The Drying Curve, Part 1

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For each and every product, there is a representative curve that describes the drying characteristics for that product at specific temperature, velocity and pressure conditions. This curve is referred to as the drying curve for a specific product. Variations in the curve will occur principally in rate relative to carrier velocity and temperature.

The curve is extremely valuable in understanding idiosyncrasies associated with the drying of each unique product. This file will discuss these aspects, giving the reader a fuller and rounder understanding of the drying process.

Before I discuss the curve, though, let me explain two fundamental temperatures to you. The dry bulb temperature is the temperature of a body or air as measured with a conventional thermometer. It is the daily high and the daily low you get on your local weather forecast. In process applications, it typically is the process control setpoint of your dryer. It is also referred to as just "temperature."

Wet bulb temperature is a different animal. It gets its name because a permeable membrane such as wet gauze is used in conjunction with a regular thermometer to obtain the reading. The gauze is wrapped around the bulb of the thermometer and inserted into the gas stream. Because the water is evaporating off the gauze in the gas stream, evaporative cooling ensures that the temperature is lower than a dry bulb thermometer in the same gas stream. Physically obtaining this reading is tricky because the reading is meaningful only at a constant rate of evaporation. Too much or too little water will affect the reading, and it takes practice to obtain the correct value.

The dry and wet bulb temperatures are fundamentals in defining the properties of the air. This topic is referred to as psychrometry and is a topic for a future column.

Back to the Drying Curve

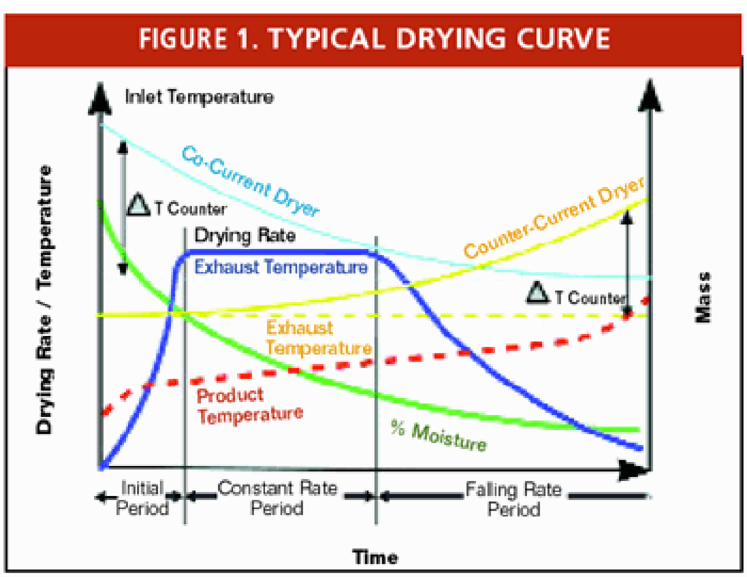

Figure 1. During processing, drying occurs in three different periods, or phases, which can be clearly defined.

Figure 1 represents a typical drying curve for virtually any product. Drying occurs in three different periods, or phases, which can be clearly defined.

The first phase, or initial period, is where sensible heat is transferred to the product and the contained moisture. This is the heating up of the product from the inlet condition to the process condition, which enables the subsequent processes to take place. In some instances, pre-processing can reduce or eliminate this phase. For example, if the feed material is coming from a reactor or if the feed is preheated by a source of waste energy, the inlet condition of the material will already be at a raised temperature.

The rate of evaporation increases dramatically during this period with mostly free moisture being removed.

During the second phase, or constant rate period, free moisture persists on the surfaces and the rate of evaporation alters very little as the moisture content reduces. During this period, drying rates are high, and higher inlet air temperatures than in subsequent drying stages can be used without detrimental effect to the product. There is a gradual and relatively small increase in the product temperature during this period.

Interestingly, a common occurrence is that the time scale of the constant rate period may determine and affect the rate of drying in the next phase.

