Using an air-assisted discharge hopper to eliminate powder flow problems

Fine powders can be a challenge to discharge from a hopper, bin, or silo. After describing the difficult traits fine powders can exhibit, problems the powders can cause, and vessel design factors that affect powder flow, this article explains how using an air-assisted discharge hopper can improve flow.

Fine powders are often difficult to handle in hoppers, bins, and silos because of their high cohesiveness, high friction on many wall materials, and low gas permeability. Cohesiveness can cause flow stoppages when the attractive forces between particles (such as Van der Waals forces, valence forces, and hydrogen bonding) cause a cohesive arch to develop over the vessel’s discharge outlet. High wall friction can prevent powders from flowing along the wall and discharging easily. A powder’s bulk density increases (reducing its gas permeability) in the straight-walled section, then decreases in the converging section when the powder is discharged. This causes a vacuum to develop, pulling in outside air through the outlet; this air flows between and counter to the particles and hinders discharge.

These powder characteristics — combined with your vessel’s design — can cause arching, ratholing, and other problems that can slow the powder discharge, cause it to become erratic, stop it altogether, or even cause your vessel to deform or collapse.

When your powder isn’t discharging properly, the first thing to do is have it tested for cohesive strength, wall friction, and gas permeability. Many independent test labs, consulting firms, and equipment manufacturers do these and other tests that can help you understand your powder better and learn how to help it flow.

If test results show that your powder just won’t flow well in the vessel you’re using, there are solutions. One is to design or modify your vessel to promote mass flow and to size the outlet properly to prevent arching and ratholing. Another and often more practical solution is to use air injection to keep the powder in motion. This promotes discharge when your powder’s characteristics make it difficult to use a hopper that has a small outlet or shallow walls.

This article focuses on how one air-injection device — the air-assisted discharge hopper — can keep your powder discharging smoothly while providing some practical advantages over other air-injection devices. Before discussing the air-assisted discharge hopper, let’s look at how vessel design affects discharge.

Vessel design factors that affect powder discharge

Powder flow patterns. The way a powder flows inside a hopper, bin, or silo significantly affects the likelihood of flow problems. One of two basic flow patterns typically occurs: funnel flow or mass flow.

Funnel flow: In funnel flow, the powder has a first-in last-out flow pattern. This pattern occurs when the wall of the vessel’s converging section (typically a conical discharge hopper) isn’t steep enough or smooth enough (that is, provides too much wall friction) for the powder to flow along it. As a result, an active flow channel forms above the outlet, with stagnant powder remaining at the periphery.
Funnel flow can cause erratic flow, reduce the vessel’s live capacity, and exacerbate side-to-side segregation. In large vessels, funnel flow can cause eccentric flow channels to develop or ratholes to collapse, inducing high loads on the vessel structure or the downstream feeder. With fine powders, controlling the discharge rate can be difficult. Since the flow channel can be unstable, the flowrate can range from no flow, when a collapsed rathole causes a cohesive arch, to uncontrollable flow, when flooding occurs because aerated powder fills the flow channel.

**Mass flow:** In mass flow, the powder has a first-in first-out flow pattern, which occurs when the hopper wall is steep enough and smooth enough to allow powder to flow along it. Provided that the outlet is large enough to prevent arching, all powder will be in motion when the powder discharges. There will be no stagnant powder, ratholes can’t form, side-to-side segregation is mitigated, and discharge rates are steady and predictable.

Fine powder flow problems can often be eliminated by ensuring that a mass-flow pattern exists inside the hopper, bin, or silo. A vessel can be designed, or in some cases modified, for mass flow. *[Editor’s note: For more information on designing a mass-flow vessel, contact the authors.] However, in some instances this isn’t possible. For example, with some fine powders, achieving mass flow would require a vessel with a very steep hopper wall, requiring more headroom than is available.

**Outlet size.** Another design factor that determines whether a powder flows well from a vessel is the outlet’s size. Powders naturally develop an arch at the outlet. The outlet must be large enough to create enough stress to cause the arch to fail. Otherwise, the arch will become stable and cohesive, stopping flow.

Test results for the powder’s cohesive strength and other characteristics can be used to calculate the appropriate outlet diameter for a powder. *[Editor’s note: Contact the authors for more information on the calculations.] But sometimes, designing a larger round outlet isn’t practical. For instance, tests may show that a powder requires an enormous outlet to discharge properly. In that case, one solution is to use a hopper with flat walls and a slotted outlet (often called a wedge- or chisel-shaped hopper).

The width of a slotted outlet needed to prevent arching is about half the required diameter of a conical hopper outlet. A slotted outlet has a greater cross-sectional area to allow the desired discharge rate, and the hopper’s flat walls and elongated outlet are less likely to produce ratholes. Unfortunately, the slotted outlet requires a relatively expensive feeder, such as a specially designed screw or belt feeder, rather than the rotary valve typically used with a conical hopper. In addition, the hopper’s flat walls need to be reinforced to prevent structural failure. Most plants prefer to use conical hoppers equipped with rotary valves because they’re generally less expensive.

