Feed Considerations for Continuous Dryers

Improving energy efficiency and product quality through continuous drying

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Drying is one of the most energy-intensive steps in a pharmaceutical process, as latent heat is required to remove a liquid component from a solid. To improve energy efficiency as well as productivity, continuous designs are often preferred over batch schemes. The equipment required is small relative to the amount of material dried, the operation is readily integrated with upstream and downstream continuous processes, and the product discharged from a continuous dryer has a more uniform moisture content.

The drying mechanisms are often complex as they involve both transfer of heat either directly by contact with a hot gas or indirectly from steam, combustion gas, or a heat-transfer fluid and mass transfer of liquid from the bulk material to the surrounding gas. Often, drying is conceptualized as a two-step process, as illustrated by a typical drying curve shown in Figure 1. A drying curve is obtained by placing a sample of bulk material or suspending it on a balance inside a heated environment. The weight of the sample is then measured over time under constant drying conditions. Ideally, the sample is dried under conditions similar to those to be expected when the material is processed in commercial equipment.

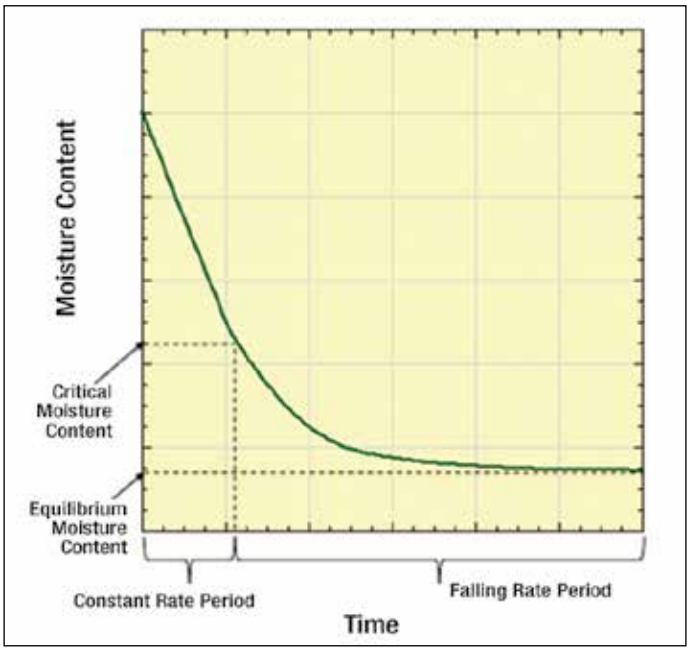

Figure 1. Typical drying curve illustrating constant and falling rate periods and critical and equilibrium moisture contents.

After a short heat-up period (not shown in Figure 1), the rate of moisture removal is constant. During this constant-rate drying period, enough moisture is available to keep the surface of the solid particles entirely wet. The temperature of the wet particle surface is the adiabatic saturation temperature, which in the case of water and air is equal to the wet bulb temperature.

At a certain moisture content, dry regions begin to exist on the surface, and the drying rate begins to decrease. This moisture level is called the critical moisture content. The critical moisture content depends on the thickness of the bed of material and the degree of mixing between the gas and solids. The critical moisture content is therefore not a property of the material itself and must be determined experimentally.

The gas used to dry the solids frequently contains moisture, i.e., it has a relative humidity. The moisture content of the bulk material leaving a dryer cannot be less than that which is in equilibrium with the gas. This equilibrium moisture content is a function of temperature and the relative humidity of the drying gas. An example equilibrium curve is shown in Figure 2.

The rate of heat transfer during the constant-rate period of drying is equal to the product of the total surface area of the particles, the heat-transfer coefficient, and the temperature

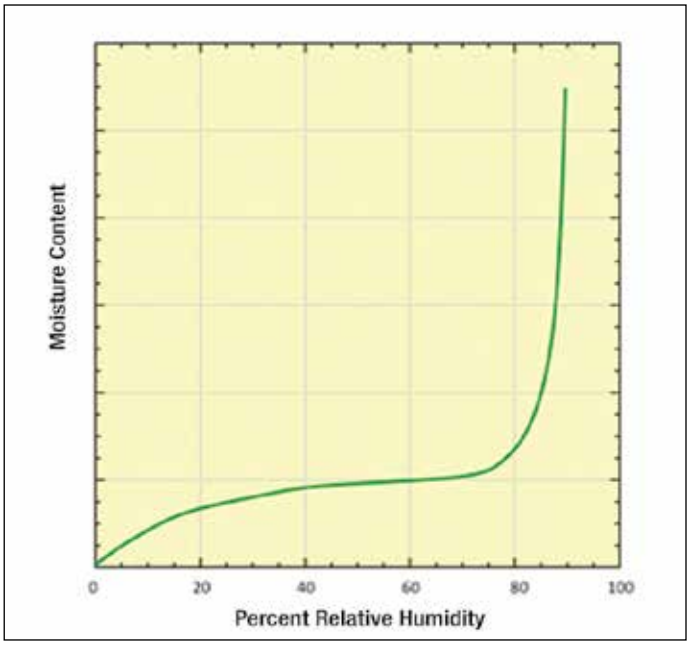

Figure 2. Equilibrium moisture content as a function of relative humidity.

