How to reliably feed material into your pneumatic conveying system

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Achieving reliable pneumatic conveying at your desired capacity depends in large part on how well the feeder meters dry bulk material into your system. This article describes various feeders for vacuum and pressure conveying systems with details on how to choose a properly designed feeder for your application.

Despite significant advances in pneumatic conveying equipment over the past several decades, many users remain frustrated by problems with these systems. In the case of one common complaint — insufficient conveying capacity — the pneumatic conveying system may be only part of the problem. The feeder *and* the feed hopper supplying it play important roles in achieving the system's desired conveying capacity.

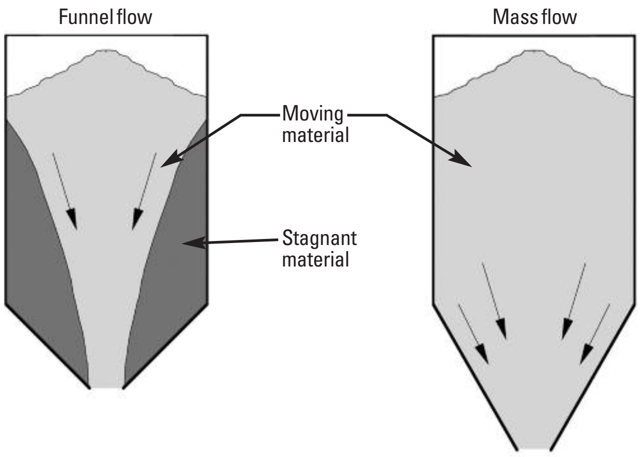
The feed hopper's role

Material flow problems in the feed hopper supplying the feeder can limit the pneumatic conveying rate. These flow problems correspond to a *funnel-flow discharge pattern* in the hopper, where the material flows only through a small flow channel, leaving large zones of stagnant material, as shown at left in Figure 1. Once the flow channel empties, a stable rathole can form, preventing flow, or a material bridge (or arch) can form, leading to erratic flow. If the hopper holds a fine powder, it can flood and overfeed the conveying system, often leading to complete line plugging. If the material in the hopper is cohesive, even using a flow aid such as a vibrator can't guarantee reliable discharge from the hopper.

To ensure reliable discharge, your feed hopper should be designed to achieve a *mass-flow discharge pattern,* in which all the material is in motion whenever any material is discharged, as shown at right in Figure 1. This pattern will prevent flow problems like bridging, ratholing, and flooding. Measuring your material's flow properties can help you determine the design features your hopper requires to achieve mass flow. [***Editor's note:*** For more information on designing a hopper for mass flow, see the later section "For further reading."]

Figure 1

Discharge patterns



The feeder's role

The feeder is important to the pneumatic conveying system because it controls the rate of material flow from the feed hopper. When the feeder is turned on, its operating speed should correlate closely to the material's discharge rate from the hopper. No matter what type of volumetric or gravimetric feeder you use, it should provide:

- Reliable, uninterrupted material flow from the hopper.
- Uniform withdrawal across the entire hopper outlet. This is particularly important for achieving a mass-flow pattern that can provide uniform residence time, minimize material caking, eliminate any stagnant zones, and provide other benefits.
- The desired control of the material discharge rate over the necessary feedrate range.

Whether a feeder can achieve these objectives depends on the feeder type. If you're like many users, you may prefer a certain feeder type based on past experience (whether good or bad) or spare parts availability, or because you want to use the same feeder type throughout your plant to simplify maintenance. It's usually possible to select a feeder that accommodates these personal preferences while providing reliable material flow to the pneumatic conveying system.

Different feeders are suitable for different pneumatic conveying systems. For a vacuum conveying system, a screw feeder, belt feeder, or rotary valve is typically used. For a low-pressure system (less than 15 psig), a rotary valve, pressure-sealing screw pump, eductor, and double-dump valve are common choices. For a high-pressure system (more than 15 psig), a high-pressure rotary valve, screw pump, blow tank, or lock hopper can be used.

In the next two sections, we'll look at guidelines for selecting a feeder that can provide reliable material flow and the desired conveying capacity in vacuum or pressure conveying systems.

Feeders for vacuum conveying systems

Because the feeder's discharge in a vacuum pneumatic conveying system is often at a near-atmospheric condition, no gas pressure differential between the feed hopper and the conveying line exists across the feeder. This means that many feeders are suitable for feeding a vacuum system.

