How to optimize your spray dryer’s performance

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You’re probably satisfied if your spray dryer produces powder that generally meets your product specs, if the dryer achieves a decent production rate, and if it doesn’t require too-frequent washdowns. And no doubt you’ve heard the expression, “If it ain’t broke, don’t fix it.” But if you take this statement to heart, you may be missing out on a chance to optimize your spray dryer’s performance. This article explains how you can adjust your spray dryer’s operation to produce more consistent product, increase your production rate while improving the dryer’s thermal efficiency, and further reduce the dryer’s cleaning requirements.

A spray dryer converts a liquid feed — a solution or free-flowing slurry — into solid particles with specific characteristics. You can select any of several dryer configurations to handle your liquid feed’s specific consistency or to produce the final powder you desire. But once you’ve selected and started up your spray dryer, don’t settle for merely adequate dryer performance. Instead, optimize it.

Although these spray dryer adjustments have a scientific basis, successfully making them is — to a great extent — an art. The following information explains how you can master this art by adjusting the dryer’s atomization, inlet and outlet air temperatures, main airflow rate, and other parameters. [Editor’s note: For basic information on spray dryer operation, see “For further reading” at this article’s end.]

Controlling atomization

Atomization turns the spray dryer’s liquid feed into small droplets immediately before the feed is dried. In a typical spray dryer, as shown in Figure 1, the droplet size formed by the atomizer controls the final dried powder’s particle size. The two most common atomizers are pressure nozzle and centrifugal types. Each is suited to handling different liquid feed consistencies and producing different final powder characteristics, and each provides advantages and disadvantages for different applications.

Reducing viscosity for better atomization. Controlling the liquid feed’s viscosity at the atomizer allows the feed to be converted into droplets. In general, you should keep the viscosity below 250 centipoise for either type of atomizer. When the viscosity is too high, the liquid tends to form nonspherical prolate (large potato-shaped particles) and, eventually, strings or threads like cotton candy rather than spherical droplets. For a pressure nozzle atomizer, indications that the feed is too viscous include speckled deposits on the drying chamber’s lower wall and sloped cone wall. For a centrifugal atomizer, a sign of excessive viscosity is feed deposited in a narrow ring, called a mud ring, around the drying chamber wall at the atomizer’s level.

While you can simply add water to the feed to reduce its viscosity, this will dramatically reduce the dryer’s production capacity. A more efficient solution is to increase the feed’s temperature. Not only does this reduce the feed viscosity, it increases the dryer’s capacity by reducing the heat required inside the dryer to raise the droplet temperature and dry your powder.

Optimizing a pressure nozzle atomizer’s performance. A pressure nozzle atomizer typically produces a powder with a high bulk density and narrow particle size distribu-
tion. A high-pressure pump feeds the liquid tangentially into a swirl chamber in the pressure nozzle; here, the liquid is forced to rotate (or swirl), and the swirling liquid passes out of the nozzle through an orifice, as shown in Figure 2. The orifice size is based on the desired liquid feed flowrate and the final powder's desired particle size. The swirling liquid forms a hollow spinning tube on the inner edge of the orifice hole; this action forces the liquid into a spray of spherical droplets that flows down into the drying chamber in a cone-shaped pattern.

The pressure nozzle atomizer's main disadvantage is that you typically can't adjust the liquid flowrate without changing your final powder's properties or shutting down the spray dryer to change the nozzle's orifice size and swirl chamber's volume (described in the following subsection).

**Widening the spray angle:** To achieve the best mixing of the liquid spray and the hot airstream entering the drying chamber, you should use the widest possible spray angle. Two factors control the pressure nozzle's spray angle: the swirl chamber's volume and the pressure in the atomizer.

- The faster the liquid feed's rotation in the swirl chamber, the wider the spray angle. The swirl chamber's volume controls the rotation speed for a given liquid flowrate: The thinner the swirl chamber, the smaller its volume and the wider its spray angle; the thicker the swirl chamber, the larger its volume and narrower or longer its spray angle.

