Retrofitting bins, hoppers, and feeders to solve flow problems

Poor material flow can be a costly problem for bulk solids processing operations, but replacing equipment to improve flow is expensive. This article describes common bulk solids flow problems and patterns and then provides retrofit alternatives to replacing poorly performing equipment.

If your bulk solids process is experiencing material flow problems during routine operation, a bin or feeder retrofit solution can be a highly cost-effective alternative to either living with the problem and accepting the lost revenue or completely replacing the poorly operating equipment. Retrofit solutions include modifying the hopper, adding a bin insert, using a flow aid, modifying the feeder, or using gas injection. Before reviewing these solutions, however, it’s important to understand the types of flow problems that can occur and the flow patterns bulk solid materials exhibit in bins and silos.

Flow problems
Flow problems can occur in many types of bulk solids handling equipment but most commonly occur in bins or silos. The following is a list of the common bulk solids flow problems:

- **Arching** (or bridging) is a no-flow condition in which material forms a stable arch-shaped obstruction over a bin outlet, as shown in Figure 1a.

- **Ratholing** is where material forms a stable open channel within a bin while the material around the bin’s perimeter remains stagnant, as shown in Figure 1b. This can reduce...
the bin’s live (or useable) volume by as much as 80 to 90 percent and cause erratic material flow. Depending on the application, material stagnation can also cause caking, spoilage, or degradation. Ratholing (and arching) can also contribute to localized or even catastrophic silo failure due to nonuniform material loading or collapsing of the stagnant material.

- **Flooding** (or flushing) is where a bulk solid material becomes aerated, causing the material to behave like a fluid and flow uncontrollably through an outlet or feeder.
- **Flowrate limitation** is an insufficient flowrate typically occurring when counter-flowing air slows the gravity discharge of a fine powder.
- **Segregation** is the separation of a material’s particles by size, shape, density, or other characteristic, as shown in Figure 2. Particle segregation may prevent a chemical reaction, cause the final product to be out of spec, or require costly reprocessing.

Many of these flow problems are the result of an undesirable material flow pattern. The flow pattern you choose for your bin can directly influence your material’s flow performance.

### Flow patterns

Many bins discharge bulk solids in a *funnel flow* pattern. With funnel flow, some of the material moves during discharge while the rest remains stationary, as shown in Figure 3a. This first-in last-out flow sequence is acceptable if the material is relatively coarse, free-flowing, and nondegradable, and if segregation during discharge isn’t a factor. Provided that the material meets all four of these characteristics, a funnel-flow bin can be the most economical storage choice.

With many materials, however, funnel flow can create serious problems with product quality or process reliability. Arches and ratholes may form, and flow may be erratic. Fluidized powders often have no chance to deaerate with funnel flow, so the material remains fluidized in the flow channel and floods when discharging from the bin. The first-in last-out flow sequence can cause some materials to cake, segregate, or spoil. In extreme cases, unexpected structural loading results in equipment failure.

These problems can be prevented with storage vessels specifically designed to move materials in a *mass flow* pattern, in which all the material moves whenever any material is discharged, as shown in Figure 3b. With mass flow, the material flow and bulk density are uniform and reliable; there are no stagnant regions, so bin level indicators work reliably and material doesn’t cake or spoil; the first-in first-out flow sequence minimizes segregation; and material residence time is uniform, so fine powders deaerate. Mass flow is suitable for cohesive materials, powders, materials that degrade over time, and applications where sifting segregation must be minimized.
To predict and control how a material will flow in a given bin or hopper, you must know the material’s flow properties. Flow properties can be measured in a bulk solids testing lab under conditions that accurately simulate how the material will be handled or processed in your plant. If your material’s properties change rapidly over time or if special precautions are required, these tests should be conducted onsite.

**Retrofit solutions**

While a 60-degree (from horizontal) hopper angle is ideal for fabricating a hopper with minimal construction waste, this angle is usually insufficient to provide mass flow for most materials. The following retrofit solutions can be a cost-effective alternative to completely replacing your poorly operating bin or silo.

**Modify the hopper.**

*Hopper liner or coating.* Adding a low-friction liner or coating to the hopper wall can often induce mass flow and doesn’t require modifying the hopper slope or height. The key is to measure the coefficient of sliding friction between your material and potential liners or coatings to determine whether the material will slide along the hopper walls.

*Plane-flow hopper.* A plane-flow (or wedge-shaped) hopper typically requires a hopper angle 10 degrees less steep than a cone-shaped hopper to achieve mass flow. Also, since a plane-flow hopper, such as the transition hopper shown in Figure 4, has an elongated material outlet, the outlet width can be half that of a cone-shaped hopper without causing material bridging. When using a plane-flow hopper, however, you must ensure that the feeder below the hopper is designed to effectively work with the elongated hopper outlet (discussed below).

**Expanded-flow hopper.** You can often overcome ratholing in a funnel-flow vessel by adding a mass-flow hopper section below the funnel-flow hopper. This expands the flow channel and prevents a stable rathole from developing and can be a highly cost-effective solution for large silos with diameters of 20 feet (6 meters) or more. This approach doesn’t necessarily solve segregation or caking problems in a silo, however.

**Larger hopper outlet.** A larger hopper outlet can be effective for overcoming bridging and flowrate restrictions but is generally not an effective solution for ratholing, flooding, or caking.

**Add a bin insert.**

*Cone-in-cone insert.* A cone-in-cone insert is essentially a smaller mass-flow hopper mounted inside a larger funnel-flow hopper. The mass-flow insert reduces the friction between the material and the larger hopper wall to prevent ratholing and bridging and reduce segregation. A cone-in-cone insert can reliably achieve mass flow without the need to drastically increase the hopper height, but the large structural loads placed on the insert by the material typically require special engineering for design and installation.