Screw feeder. A screw feeder consists of a rotating screw encased in a tubular housing; the screw captures material discharged from the feed hopper and moves it toward the pneumatic conveying system's inlet. The screw feeder is well-suited to a feed hopper with an elongated (slotted) outlet. Since the screw is totally enclosed, it's ideal for handling fine, dusty materials. Because it has few moving parts, the feeder also requires less maintenance than other feeders, such as belt feeders, for vacuum conveying systems.

The key to properly designing a screw feeder is to ensure that it provides an increase in feeding capacity in the feed direction.

Several types of screw feeders are available, but the key to properly designing a screw feeder is to ensure that it provides an increase in feeding capacity in the feed direction. This feature is particularly important when the screw is used under a feed hopper with a slotted outlet. One common way to achieve this is to use a mass-flow screw feeder design, as shown in Figure 2. This design's combination of increasing screw flight pitch and decreasing conical shaft diameter provides uniform discharge through the hopper outlet.

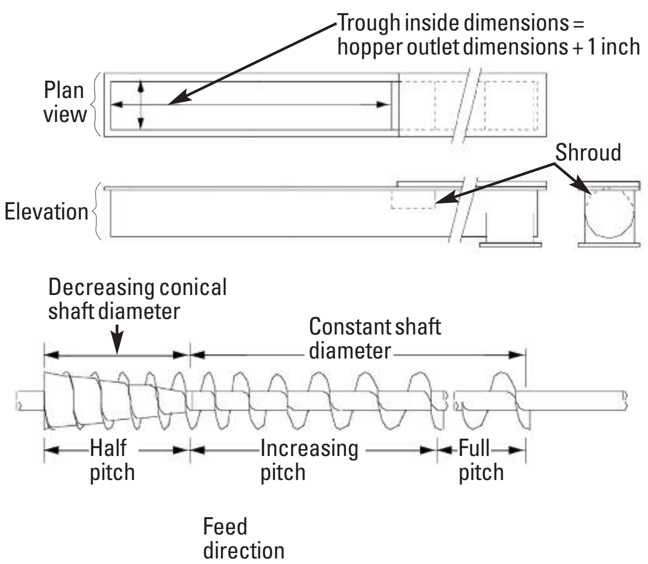
Use the following guidelines to design a screw feeder's solid flight screws, particularly when the flight diameter is 4 inches or larger:

- When using a mass-flow screw (with a variable flight pitch and tapered shaft), a good rule of thumb is to limit the screw length under the hopper outlet to no more than about 6 times the screw diameter. This minimizes problems with pitch tolerance variations that occur during screw manufacturing.

When using either a standard screw (with a uniform pitch and shaft) or mass-flow screw:

Figure 2

Mass-flow screw feeder



- Choose a smooth surface finish for the screw flights and shaft, but use a rough surface finish on the trough.
- Use a U-shaped trough rather than a V-shaped trough. The shallow sides of a V-shaped trough will often prevent material flow and cause a funnel-flow discharge pattern in the hopper, even if the hopper was designed for mass flow.
- The U-shaped trough's inside width should be 1 inch larger than the screw diameter, and the hopper outlet width should be equal to the screw diameter to allow a nominal 0.5-inch clearance on each side of the screw in the trough. These dimensions will help prevent formation of a material ledge at the trough's top, which could obstruct flow.
- Use a curved shroud in the trough just beyond the hopper outlet to effectively convert the U-shaped trough into a circular pipe section. This will prevent material flow into the screw sections beyond the hopper outlet, providing better feed control and efficiency. The shroud's length usually doesn't have to exceed the screw flight diameter.
- Keep the screw speed between roughly 2 and 40 rpm. Below 2 rpm, the material discharge rate from the screw's end can be irregular, and an expensive gear reducer will be required drop the motor speed from a nominal 1,800 rpm to 2 rpm — a 900:1 reduction! Above 40 rpm, screw efficiency drops, increasing the screw's power requirement, abrasive wear on the screw flights, and particle attrition. Note that because the power to turn the screw is proportional to screw speed, operating the screw at an unnecessarily high speed wastes power.
- As far as possible, avoid using internal hanger bearings in the screw feeder, because the bearings obstruct material discharge from the hopper outlet and can upset the mass-flow discharge pattern. The hanger bearings will also be fully immersed in the material in the trough, reducing the bearings' operating life. If the screw feeder handles a combustible powder, internal hanger bearings can also become an ignition source, so avoid them!