- Increasing the atomizer pressure by increasing the liquid flowrate should form a wider spray angle. However, as the atomizer pressure increases, the spray pattern's edge tends to curve inward toward the spray's centerline, as shown in Figure 3. This is caused by the momentum change between the liquid droplets and the hot airstream in the drying chamber: The pressure within the spray tends to become lower than that outside the spray, causing the cone-shaped pattern to contract.
Increasing the atomizer pressure also produces finer particles, which requires a smaller orifice for a given flowrate. Using a bigger orifice will reduce the pressure. For a given orifice size, the atomizer pressure varies as the square of the liquid feed flowrate; a higher flowrate produces a much higher pressure.

Adjusting the liquid feed flowrate: By controlling the liquid feed flowrate into the drying chamber, you can control the dryer’s outlet air temperature and keep it at a given level to control the final powder’s moisture content. If your powder can be dried at a higher inlet air temperature, you can pump the liquid feed into the dryer at a higher rate to keep the outlet air temperature down and prevent melting or scorching your powder. This will require using a larger orifice. Or if you prefer to produce a finer powder, you can use a smaller orifice, which will increase the atomizer pressure and produce finer particles.

Reducing your liquid feed’s solids content will also affect the feed flowrate. Because the dryer evaporates only water, if you dilute the feed, you’ll produce less powder even though you keep the dryer’s outlet air temperature at the correct level.

Optimizing a centrifugal atomizer’s performance. In the centrifugal atomizer, as shown in Figure 4, the liquid feed enters the atomizer, where a spinning wheel causes the feed to rotate at high speed. The difference in speed between the liquid and the surrounding air at the wheel’s edge causes the liquid to form small spherical droplets. The droplets move radially outward from the wheel’s edge into the drying chamber’s hot airstream in the shape of a flat cloud. The centrifugal atomizer’s performance is much easier to optimize than that of the pressure nozzle because the major factor affecting particle size is the centrifugal unit’s wheel tip speed.

Adjusting wheel tip speed for controlling particle size and hydraulic capacity: The centrifugal atomizer’s wheel tip speed is proportional to the wheel’s rotation speed. For instance, a 130-m/s tip speed (just over 290 mph) requires the wheel to rotate at speeds between 6,000 and 50,000 rpm, depending on the wheel diameter.

To produce a finer particle size, run the wheel at a higher speed; for a larger particle size, run it at a slower speed. Work with your spray dryer manufacturer to determine the optimal wheel speed for achieving your desired particle size and to ensure that you don’t exceed the atomizer’s maximum wheel speed.

To enhance the centrifugal atomizer’s hydraulic capacity — that is, the atomizer’s ability to pump the liquid feed into the drying chamber — use a wheel speed that’s high enough to create a pumping action within the atomizer. Too low a wheel speed or too high a feed flowrate can exceed the atomizer’s hydraulic capacity. This can cause the wheel to overflow and, possibly, force the feed up the atomizer spindle (on which the spinning wheel rotates) and through the bearings, which typically quickly destroys the atomizer.

[Editor’s note: For more information on atomizer types and operation, contact the author or see “For further reading” at this article’s end.]

Controlling the inlet air temperature

A higher inlet air temperature improves your spray dryer’s thermal efficiency and production rate. This inlet air temperature is controlled by the firing rate of the burner in the air heater that warms the air before it enters the drying chamber. The burner can contact the air directly (called a direct-fired air heater) or indirectly through a metal heat exchanger (called an indirect-fired air heater). The indirect-fired air heater is typically designed to operate at a maximum outlet air temperature of 330°C, but the direct-fired air heater is designed for each specific installation to ensure that the air temperature won’t damage the powder.

The effects of your powder properties. Consider three of your powder’s properties — ignition temperature, risk of thermal degradation, and hygroscopicity — to determine the maximum inlet air temperature appropriate for your spray drying process.

Ignition temperature: In some cases, a powder exposed to a temperature above its ignition temperature will ignite and burn. Inside a spray dryer, such an ignition can cause a fire and possibly an explosion. At the very least, the powder’s ignition will create a huge cleanup job.

