudinal steam tubes attached to the vessel’s inside wall, as shown in Figure 2. The drying vessel mechanically
rotates at a relatively slow speed on trunnions, driven by a motor and chain drive. Feed material enters the vessel at one end and forms a non-fluidized, cascading bed of material that is continuously lifted and turned over by the internal steam tubes as the vessel rotates. The “fill factor” of material for this type of dryer is typically 10 to 20 percent of the vessel’s interior volume.

When drying sticky materials, the shallow bed depth in the steam-tube rotary dryer doesn’t provide a sufficient reservoir of semi-dried material at the dryer’s feed end to mix with the sticky material and prevent fouling on the steam tubes. Externally backmixing dried material into the sticky feed material may be necessary to prevent such fouling.

Unlike a direct-contact rotary dryer, which uses internal lifting flights to broadcast material across the vapor space to promote evaporation, the lifting action of the steam-tube rotary dryer is only marginally effective. The degree of contact between the material and the exhaust air in the steam-tube rotary dryer is minimal compared to a direct-contact rotary dryer.

Dryer comparison
As shown in Table I, the steam-tube rotary dryer outperforms the fluid-bed dryer with in-bed heating coils in thermal efficiency and horsepower requirements but underperforms in a number of other parameters.

**Thermal efficiency.** As an indirect-contact dryer, the steam-tube rotary dryer uses air only as a “sweep” mechanism and not as a heat source. This minimizes the amount of air used and the amount of heat energy wasted in the dryer’s exhaust. The fluid-bed dryer with in-bed heating coils, on the other hand, is a combination dryer, which uses air both as a fluidizing agent and to heat the material. Consequently, the fluid-bed dryer’s airstream exhausts a significantly higher amount of wasted heat energy.

**Horsepower requirements.** The steam-tube rotary dryer consumes less power than the fluid-bed dryer. This is because the motors associated with rotating the drying vessel and running the exhaust fan are relatively small compared to the large blower required for the fluid-bed dryer. The blower must have sufficient horsepower to overcome the pressure drop across the air distributor plate and fluidize the material bed. Also, the fluid-bed dryer’s exhaust fan will be much larger than the fan required for the steam-tube rotary dryer to exhaust the greater quantity of air that passes through the material bed.

**Air-material contact effectiveness.** The fluid-bed dryer forces drying
air through the material, providing a high degree of air-material contact, whereas the steam-tube rotary dryer uses an air sweep over the material bed, providing minimal air-material contact.

Mixing effectiveness. In the fluidized-bed dryer, the air flowing through the material bed fluidizes and mixes the material so the bed resembles a boiling pot of water. Material mixing in the steam tube rotary dryer is minimal because the dryer doesn’t use “lifting flights” to broadcast material onto the rolling bed; instead, longitudinal steam tubes affixed to the vessel’s inner wall lift and tumble the material as the dryer rotates.

Temperature controls. Because the fluid-bed dryer can be “zoned,” you can control each zone’s bed temperature by regulating the fluidizing air temperature and the heating fluid temperature in the in-bed heating coils. The steam tube rotary dryer doesn’t allow for zoning, so the material’s discharge temperature is controlled by regulating the overall temperature of the heating fluid.

Material cooling. Since the fluid-bed dryer allows for zoning the drying air in addition to the bed material, the dryer can incorporate a material cooling zone at the discharge end of the rectangular drying chamber. With a steam-tube rotary dryer, however, if your application requires the material discharge temperature to be lower than the normal boiling point of the evaporated moisture, you’ll have to add an external cooler downstream from the dryer.

Maintenance. Because the fluid-bed dryer has no moving parts, the dryer’s maintenance costs and downtime are low. The steam-tube rotary dryer, on the other hand, has many moving parts, including trunnion and thrust roller assemblies, bearings, drive components, breeching seals, and steam and condensate rotary joints, all of which will wear and require periodic replacement.

Emptying material from the dryer. The fluid-bed dryer is designed with “dump gates” in the overflow weirs and discharge slide-gate valves level

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Table I

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Fluid-bed dryer with in-bed heating coils</th>
<th>Steam-tube rotary dryer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal efficiency (in Btus per pound of water evaporated)</td>
<td>1,400 to 1,600</td>
<td>1,200</td>
</tr>
<tr>
<td>Required horsepower</td>
<td>Higher (fluidizing blower, exhaust fan)</td>
<td>Lower (drive motor, exhaust fan)</td>
</tr>
<tr>
<td>Air-material contact effectiveness</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Mixing effectiveness</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Temperature control</td>
<td>Zoned control with fluidizing air and heat-transfer fluid temperature</td>
<td>No zoning, control at material discharge with heat-transfer fluid temperature</td>
</tr>
<tr>
<td>Material cooling</td>
<td>Integral cooling zone optional</td>
<td>External cooler required</td>
</tr>
<tr>
<td>Maintenance</td>
<td>No moving/wear parts</td>
<td>Wear parts include trunnion and thrust roller assemblies, bearings, drive components, breeching seals, and steam and condensate rotary joints</td>
</tr>
<tr>
<td>Emptying material from dryer</td>
<td>Very good — fluidizing air with discharge ports at air distributor level</td>
<td>No positive mechanism for 100 percent material removal</td>
</tr>
<tr>
<td>Fouling of heat-transfer surfaces</td>
<td>Low when operated with deep material bed and internal backmixing</td>
<td>High due to shallow material bed unless operated with external backmixing of dried material</td>
</tr>
<tr>
<td>Cleanability</td>
<td>Good</td>
<td>Very difficult</td>
</tr>
<tr>
<td>Uniform material discharge moisture and temperature</td>
<td>Good</td>
<td>Variable</td>
</tr>
<tr>
<td>Fines separation</td>
<td>Good</td>
<td>Poor</td>
</tr>
<tr>
<td>Clinker formation</td>
<td>Low</td>
<td>Possible with sticky materials</td>
</tr>
</tbody>
</table>
with the air distributor to allow for complete material discharge from the dryer. The steam-tube rotary dryer has no positive mechanism to ensure 100 percent material discharge.

**Fouling of heat-transfer surfaces.** Maintaining a deep and highly back-mixed material bed, as previously described, reduces the likelihood that sticky material will foul the in-bed heating coils in the fluid-bed dryer. Sticky material will tend to foul the steam tubes in a steam-tube rotary dryer, however, unless the system is designed to externally backmix dried material with the wet material feed prior to feeding the sticky material into the dryer.

**Cleanability.** A fluid-bed dryer can be designed with hand holes and manholes (both above and below the air distributor plate) to allow for water hose washdown after emptying the dryer. Cleaning a steam-tube rotary dryer is typically much more difficult.

**Uniform material discharge moisture and temperature.** Compared to the steam-tube rotary dryer, material discharged from the fluid-bed dryer will have a more uniform moisture and temperature because of the higher levels of air-material contact, mixing, and temperature controls previously described.

**Fines separation.** The velocity of the fluidizing air can be adjusted to elutriate (or separate) fines from the material stream when using a fluid-bed dryer. This method of fines removal isn’t available when using a steam-tube rotary dryer, resulting in fines contained in the dried material.

**Clinker formation.** Sticky, cohesive materials have a tendency to form lumps called “clinkers” during drying as a result of case (or surface) hardening. Clinkers are more likely to form during the slow tumbling action of a steam-tube rotary dryer than in the highly turbulent conditions in a fluid-bed dryer.

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