The third phase, or falling rate period, is the phase during which migration of moisture from the inner interstices of each particle to the outer surface becomes the limiting factor that reduces the drying rate.

The Drying Curve, Part 2

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Applying the Drying Curve to Your Drying Process

FIGURE 1. TYPICAL DRYING CURVE

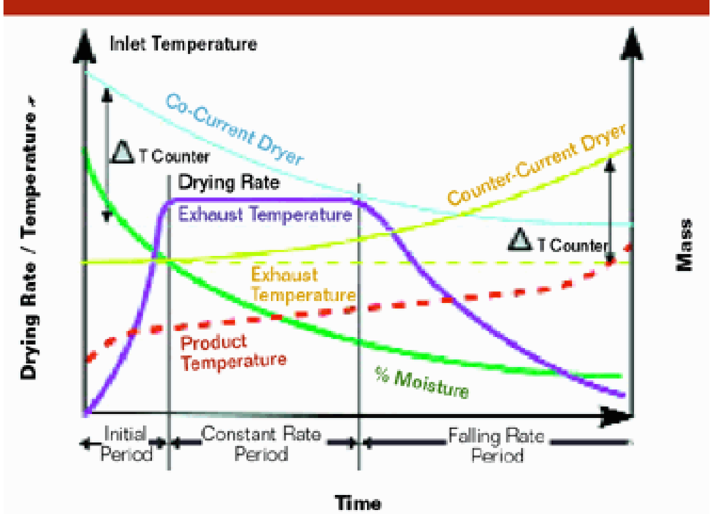

Figure 1. During processing, drying occurs in three different periods, or phases, which can be clearly defined.

As I explained in my column last month, the initial and constant drying rates may affect the falling rate and offer benefits or advantages as well as limitations. Most commonly, the elapsed time for this falling rate period is frequently directly dependent on the drying criteria achieved during the constant rate period. That is, if materials are dried rapidly in the high moisture range, they may continue to dry relatively quickly in the low moisture range. This can be attributed to the formation of a porous structure (capillaries), which favors more rapid diffusion and increases the exposed surface area of the product.

The levels of initial drying rates also may enhance and modify the quality of the final product. For example, rehydration rates for products such as instant coffee or milk tend to follow the drying rate pattern.

Certain products skin, crack or shrink at elevated temperatures. In this case, high initial drying rates will be detrimental to the drying process by encapsulating moisture within the product, retarding movement of moisture from the inside to outside of the product. In instances where cracking or shrinking occurs, it also may reduce product quality and disfigure certain materials.

Product density also relates to drying rate and, in general, the faster the drying rate, the lower the density.

The temperature curve for the product increases from the feed temperature (most commonly ambient temperatures) to approximately the wet bulb temperature during the constant rate period and then to almost dry bulb temperatures as it nears the end of the drying cycle. During the constant rate period, the product temperature remains reasonably constant due to the effects of evaporative cooling. That is, when evaporating water with a hot stream of gas, the water film at the surface of the solid will assume the wet bulb temperature of the drying gas, and the evaporative process can be considered to be adiabatic (a process in which the system is changing without the transfer of heat to or from the environment).

As the drying process proceeds through to the falling rate period, the moisture content progressively reduces and the rate of mois-ture removal decreases markedly. The product temperature starts to increase more rapidly because the effects of evaporative cooling are reduced. As a result, temperature-sensitive products become in danger of thermal degradation. The falling rate period is dependent on the desired final moisture content and is typically longer than the constant rate period. Hygroscopic products or products with high bound moisture contents will have an extended falling rate period to achieve low final moisture contents.

Figure 1 also illustrates the relative temperature profiles of the carrier stream for co- and counter-current drying systems. Higher inlet temperatures can be used for co-current systems, and there is a lower potential for thermal damage to the product because the final product temperature approaches the controlled exhaust temperature.