Have your powder tested by an independent safety testing laboratory to determine if your powder is flammable and
at what temperature it can ignite. The tests identify the cloud ignition temperature and minimum ignition layer temperature. The minimum ignition layer temperature is usually the lower of the two, and it's normally safe to operate your spray dryer with an inlet air temperature 50 degrees lower than your powder's minimum ignition layer temperature; however, you should consult your insurance company for a final opinion. [Editor's note: For more information on explosion safety tests, see articles listed under “Safety” in Powder and Bulk Engineering’s comprehensive “Index to articles” in the December 2000 issue and at www.powderbulk.com.]

Risk of thermal degradation: Although most powder in the spray dryer remains below the outlet air temperature, a few particles are typically re-entrained in the hot inlet airstream at the drying chamber's top. These can become scorched and reduce the final powder's quality by changing in color, flavor, or other functional properties. Controlling your inlet air temperature can help prevent these problems.

Hygroscopicity: If a hygroscopic powder — such as sugar or instant drink powder — is left out in the air, it absorbs
water and becomes sticky. You can feel this by rubbing the powder between your thumb and forefinger. The higher the ambient humidity, the stickier the powder becomes.

In the spray dryer, the water evaporated from the liquid feed during drying increases the drying chamber air’s humidity. The higher the inlet air temperature, the more water is evaporated and the higher the humidity becomes. If you see powder deposits all over your drying chamber wall, it’s typically because you’ve operated the dryer above the optimal inlet air temperature and the humidity has increased so much that the powder isn’t drying properly. To solve this problem, try operating the dryer after reducing the inlet air temperature by about 20°F. Then if the dryer wall is completely clean, you can increase the inlet air temperature by a few degrees and try operating the dryer again. Finding the optimal inlet air temperature can improve your production rate by reducing product losses and downtime for cleaning.

The effects of ambient humidity. Ambient humidity in your plant varies from summer to winter and even during a passing rainstorm. If the ambient humidity is low, your drying chamber wall will usually remain clean during drying. But high ambient humidity can cause powder to deposit on the wall and create moist lumps in the final powder, which can force you to shut down the process and clean out the dryer. Seasonal variations in ambient humidity and their effects on spray drying production rates can be seen in Figure 5. The figure shows that the production rates for several different powders dropped during the summer months, when ambient humidity was highest. To control humidity’s effects on your spray drying process and maximize your overall production, increase the inlet air temperature during dry weather and reduce it during wet weather.

You can also install an inlet air dehumidifier upstream from the spray dryer to prevent seasonal humidity variations from affecting your process. In the dehumidifier, ambient air is drawn through filters to remove dust and airborne contaminants that can foul the spray dryer. The air is passed across a chilling coil in which a recirculating stream of water and glycol cools the air to about 33°F, causing the ambient moisture to condense on the coil sur-
face. The condensate runs down the coil surface, collects in a trough at the dehumidifier’s base, and from there runs to the plant’s drain.

In this system, effective dehumidification depends on the air velocity across the coil surface. Too high a velocity will prevent water droplets from clinging to the coil surface, producing a mist that passes downstream to the spray dryer. To minimize this problem, you can install a demister downstream from the dehumidifier. The demister consists of a set of chevrons (V-shaped channels) or a coarse polymer demisting pad that collects the fine mist droplets and causes them to coalesce into larger droplets that will flow by gravity to the drain.

**Controlling the outlet air temperature**

Adjusting the feed flowrate to the atomizer controls the spray dryer’s outlet air temperature. To change the flowrate, you must adjust the feed pump’s speed via its variable-frequency drive. As more feed is atomized into the drying chamber, it cools the hot airstream in the chamber, reducing the outlet air temperature. **Note:** Unless your feed is properly atomized, the outlet air temperature won’t be reduced. For example, poor atomization resulting from your centrifugal atomizer’s insufficient rotation speed produces a mud ring around the upper chamber wall. When this occurs, the outlet air temperature rises, the feed pump automatically introduces more feed into the atomizer to reduce this temperature, and your spray dryer will soon halt operation because the outlet air temperature limit has been exceeded. Now, you must clean out the very messy drying chamber before drying can resume.

