Controlling dryer operation for product quality

When sizing a continuous dryer for your application, the design engineer selects an operating design point for the dryer that corresponds to your specific feed and process requirements. These include the wet feed rate, feed moisture content, feed temperature, final product moisture content, material temperature in each drying zone, material residence time in each drying zone, and the maximum allowable heating temperature in each drying zone. However, once the dryer is operating, some of the incoming feed’s characteristics — such as the wet feed rate, feed moisture content, and feed temperature — will vary. While such variation is normal, it requires the dryer’s control system to automatically adjust the drying operating variables so that the dryer can achieve an acceptable final product quality.

In this column, we’ll discuss typical control systems for continuous direct-contact (convection) and indirect-contact (conduction) dryers, the limitations of these control systems, and how new technologies may overcome these limitations. Our discussion will focus on achieving an acceptable final product with the desired moisture content and no thermal degradation. (For simplicity, we won’t discuss particle size, shape, and density as variables affecting product quality. These variables often are determined by the dryer type: For instance, a spray dryer’s atomization method can affect particle size, shape, and density, greatly influencing product quality. In a milling dryer, particle size reduction strongly influences the product quality, and in an agglomerating dryer, particle growth is an important factor.)

Controlling convection drying

Cocurrent flow. In a continuous, cocurrent-flow convection dryer, such as a flash dryer or spray dryer, heated air directly contacts the material as both the air and material flow in the same direction through the dryer. The simplest control method for this dryer type is feedback control based on measuring the dryer’s outlet air temperature and then adjusting the heated inlet air temperature or wet feed rate, or both, accordingly. (Adjusting just one variable, the heated inlet air temperature, is primary feedback control; adjusting the second variable, the wet feed rate, when primary control doesn’t work is a secondary control method called cascade-loop control.) The control system may impose limits on the maximum heated inlet air temperature to prevent heat damage to dried material deposits on the dryer wall or to prevent a fire or dust explosion in a dryer handling an organic material.

The dryer’s allowable inlet and outlet air temperatures for achieving the required final product moisture content without thermal degradation are defined in pilot-plant tests during the dryer’s design phase. Since the material residence times in the flash dryer and spray dryer are less than 30 seconds, drying in this equipment is normally in the constant-rate drying zone, where heat transfer, not moisture diffusion, is the controlling step. (Find more information in the previous Drying Desk columns “Seven ways to increase your dryer’s production capacity,” September 2002, pages 58-61, and “What pilot-plant drying tests can tell you,” September 2003, pages 20-23.) From the drying curve shown in Figure 1, we can see that the material temperature is constant during constant-rate drying, corresponding to the drying airstream’s wet bulb temperature. This means that the material’s temperature has little effect on the final product moisture level, so the control system can simply measure the outlet product moisture content, rather than the material temperature.

Cross flow. In a continuous, cross-flow convection dryer, such as a belt conveyor dryer or fluid-bed dryer, the heated air flows through the material perpendicular to the material’s flow direction. Since constant- and falling-rate drying can occur in this dryer, it’s well-suited to being divided into drying zones. In each zone, material is separated from that in the preceding and following zones, so that the temperature of the heated inlet air to each zone can be independently controlled.

The first zone is typically designed for constant-rate drying, where the wet bulb temperature’s evaporative cooling effect on the material can allow the use of a higher inlet air temperature. As with the cocurrent-flow convection dryer, the control system can sense this zone’s outlet air temperature, rather than the material temperature, to adjust the inlet air temperature in this zone.

The subsequent drying zones then provide the residence time and additional heating required for diffusion-controlled drying in the falling-rate regime. Material moisture content in these diffusion-controlled zones depends strongly on the material temperature, material residence time, residence time distribution, and, in some cases, the humidity of the drying air in contact with the material. Although measuring the material temperature or the zone’s outlet air temperature is typically used to control the heated inlet air temperature or...
Relying only on temperature measurements in diffusion-controlled drying zones can result in process problems. Let’s say that the dryer’s final drying zone is used for product cooling rather than drying: If the material temperature may also change along the zone’s length (that is, vary with residence time). Measuring the material temperature also doesn’t account for the influence of the drying air’s humidity.