Belt feeder. A belt feeder is a belt conveyor that is flood-loaded and has an adjustable gate; material discharged from the feed hopper flows onto the belt, forming a bed that's sheared by the gate to a constant width and depth as the material flows toward the vacuum conveying system's inlet. Like a screw feeder, a belt feeder can be a good choice for feeding material from a hopper with a slotted outlet, and it can handle a higher feedrate than most screw feeders or rotary valves. One set of the belt feeder's idlers can be mounted on load cells outside the feeder's loading zone to weigh the material as it's fed, providing gravimetric feeding.

The belt feeder is particularly suited to feeding cohesive, friable, and coarse materials. Because the belt feeder isn't enclosed, it's less suitable than a screw feeder or rotary valve for handling fine, dusty materials such as fly ash, alumina, or cement. The feeder isn't suitable for handling combustible or toxic dusts unless the entire unit is enclosed and sealed and its design follows safe handling practices for combustible materials and dusts. (See *National Fire Protection Association (NFPA) Standard 654: Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids* [www.nfpa.org].) In fact, the cause of the 2008 Imperial Sugar plant explosion in Georgia that killed 14 workers was found to be an overheated bearing in an enclosed belt conveyor.

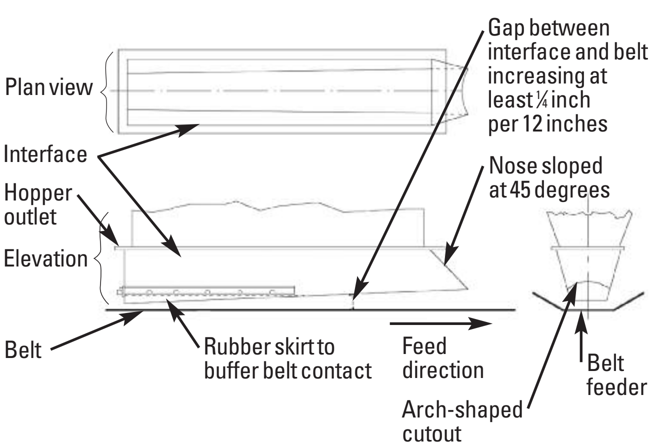
As with a screw feeder, the belt feeder must be designed to provide an increase in feeding capacity in the feed direction. An effective way to increase feeding capacity with a belt feeder is to install it below the hopper outlet with a properly designed interface, as shown in Figure 3. The interface is typically constructed of steel, and its bottom edge is mounted with rubber skirting to buffer contact with the belt.

When designing a belt feeder for your vacuum conveying system:

- Design the belt feeder's interface so that the gap between the interface and the belt increases at least ¼ inch per each 12 inches (Figure 3).
- To ease material withdrawal from the hopper along the belt, design the belt feeder interface with a nose sloped at 45 degrees (Figure 3) and an arch-shaped cutout.
- Use diverging skirts that are wider apart at the downstream side to prevent material spillage and reduce power requirements.
- You can use flat idlers with a 12-inch or narrower belt, but with wider belts, use 20- or 35-degree equal-length troughing idlers to reduce spillage and prevent belt sag.
- Carefully design the chute at the belt feeder discharge so that it converges down to the pneumatic conveying line; this will ensure that material can't plug this vital section.

Figure 3

Belt feeder with properly designed interface



Rotary valve. A rotary valve, as shown in Figure 4, is the most common feeder for pneumatic conveying systems. The valve, mounted below the feed hopper, has several vanes mounted on a rotor inside a circular housing. As the rotor spins, material falls into the pocket formed by two upward-facing vanes and then the pocket opens at the valve's lowest point to discharge the material into the pneumatic conveying system's inlet. The rotary valve is generally installed below only round or square hopper outlets, thus restricting its use with highly cohesive materials. When used for a vacuum conveying system, the rotary valve doesn't typically need to serve as an airlock or seal.

In general, a rotary valve with eight or more pockets has less leakage.

When designing a rotary valve to feed your vacuum conveying system:

- Provide a properly designed interface with the feed hopper outlet above the rotary valve to ensure that material is withdrawn uniformly across the entire outlet cross-section. This typically includes placing a short vertical pipe section with a height of about 1 to 2 hopper-outlet diameters between the outlet and rotary valve inlet. (This pipe section can be round or square to match the valve inlet.) Without such an interface, a preferential flow channel develops on the side of the outlet where the empty rotary valve pockets are first exposed to the material, resulting in nonuniform discharge from the outlet.
- Ensure that the rotary valve doesn't have an internal convergence; such a convergence can cause material to remain stagnant and obstruct discharge from the hopper, upsetting the mass-flow pattern.
- Properly orient the rotary valve to the pneumatic conveying line. The rotor vanes should be orthogonal (perpendicular) to the conveying line's direction to help prevent premature damage to the valve's end seal.