Controlling the outlet air temperature will also help control your final powder’s moisture content and the effects of thermoplasticity, as well as localized condensation inside the drying chamber.

**Moisture content.** The outlet air temperature is the major influence on your powder’s residual moisture content. A lower outlet air temperature causes the powder’s moisture content to increase. The inlet air temperature is also related: The inlet air temperature changes the outlet air’s relative humidity. Thus, if you increase the inlet air temperature to improve your production rate, you also need to slightly raise the outlet air temperature to maintain the same powder moisture content. As a rule of thumb, for every 100°F rise in inlet air temperature, raise the outlet air temperature by 12°F. This will maintain the same relative humidity in the outlet air and, hence, the same powder moisture content.

**Thermoplasticity.** A thermoplastic powder becomes softer at higher temperatures but hardens again at lower temperatures. When the temperature rises, the particles first soften, then become sticky: The temperature at which they become sticky is called the sticking temperature.

If the outlet air temperature is high enough to warm your drying chamber wall above your powder’s sticking temperature, the particles will soften on contact with the wall and tend to stick there. This alone doesn’t indicate that the powder is thermoplastic. But if, after the dryer has cooled down, you can easily sweep the powder deposits from the dryer’s cone section, the powder is thermoplastic. You need to reduce the outlet air temperature to ensure that such a powder doesn’t adhere to the drying chamber wall during drying and reduce your production rate.

To determine the optimal outlet air temperature for a thermoplastic powder, you need to identify its sticking temperature. The simplest way is to use the *graduated hot bench* method, which requires an electrically heated, polished metal plate (the bench) and test crystals with a known precise melting point. The temperature along the plate is graduated so that one end is much hotter than the other.

Follow these steps for the test:

- Sprinkle a powder sample along the surface of the plate.
- Using a soft brush, try to sweep the powder off the surface.
- Note the point along the plate at which the powder sticks rather than is swept off.
- Use the test crystals to measure the plate’s temperature at this point, which is the powder’s sticking temperature.

However, a drawback to this test is that the plate’s temperature tends to dry the powder during the test, which can affect its moisture content and, thus, the accuracy of the test results.

Once you know the powder’s sticking temperature, you can try operating the dryer at an outlet air temperature below this point to prevent the powder from sticking. However, this will increase the powder’s moisture content. A better solution may be to install an air broom or similar device on the spray dryer. Such a device directs airflow along the wall inside the drying chamber to remove the powder deposits.

**Condensation in the drying chamber.** The proper outlet air temperature is important in preventing condensation inside the spray dryer, which can cause your powder to stick to the inside surfaces.

Condensation results when humid air is cooled and the moisture vapor condenses and forms water droplets on the nearest surfaces. You can see this effect in the form of dew on the grass on some mornings. A humid air mass’s dew point temperature depends on the air’s humidity — its water content — but grows higher as the humidity increases. Thus, if any part of the spray dryer’s inside sur-
face is at a temperature below the dew point, condensation will form on that part. Particles tend to adhere to these condensed water droplets, becoming sticky and then adhering directly to the dryer surface. Such condensation deposits often show up as straight lines of powder that trace the pattern of wall- and roof-stiffening steel members in the drying chamber. This is because the heavier steel mass at these locations is often cooler than the adjacent thinner chamber wall.

Another common location for condensation deposits is on the cooling ring that surrounds the spray dryer’s hot air inlet. This ring supplies cooling air to the dryer roof area near the hot air inlet to prevent the area from overheating and damaging powder that may contact it. If too much cooling air is being drawn through the cooling ring, condensation deposits can also show up on the cooling ring’s inner surfaces.

