This article provides tips for selecting an effective bulk solids storage system and avoiding material flow problems resulting from poorly designed storage vessels.

Having been active in engineering projects at plants handling a myriad of powders and bulk solids for more than two decades, I’ve heard the phrase, “I wish I’d thought of that!” many times. Though some bulk material handling processes get it right the first time, in many cases I’m called in to correct basic engineering design mistakes that have resulted in increased costs from reduced operating efficiency, increased equipment maintenance, and lost or out-of-spec final products.

If you’re in charge of implementing a new bulk solids storage and handling system, don’t assume that the equipment will meet your needs; instead, ask questions, do the necessary engineering, and follow through with a design that’s engineered to succeed. Most problems are caused by upfront design mistakes rather than operating errors. Spending 10 to 20 percent more upfront to ensure that your system is engineered correctly can save you 10 times that amount in long-term operating costs and costs to fix poorly designed equipment.

The following tips will help you select or design the best bulk solids storage equipment for your application.

1. Avoid using assumed bulk material flow properties.

A common mistake when designing or selecting storage equipment is to use assumed material properties. For many common materials, such as coal, limestone, sugar, or wood chips, bulk density, moisture content, or particle size data is readily available either online or in industry-specific reference books. It may be tempting to use this published data, but this approach can be risky. Two material samples with the same name may have very little in common. Coal, for example, comes in many forms, including anthracite, bituminous, sub-bituminous, and lignite. The ash production and heating values from burning each of these coals can vary significantly. Also, the average moisture content for each coal type is different, ranging from 5 percent moisture in anthracite up to 40 percent moisture in lignite. If you use an assumed coal moisture content of 10 percent to design your storage system but are actually handling lignite at 40 percent moisture, you’ll likely experience flow problems.

Such physical differences between materials that are nominally the same can dramatically affect handling efficiency, processability, and mass balance, so it’s vital that you test your specific material’s properties when designing a storage system. Even fly ash no longer has “standard” properties since the material’s flowability can be dramatically altered by the dry sorbents used in EPA-mandated air pollution control and scrubbing systems. This point is more critical than ever with traditional fossil fuel power plants co-firing with biomass. The flow properties of the biomass — even a material as simple as wood chips — can vary greatly depending on whether the chips are from a hardwood, such as oak or maple, or from a softwood, such as pine or spruce. Softwood chips are often stringy, prone to interlocking, and contain a high percentage of pitch (or tar), making them stick in diverter gates, feeders, and transfer chutes. Also, defining the particle size for anisotropic (or irregularly shaped) wood chips can be tricky because the particle size must be defined in three dimensions rather than by the screen size the material can pass through, which is commonly done for other materials.

You must also carefully consider your material’s bulk density since material-induced structural loads are directly proportional to the material’s bulk density. Don’t just measure the material’s loose or “as poured” bulk density; also measure the material’s compressibility to determine the bulk density over the full range of pressures you expect the material to be subjected to in storage.
Focus on discharge rather than storage.

Storing a material is relatively easy. Anyone with a basic understanding of geometry and bulk density can design a bin or silo to “store” a powder or bulk solid at a certain tonnage or volumetric capacity. The difficult part is ensuring that the vessel will reliably discharge the material at the required flowrate. In the late 1950s, Andrew Jenike developed unique scientific methods\(^1\) for designing bins, hoppers, and silos.

While material flow can be a problem with a variety of bulk material handling equipment, such as feeders, transfer chutes, and dust collectors, flow problems most commonly occur in storage vessels. Common flow problems and their consequences include:

- **Arching or bridging**, as shown in Figure 1a, in which material forms a stable arch-shaped obstruction over the hopper outlet, stopping material flow
- **Ratholing**, as shown in Figure 1b, in which material forms a stable open channel in the bin, stopping or causing erratic material flow
- **Flooding or flushing**, where an aerated bulk solid behaves like a fluid and flows uncontrollably through an outlet or feeder

Flow problems in a storage vessel can have many adverse consequences for production, product quality, and worker safety. Ratholing will limit a vessel’s live (or usable) capacity so much so that the vessel’s active volume may only be 10 to 20 percent of its rated storage capacity. Depending on the material, stagnation in a poorly designed storage vessel can lead to material caking, spoilage, or other forms of quality degradation. Also, the non-uniform material loading caused by arches and ratholes and their tendency to occasionally collapse can cause localized, or even catastrophic, silo failure.\(^2\) The segregation of a material by particle size may prevent a desired chemical reaction, cause the final product to be out-of-spec, or require costly rework to desegregate the material.

Flow problems are often the result of a hopper discharging material in an undesirable flow pattern. The flow pattern you choose for your bin can directly influence your material’s flow performance. Unfortunately, most standard-design storage
equipment can yield undesirable performance with difficult-to-handle materials, such as fine powders, sticky materials, or materials whose particles tend to interlock or cake.