Feeders for pressure conveying systems

To feed material into a positive-pressure pneumatic conveying system, the feeder must have a means of sealing against the pressure in the conveying system. Some devices suitable for this purpose control the rate of material discharge into the conveying system and hence are truly feeders, while others serve only as pressure-sealing devices and can't meter material.

Rotary valve. As previously discussed, the rotary valve operates well as a feeder. Because it can also provide a seal, the rotary valve is very useful for feeding material into a pressure conveying system. A standard rotary valve is most often used in pressure conveying systems operating under 15 psig; a specially designed high-pressure rotary valve (discussed later in this subsection) feeds higher-pressure pneumatic conveying systems.

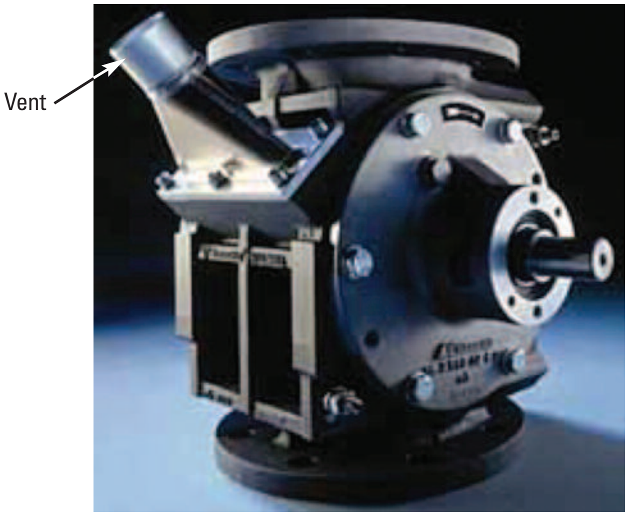
The amount of leakage through a rotary valve increases with the total pressure differential across the valve, the valve size (typically listed as rotor diameter), and the vane-tip-to-housing clearance. In general, a rotary valve with eight or more pockets has less leakage. To help achieve reliable operation, ensure that the valve has a vent on its clean side. The vent will prevent upward gas leakage into the feed hopper that can induce bridging at the hopper outlet or slow the discharge of a fine powder. Also make sure that the vent isn't blocked. The rotor should also be tightly seated and the pressure differential across the valve shouldn't be too high for the valve's pressure rating and size.

When designing a rotary valve for your low-pressure conveying system, follow the rotary valve requirements previously listed for vacuum conveying systems, as well as these requirements:

- Vent the rotary valve (Figure 4), particularly when it will handle a fine powder. Unvented gas flowing up into a fine powder can significantly slow its discharge rate.
- The rotary valve will often discharge a fine powder much more slowly than it discharges coarse granules. If your material is a fine powder, use data from a powder permeability test to estimate the effects of upward gas flow on the powder in the feed hopper. This analysis will help determine the hopper outlet size and valve size required to feed the fine powder into your pressure conveying system. The analysis can also predict flooding behavior to help you avoid conditions in which the powder can flood uncontrollably into the conveying system.

Figure 4

Rotary valve



To feed a pneumatic conveying system operating above 15 psig, you can use a *high-pressure rotary valve.* Such a valve, which is usually limited to handling nonabrasive materials, has a thicker housing and vanes, more robust shaft bearings, and better seals. Follow the rotary valve guidelines previously discussed to design a high-pressure rotary valve for your application.

Pressure-sealing screw pump. A pressure-sealing screw pump, as shown in Figure 5, is used for feeding low-pressure pneumatic conveying systems. (In some applications, this feeder may also be used with a vacuum conveying system.) The feeder has an inlet-conveying section that contains a screw; a sealing section; and a discharge section. In the feeder, the material forms a plug long and dense enough to seal against the downstream gas pressure in the conveying system without requiring high material pressures, thus minimizing screw torque and wear.

The feeder also serves as a pressure-sealing device that doesn't rely on tight mechanical tolerances, as other feeders do. The pump not only serves as a pressure-sealing device but is a true feeder because it meters material to the conveying system. If necessary, the pump's discharge can be designed to break up a cohesive material plug to deliver a uniform material stream to the pneumatic conveying system.