Because factors other than material temperature and outlet air temperature can affect the final product’s moisture content in diffusion-controlled drying, we need another sensing parameter for effective dryer control. Why not directly measure the material moisture content? Before we consider methods for doing this, let’s look at how the same control limitations in convection drying can also apply to conduction drying.

**Controlling continuous conduction drying**

In a continuous conduction dryer, in which a metal wall separates the heating fluid (steam, hot water, or hot oil) from the material to be dried, the material is heated up to its moisture component’s boiling point. (Find more information in the previous column, “When to use an indirect-contact dryer,” September 2004, pages 48-51.) At this point, the moisture is vaporized into the vapor space above the material, and then sweep air or applied vacuum removes the moisture from the dryer. It’s not uncommon for the material temperature to remain constant at the moisture’s boiling point throughout the entire drying operation. But when the temperatures of both the vapor space and material are essentially constant, what do we measure to regulate the dryer’s heat input so we can achieve the desired final product moisture content without overdrying or underdrying the product?

Once again, directly determining the material moisture content to control drying may be the best solution.

**New direct moisture sensing methods**

Technologies suitable for directly determining material moisture include near infrared, radio frequency, and microwave. Each of these so-called “wave technologies” is suitable for controlling the drying of powders and granules.

**Near infrared.** The near-infrared (NIR) method determines material moisture content by comparing reflected energy at two NIR wavelengths. The NIR device projects a stabilized infrared light beam at a specific focal distance onto the material and then uses a sensor to filter the light reflected from the material at two wavelengths — one specific to
moisture and one as a reference. The instrument, which is calibrated for the material’s solids and moisture components, electronically analyzes these two reflected signals to determine the material’s moisture content.

The NIR technique can effectively measure moisture in particles up to 1 millimeter in diameter. The material must cover the entire projected infrared beam to yield accurate moisture measurements, so the technique works best when the material moves across the infrared beam while on a flat surface, such as on the belt in a belt conveyor dryer or a fluid-bed dryer. Although heavy dusting in the air space between the sensor lens and the material surface can impact the measurement, this effect is typically minimal because the energy field is concentrated at the beam’s set focal distance. However, dust adhering to the sensor lens can affect the measurement. One way to protect the NIR sensor from sticking dust deposits in a fluid-bed dryer is to install a sensing probe outside the dryer and a Pyrex glass window in the dryer wall, so that the infrared beam is projected into the dryer through the window. This window will need to be constantly swept clean by moving material. The external sensing probe and Pyrex glass window can also be used in another application: The NIR sensing probe can operate in environments only up to about 130°F, so for a dryer with a higher-temperature environment, installing the sensing probe outside the dryer and a Pyrex glass window in the dryer wall allows the sensing probe to project the infrared beam into the dryer without being exposed to high temperatures.

Radio frequency. In a radio-frequency (RF) device, a probe projects an RF energy field into the material, and a sensor measures the loss or change in the material’s dielectric constant as affected by the material’s moisture content. This method is most effective when the material has a constant density and is deep enough to absorb the RF energy field emitted from the probe. The probe can operate in environments up to 480°F RF moisture sensing has been used on belt conveyor dryers, fluid-bed dryers, and conduction dryers.

Microwave. The microwave (µW) method is used mainly to determine moisture content in a large mass of solids, such as a bale of cotton or paper. In a bulk mass dryer, such as a hopper (or column) dryer, a slow-moving bed of granular material flows down the hopper in mass flow against a counter-current upward flow of heated drying air. A microwave transmitter is installed on the opposite wall, and a receiver is installed on one vertical wall of the dryer, and a receiver is installed on the opposite wall. The transmitter projects a microwave beam across the moving bed of solids, and the loss of microwave energy detected by the receiver results directly from the amount of moisture contained in the solids in the beam’s path.

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Feedforward drying control
When applied to continuous drying, these direct moisture-sensing methods can continuously sense material moisture and transmit the information to the dryer control system, which can then provide an electrical signal to regulate the appropriate drying variable. Not only can these methods provide conventional feedback control of the drying process, they may allow feedforward control. In feedforward control, direct, continuous measurement of the incoming feed’s moisture would enable the dryer control system to continuously adjust the heat input parameters for predictable dryer operation, thus achieving on-spec final product with the desired moisture content and no thermal degradation.

I believe we’re just at the beginning stages for developing dryer instru-