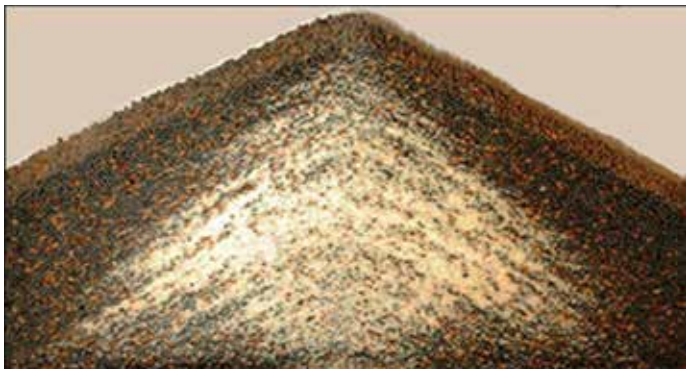

Figure 3. Sifting segregation after pile formation; light-colored fines remain in center while darker, coarser particles concentrate at perimeter.

driving force. The driving force is the difference between the bulk gas and the temperature of the liquid on the particle surface. The specific surface area of the bulk material is inversely proportional to the particle diameter, while the heat-transfer coefficient generally becomes smaller with increasing particle diameter. The equilibrium moisture content is frequently greater for smaller particles, due to the higher capillary forces that hold water associated with smaller pores.

Hence, the residence time of the solids inside the dryer and the particle size of the material can have a dramatic effect on dryer performance. Because material is typically introduced from a surge or feed hopper, its design is critical. The discharge rate of the hopper must be steady to ensure a controlled dryer residence time. Care must be taken to ensure that segregation by particle size, which can occur when the hopper is filled, does not lead to a dryer feed that is variable in particle size distribution.

Under some conditions, fine particles will percolate or sift through coarse particles. For example, if the feed is relatively free flowing, large particles will tumble towards the walls of the surge hopper and fine particles will become concentrated beneath the fill point (see Figure 3). As a result, side-to-side variation of particle size will take place.

SIFTING SEGREGATION CONSEQUENCES

The consequences of sifting segregation depend on the flow pattern that occurs when material is discharged from the surge hopper. In general, there are two primary flow patterns that can occur: funnel flow and mass flow. In funnel flow, an active flow channel forms above the outlet, with stagnant material remaining (i.e., ratholes) at the periphery. Funnel flow can cause erratic flow due to collapsing ratholes and flooding in the case of fine powders, exacerbate segregation, and allow particle degradation (e.g., caking, spoilage) in stagnant regions. Flow patterns are illustrated in Figure 4.

In mass flow, the entire bed of solids is in motion when material is discharged from the outlet. This behavior eliminates stagnant regions in the vessel and affords a first-in, first-out flow sequence, which provides a more uniform discharge rate. Mass flow also provides a more uniform velocity profile, which reduces the effects of sifting segregation. Hence, a mass flow hopper should be used to handle material fed into a continuous dryer.

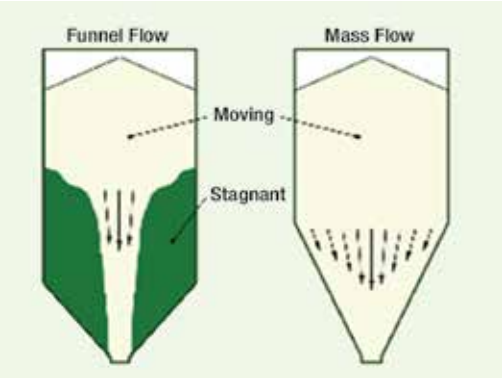

Figure 4. Funnel flow and mass flow behavior in a surge or feed hopper.

Design charts originally developed by Jenike [2] provide allowable hopper angles for mass flow given values of wall friction. The angle of wall friction ϕ' is obtained by following the method described in ASTM D-6128 [1] where a sample of powder is placed inside a retaining ring on a flat coupon of wall material, and a normal load is applied. The powder is forced to slide along the stationary wall material, and the resulting shear stress is measured as a function of the applied normal stress. The wall yield locus is then constructed by plotting shear stress against normal stress. The angle of wall friction ϕ' is the angle that is formed when a line is drawn from the origin to a point on the wall yield locus. This angle of wall friction is the inverse tangent of the wall friction coefficient.

The outlet of the hopper section must be large enough to prevent stable obstructions to flow from developing. The required outlet size depends on the cohesive strength and the bulk density of the powder. The relationship between the cohesive strength of a powder and its consolidation pressure (i.e., its flow function) is measured by shear cell testing as described in ASTM D-1628 [1] or D-6773 [3].

From cohesive strength and bulk density test measurements, the minimum outlet size required to overcome arching B_{min} can be calculated from:

$$B_{min} = \frac{H(\theta')\sigma_{crit}}{\rho_b g}$$

where $H(\theta')$ is a function given by Jenike [2], σ crit is the critical cohesive strength taken from the flow function following a method described by Jenike [2], ρ_b is the bulk density of the powder, and g is equal to the gravitational constant.

In summary, dryers run optimally when operated with uniform feeds. Mass flow hoppers mitigate sifting segregation, which can cause feed non-uniformities, and provide steady feeds to continuous dryers. Wall friction, bulk density, and cohesive strength tests must be performed to be able to specify wall materials, geometry, hopper angle, and outlet dimensions that ensure mass flow and prevent obstructions to flow. ■

REFERENCES

1. ASTM D-6128, "Standard Test Method for Shear Testing of Bulk Solids Using the Jenike Shear Cell", ASTM Int. (2006).
2. Jenike, A.W., Storage and Flow of Solids, Bulletin 123, University of Utah Engineering Station, 1964 (revised, 1976).
3. ASTM D-6773, "Standard Shear Test Method for Bulk Solids Using the Schulze Ring Shear Tester", ASTM Int. (2008).