To select a pressure-sealing screw pump, follow these guidelines:

- Choose the pump based on your material characteristics. While the pressure-sealing screw pump can handle almost any material that can be conveyed in a screw conveyor, the material should be fine and compressible enough — or at least contain enough fines — to allow the material to form a low-permeability plug in the pump's sealing section.
- You can use the pump to replace a rotary valve that operates unreliably because of downstream moisture or vapors that condense on the valve vanes and cause material buildup in the pockets.

Eductor. An eductor, as shown in Figure 6, can be used to discharge material from a feed hopper outlet into a low-pressure pneumatic conveying system. The device has no moving parts or internal mechanical devices. Instead, motive air for the device is supplied by a blower or compressor and passes through the device's nozzle and into suction and expansion chambers. The motive air accelerates in the nozzle, creating a vacuum in the suction chamber that draws the material into the device. Then the motive air and the material entrained in it are carried through the expansion chamber and discharged into the conveying system. The device is used primarily as a pressure-sealing device rather than a feeder, because it doesn't carefully control the material feedrate into the conveying system.

The eductor provides gentle handling without shearing or attrition and is particularly well-suited to feeding hot or abrasive materials. It can also be used to vent a rotary airlock. An eductor is typically very sturdy, and its lack of moving parts minimizes its service and maintenance requirements.

To select an eductor for your conveying system:

- Use an effective maximum material loading ratio (the material mass-flow rate divided by the conveying gas mass-flow rate) for the eductor: This is typically 4.
- Use a suitable maximum pressure differential through the conveying line and after the eductor — typically 4 psig.
- As a rule of thumb, use the eductor only if your conveying system is no longer than 200 feet.

Figure 5

Pressure-sealing screw pump

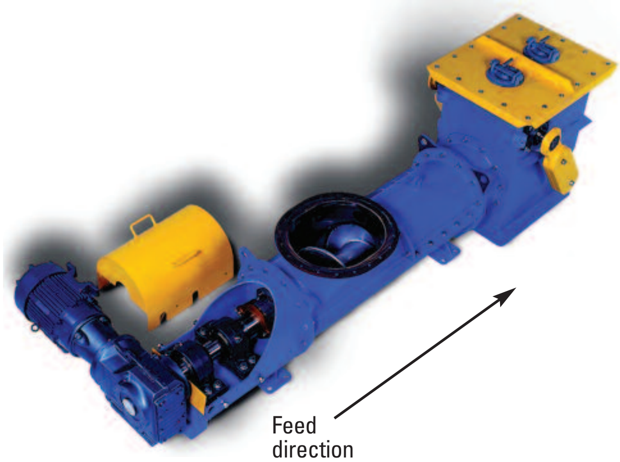
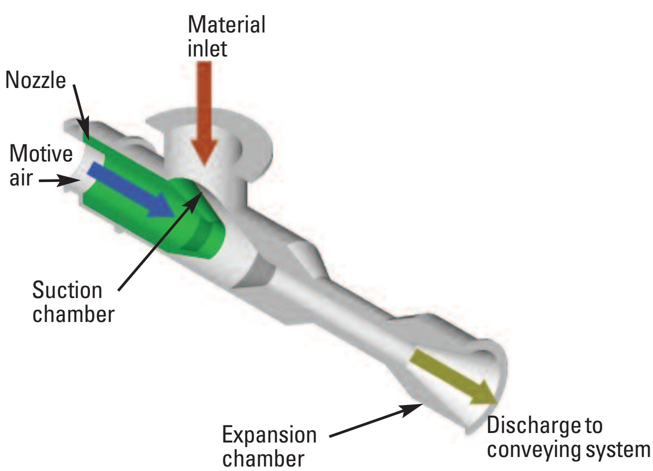


Figure 6

Eductor



Double-dump valve. A double-dump valve is typically used between a feed hopper outlet (or a dust collector's hopper outlet) and a low-pressure pneumatic conveying system to allow material to flow into the conveying system while preventing gas from flowing back into the valve. (In some applications, this feeder may also be used with a vacuum conveying system.) The valve consists of a small chamber with two gates — one at the top and the other at the bottom. When the top gate is open and the bottom gate is closed, material drops into the chamber; then the top gate is closed and the bottom gate is opened to discharge the material into the conveying system. This unit is a true feeder because the valve timing controls the feedrate from the hopper to the conveying system; the valve also serves as a pressure-sealing device. Be aware, however, that the feed from the double-dump valve isn't continuous on a short-time-scale basis.