To help prevent condensation from creating powder deposits in your dryer, make sure that the dryer is well-insulated. Then, during startup, raise the outlet air temperature enough to warm the dryer surfaces — including its thicker steel members — to a temperature above the dew point by adequately warming up the dryer before you pump the liquid feed into it.

**Controlling the main airflow rate**

The main airflow rate (the airflow through the spray dryer’s main distributor, or air disperser, at the dryer’s top) strongly influences the dryer’s production rate. Eliminating leaks in the dryer and controlling the main airflow rate’s effects on the pressure drop in the cyclone (which separates the powder from the airflow downstream from the dryer) will help maintain your dryer’s production rate.

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**Leaks.** The main airflow rate — in concert with the inlet air temperature — directly affects the dryer’s production rate. While in some cases you may want to deliberately reduce the main airflow rate to achieve a particular drying condition, the main airflow rate is often reduced inadvertently because of air leaks through seals in the dryer, reducing your dryer’s production rate.

Leaking seals occur at access and inspection doors and cleanout ports in the spray dryer and related equipment. Check these seals visually when you’re cleaning out the dryer and related equipment, and also listen at these points
while the dryer is operating. If you hear a whistling noise from a flange or door seal, it's probably caused by a leak. The simplest way to accurately locate such a leak is to open the door, coat the door's metallic face with a colored marking compound, then close the door. The color will transfer to the rubber or silicone seal wherever the metallic face and the seal mate correctly, but will leave the seal uncolored at points where they don't mate well. Mark the leak point so it can be repaired as soon as possible.

A leaking seal can also create a powder deposit inside the drying chamber or in the ductwork that carries powder to the cyclone. Such a deposit results from condensation that forms on the cold surfaces adjacent to the leak. After a production run and just before you clean the spray dryer and related equipment, check for deposits that may indicate leaking seals. To find a leak's exact location, use the marking compound method.

To repair a leaking door seal, bend the door's metallic face toward the seal. You can use a large wrench and extension pipe to do this to the drying chamber's access door, but on a smaller door, you may need to use a tool supplied by the dryer manufacturer. If the rubber or silicone seal has been damaged, replace it with tubular seal material from your dryer manufacturer or other supplier.

**Cyclone pressure drop.** As the inlet air passes through the air heater upstream from the spray dryer, through the spray dryer's main distributor and the dryer, and through the ductwork and cyclone downstream from the dryer, it causes a pressure drop across each component. The pressure drop increases as the square of the main airflow rate.

In the cyclone, the pressure drop helps to swirl the powder and air around the cyclone's interior, throwing the powder against the cyclone wall and causing it to fall to the cyclone discharge. The higher the pressure drop, the faster the powder swirls — but this may or may not be a good thing.

For a fine powder containing no or little fat, a higher pressure drop is good because it improves the cyclone's collection efficiency. The optimal cyclone pressure drop for this type of powder is about 8 inches water column.

For a fine powder containing more fat, however, the higher pressure drop has a disadvantage: The higher swirling speed of the powder and air causes the fatty powder to smear around the cyclone's conical lower section. This results in a firm layer of buildup on the cyclone's inside surface, which can ultimately block the cyclone and prevent any powder from discharging. To reduce the swirling velocity and, hence, potential buildup, you need to reduce the pressure drop across the cyclone. You can do this by inserting a larger-diameter cone insert into the cyclone and, if necessary, reducing the main airflow rate, although this will also reduce the production rate.

The pressure drop that allows the cyclone to operate successfully depends on your powder's fat content, but can be as low as 4 inches water column. Interestingly, such a low pressure drop doesn't significantly reduce the cyclone's collection efficiency because a higher-fat powder tends to be easier to collect than a nonfat or low-fat powder.

[Editor's note: For more information on spray dryer optimization (including optimizing the powder cooling system, nozzle pressure fluctuations, and powder density) and controlling spray dryer system losses, contact the author.]

For further reading

Find more information on spray dryers, their components, and their operation in articles listed under "Drying" in Powder and Bulk Engineering's comprehensive "Index to articles" (in the December 2000 issue and at www.powderbulk.com).

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