*Inverted cone insert.* An inverted cone insert is principally used to expand the material flow channel in a funnel-flow vessel. An inverted cone insert may also help with ratholing but won’t solve segregation or material stagnation issues. The inverted cone also doesn’t usually help with bridging or flowrate limitation.

*Flow-tent inserts.* Flow-tent inserts are wedge-shaped cross members installed in hoppers or gravity reclaim stockpiles with multiple outlets to help reduce ratholing. Flow-tent inserts aren’t effective for preventing bridging, segregation, or flowrate limitation.

**Use a flow aid.**

In some cases, gravity is insufficient for maintaining material flow, and flow aids are required to provide additional force. Be sure to consult your supplier when considering flow aids, however, to ensure that the devices are properly applied.

*Air blaster.* A high-pressure air blaster uses a combination of shock and pressure waves to break up bridging material in a hopper, particularly in instances where the bridge formed while the material was at rest. An air blaster isn’t suitable for breaking up ratholes, which are far more...
difficult to collapse than bridges, and isn’t recommended for combating segregation or flowrate problems.

Vibration. Devices that induce high-frequency/low-amplitude or low-frequency/high-amplitude vibration (such as a thumper) can be very effective if you’re experiencing moderate bridging problems. These devices shouldn’t be used for ratholing problems, however, because the vibration tends to pack the material on the hopper side walls. Be sure to mount the device carefully to avoid crack formation in the hopper wall, and turn off the vibration after material flow has been restored. Vibration doesn’t help with segregation or flowrate limitation and can actually exacerbate segregation problems.

Agitation. A moving agitation device, such as an internal scraper in a bin, can be effective at overcoming bridging and ratholing problems in small bins. Many packaging hoppers have rotating internal agitators to maintain flow with cohesive powders, where gravity alone may not be sufficient. For large bins, the only agitators that are generally effective are large-scale screw reclaimers or plows that are designed to operate under heavy loads.

Modify the feeder.
A bulk solids feeder must draw material uniformly across the entire hopper outlet to ensure mass flow. A poorly designed feeder or partially opened gate valve can effectively reduce the hopper outlet size, resulting in funnel-flow problems regardless of the hopper design. In many cases, retrofitting the screw, belt, or rotary valve feeder can effectively improve material flow.

Mass-flow screw. A properly designed screw feeder provides an increasing capacity to accept material in the direction of the feed. This is critical when the screw is mounted below a hopper with an elongated outlet. This increasing capacity allows material to enter the feeder along the entire length of the exposed screw. One common way to accomplish this is by using a mass-flow screw design, as shown in Figure 5. The screw uses a conical (tapered) shaft with a decreasing diameter combined with a section of increasing pitch (space between screw flights). This retrofit can often solve bridging, ratholing, and segregation problems and can also help to ensure a high discharge rate.

Mass-flow belt feeder interface. A properly designed belt feeder must also provide increasing capacity in the direction of the feed. An effective way to do this is to install a mass-flow belt feeder interface, as shown in Figure 4. The belt feeder interface should taper in both the plan view and the elevation view to allow material to discharge along the entire length of the hopper outlet. The interface should also have a slanted “nose” and an arch-shaped cutout to ease material egress onto the belt. Like the mass-flow screw, this design can solve many flow problems.

Rotary valve. A hopper outlet feeding into a rotary valve should typically have a short vertical pipe section about 1 to 2 times the outlet diameter between the hopper outlet and the valve inlet. Without this pipe section, a preferential flow channel can develop on the side of the hopper outlet where the empty valve pockets are first exposed to the material, resulting in nonuniform discharge. Material then stagnates over the remaining portion of the hopper outlet, potentially causing bridging, ratholing, and other flow problems. Also, if the hopper is feeding fine powder into a pressurized pneumatic conveying system, the rotary valve should be vented to prevent gas from flowing counter to the material and impeding discharge. Such venting won’t reduce segregation, however.

Use gas injection.
With some fine powders, gas injection can be an effective retrofit technique to increase the material flowrate or overcome bridging. Gas injection isn’t generally recommended for segregation or ratholing, however, because the gas will usually exacerbate these problems. The gas (typically air) can be injected into the material using small nozzles, fluidizing pads, or sintered (porous) metal membranes.

In some cases, just a small amount of gas is required to assist flow, but in other cases, full fluidization powder is required to ensure liquid-flow behavior and prevent bridging, ratholing, or flowrate limitation. You should be mindful that a fully fluidized powder will need a feeder that can handle liquid-flow behavior — a screw or belt feeder won’t be suitable.
References

For further reading
Find more information on this topic in articles listed under “Solids flow,” “Storage,” and “Feeders” in *Powder and Bulk Engineering*’s comprehensive article index in this issue or the Article Archive on *PBE*’s website, www.powderbulk.com. (All articles listed in the archive are available for free download to registered users.)

Eric P. Maynard is director of education and senior consultant at Jenike & Johanson, Inc. (epmaynard@jenike.com). He has been with the company for 20 years and has worked on more than 500 projects, designing handling systems for materials including chemicals, plastics, foods, pharmaceuticals, coal, and cement. He holds a BS in mechanical engineering from Villanova University in Pennsylvania and an MS in mechanical engineering from Worcester Polytechnic Institute in Massachusetts.

Jenike & Johanson
Tyngsboro, MA
978-649-3300
www.jenike.com