Use the double-dump valve only for a free-flowing material that isn't cohesive or sticky.

Follow these double-dump valve selection guidelines:

- Use the double-dump valve only for a free-flowing material that isn't cohesive or sticky.
- Be aware that while the valve provides excellent sealing when it's in good condition, material or fines buildup on the gate seatings can prevent the gates from closing completely, severely affecting the valve's sealing capacity. Seating wear will also reduce the valve's sealing capacity.

Screw pump. A screw pump (also known as a *Fuller-Kinyon pump* or *FK pump*) is commonly used to feed cement or raw meal to a high-pressure pneumatic conveying system and provides much higher pressure-sealing capacities than a pressure-sealing screw pump. The pump consists of a cylindrical housing enclosing a screw with a decreasing pitch in the feed direction. As the material advances, it consolidates and its bulk density increases significantly; this causes the material to form a tight seal against the downstream gas pressure. After discharging from the screw, the material is fluidized by compressed air and discharged into the pneumatic conveying system. The screw pump serves as a pressure-sealing device rather than a true feeder unless it's used with a prefeeder.

Use these guidelines when selecting a screw pump:

- Select the screw pump only if your material is a fine, fluidizable powder.
- To achieve a controlled discharge rate to your conveying system, use the screw pump with a prefeeder that's matched to your material characteristics.

Blow tank. A blow tank (or *transporter*) is an enclosed vessel often used to introduce material into a high-pressure pneumatic conveying system. Material is transferred into the blow tank, the tank is sealed and pressurized, and then the tank's entire contents are fed as one batch into the pressure conveying system. After discharge, another batch of material is transferred into the tank and the cycle repeats. The blow tank is suitable for most materials.

Follow these selection guidelines for the blow tank:

- If your material is free-flowing and not highly compressible, use a bottom-discharge blow tank.
- If your material is fine and compressible and fluidizes well, use a top-discharge blow tank.
- If you need to provide near-continuous feed to your conveying system, use two or more blow tanks and operate them in turns.

Lock hopper. The typical application for a lock hopper, which also consists of an enclosed vessel, is to allow feeding into a high-pressure pneumatic conveying system. The lock hopper is usually located between the feed hopper, which can be at atmospheric pressure, and a high-pressure feeder, such as a blow tank. Material from the feed hopper enters the lock hopper, which is initially at atmospheric pressure; the lock hopper is then pressurized to the same pressure as the downstream blow tank (or other high-pressure feeder). The equal pressure in both allows material to flow at a pressure-equalized condition into the blow tank, which, after the blow tank is sealed, permits continuous material flow from the blow tank into the conveying system. Once the material from the lock hopper drops into the blow tank, the lock hopper is vented to atmospheric pressure again and the cycle repeats.

The lock hopper isn't suitable for all materials. For instance, fine, cohesive, and compressible materials often form flow obstructions in the lock hopper unless it's properly designed. Rather than being a true continuous feeder, the lock hopper essentially serves as a pressure-sealing device that intermittently delivers a batch of material. To select a lock hopper, follow the same guidelines listed for the blow tank.

Selecting a feeder for your conveying system

Choosing a feeder that can deliver material to your pneumatic conveying system at the desired capacity depends on your material, conveying system, and handling conditions. For an overview of how well the feeders described here are typically suited to various conveying applications, see the table under "Tool & Resources" at *Powder and Bulk Engineering*'s Web site (www.powderbulk.com). Be aware that there are exceptions to the general information provided in the table.

To ensure that the feeder you select can reliably feed material to your pneumatic conveying system, the feeder must be properly designed. This also includes properly designing the feed hopper so it can provide uninterrupted, uniform flow to the feeder. As the saying goes, "If you ain't feedin' it, you ain't conveyin' it!" **PBE**

For further reading

Find more information on feeding pneumatic conveying systems in articles listed under "Feeders" and "Pneumatic conveying" and on designing hoppers for mass flow in articles listed under "Storage" in *Powder and Bulk Engineering*'s comprehensive article index (in the December 2010 issue and at *PBE*'s Web site, www.powderbulk.com) and in books available on the Web site at the *PBE* Bookstore. You can also purchase copies of past *PBE* articles at www.powderbulk.com.

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