**Using air injection to solve flow problems**

So, if your fine powder isn’t discharging properly from your vessel and you can’t or don’t want to redesign the vessel and outlet, what can you do? Prudent injection of air (or another gas) into the discharge hopper can solve the powder flow problems we’ve described. Adding air separates individual powder particles, thereby reducing the powder’s cohesive strength and making arching less likely. Ratholes can be eliminated by injecting just enough air to create a thin layer of fluidized powder along the hopper wall so that the powder flows along the wall instead of stagnating or stopping. Adding a small amount of air near the outlet to separate a fraction of the individual particles can reduce or eliminate the natural vacuum pressure that opposes the powder flow, allowing the powder to discharge, even from a small outlet.

There are several ways to inject air into a vessel to aid material flow. For instance, aeration pads or nozzles can be attached at intervals around the discharge hopper. But these don’t provide full coverage, often leaving gaps where no air is injected, and they may not be flush with the hopper wall, obstructing some powder flow. Another device that avoids these problems is the air-assisted discharge hopper. This hopper, available from several equipment suppliers, can be built into a new vessel in the design and construction stage or it can be retrofitted to an existing vessel.

**Air-assisted discharge hopper closeup**

The air-assisted discharge hopper, illustrated in Figure 1, is the same general size and shape as a standard conical discharge hopper. Its wall typically has three layers: a plain stainless steel external layer, an air plenum, and a sintered stainless steel mesh membrane.
stainless steel mesh inner layer (or membrane). An air supply connects to the hopper and gently injects an air layer into the plenum, evenly distributing it around the entire hopper at a typical pressure of 3 to 5 psig. (When handling cohesive powders, you may need to add air at a higher rate.) The air passes through the sintered stainless steel membrane, producing an air-hockey-table effect, which reduces the wall friction and prevents ratholing and arching.

The air-assisted discharge hopper can be designed to sanitary standards, is robust, and is more economical than many other methods of inducing powder flow. The hopper has no mechanical parts, keeping its maintenance and capital costs relatively low. The hopper can easily be cleaned using water, high-pressure steam, or chemical cleaning products. If the process must be inerted, nitrogen can be injected into the hopper rather than air.

Case study
A manufacturer wanted to store fine alumina powder in a conical hopper with a 1-inch-diameter outlet that would mate with existing downstream equipment. Wall friction tests of the powder revealed that the conical hopper would have to be extremely tall, with walls 6 degrees from vertical, to achieve mass flow of the powder and prevent ratholing. Cohesive strength tests showed that the outlet would have to be 6 inches in diameter to prevent a cohesive arch from developing at the outlet. In addition, gas permeability testing suggested that an even larger outlet would be required to provide the desired discharge rate.

The result is effective discharge at a good rate, without the difficulties and expense of drastically redesigning a vessel that would be a challenge to integrate into the manufacturer’s plant.

Since these requirements made installing a mass-flow hopper impractical, the manufacturer decided to try something different. It had an equipment supplier fabricate an air-assisted discharge hopper with a wall angle 20 degrees from vertical and a 1-inch-diameter outlet. The hopper was constructed with several plenums to allow injection of air at different rates into various areas. In operation in the plant, the air-assisted discharge hopper injects a small amount of air to reduce the friction between the sintered stainless steel membrane and the powder. This allows the powder to slide along the wall, reduces the powder’s cohesive strength, prevents arching, and reduces the vacuum inside the hopper to ensure that the powder flows at the desired rate.

The result is effective discharge at a good rate, without the difficulties and expense of drastically redesigning a vessel that would be a challenge to integrate into the manufacturer’s plant, and without the gap or obstruction problems that are created by other air-injection devices. PBE

For further reading
Find more information on this topic in articles listed under “Material flow” and “Storage” in Powder and Bulk Engineering’s article index (in the December 2012 issue and at PBE’s website, www.powderbulk.com) and in books available on the website at the PBE Bookstore. You can also purchase copies of past PBE articles at www.powderbulk.com.

Greg Mehos, PE, is a lead project engineer at Cabot Corp., 157 Concord Road, Billerica, MA 01821 (greg.mehos@cabotcorp.com, www.cabotcorp.com). He has a BS from the University of Colorado, an MS from the University of Delaware, and a PhD from the University of Colorado, all in chemical engineering. He’s been working on powder handling projects for more than 20 years. Tony Boroch (ae.boroch@younginds.com) and Curt Wykoff (cfwykoff@younginds.com) are project engineers at The Young Industries, 16 Painter Street, Muncy, PA 17756 (www.younginds.com).

Using an air-assisted discharge hopper can be a practical way to solve powder flow problems when a mass-flow hopper just isn’t an option.