**3 Carefully evaluate whether you should use a standard design.**

Most standard storage silos and bins discharge material in a *funnel flow* pattern. With funnel flow, some of the material moves while the rest remains stationary, as shown in Figure 3a. This first-in-last-out sequence is acceptable if the material is coarse, free-flowing, and non-degradable and if segregation during discharge isn’t an issue. A funnel-flow silo typically uses a 60-degree (from horizontal) hopper angle. This standard hopper angle can be an economical choice from a capital expense perspective because manufacturing units with this geometry is easy and inexpensive and generates minimal waste.

A 60-degree hopper angle will promote funnel flow for most bulk solid materials. If you’re storing a difficult-to-handle material, selecting such a hopper can cause flow problems and greatly increase operating costs.

Even if the equipment supplier guarantees your vessel’s performance, the supplier likely won’t replace the equipment for free or reimburse you for production downtime if you experience flow problems.

You can prevent these flow problems by installing a storage vessel specifically designed to discharge your material in a *mass-flow* pattern. With mass flow, all material moves whenever any is withdrawn in a first-in first-out flow sequence, as shown in Figure 3b. Material flow is uniform and reliable with no stagnant regions, so material won’t cake, level indicators work reliably, and segregation of the discharge stream is minimized. Also, with mass flow the material’s bulk density at discharge is independent of the amount of material (or *head*) in the vessel.

To achieve mass flow in a storage vessel, the hopper wall must be steep enough and sufficiently low in friction to allow the material to flow along the wall surface despite the hopper’s converging geometry. Also, with abrasive materials, such as sand or bottom ash, the hopper walls must be lined with an abrasion-resistant liner to minimize wear to the hopper wall over time. Achieving mass flow often requires a nonstandard vessel design, which may cost more upfront but will save money in the long run in reduced downtime and repair costs.

**4 Make sure the feeder will maintain reliable flow.**

In many cases, poor flow from a storage vessel can be caused by the feeder drawing material from the vessel and discharging it into the downstream process. Effective material discharge from storage requires that the feeder withdraws material uniformly through the entire cross-section of the hopper’s discharge outlet. Regardless of the hopper design, an obstructed outlet due to a poorly designed feeder or partially closed slide gate will result in funnel flow. The following guidelines can help prevent flow problems from a poorly designed screw, belt, or rotary valve feeder:

**Mass-flow screw feeder.** The key to a proper screw feeder design is to provide an increase in capacity in the direction of the material feed. This is critical when the screw is used under a hopper with a slot-shaped outlet. A standard screw with a constant-diameter shaft and constant-pitch flights will pull material preferentially from the back of the hopper outlet, as shown in Figure 4a, because the first screw flight is the only one that isn’t already filled with material.

A mass-flow screw feeder, as shown in Figure 4b, overcomes this problem by using a tapered (or conical) shaft in the screw’s first section and flights that increase in pitch in the following section. This allows material to
enter the screw along the entire length of the hopper opening rather than just filling the first flight while the rest of the material remains stagnant.

**Mass-flow belt feeder interface.** As with a screw feeder, the key to a proper belt feeder design is to provide increasing capacity in the direction of the material feed. This is achieved by using a mass-flow belt feeder interface, as shown in Figure 5. The belt feeder interface tapers in both plan view and elevation view to allow the material pile on the belt to grow wider and taller in the direction of the feed. The interface also has a slanted *nose* (or front end) with an arch-shaped cutout to ease material flow onto the belt.

**Rotary valve.** A rotary valve feeder mounted directly to the hopper outlet may have a tendency to develop a preferential material flow channel on the side of the hopper outlet where the empty valve pockets are first exposed to the material. The valve pocket quickly fills with material from this channel while material stagnates over the remaining portion of the hopper outlet, potentially causing bridging, ratholing, and other flow problems. You can typically prevent this by installing a vertical pipe section with a height about one to two times the hopper outlet diameter between the hopper outlet and the rotary valve inlet. If the storage vessel is feeding into a pressurized conveying system, the rotary valve should also be vented to avoid *gas counter flow*, where conveying gas flows up through the rotary valve and impedes the flow of the discharging material stream. This can be a particular problem with fine powders.

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**Be sure to consider combustible dust hazards.**

Most dusts generated by bulk solids manufacturing operations are combustible, which means they can burn rapidly, causing either a flash fire or an explosion. Though most people know about the hazards of flammable gases and liquids, many are unaware of the combustible dust hazards associated with bulk solids storage and dust collection equipment. According to the US Chemical Safety and Hazard Investigation Board, 281 combustible dust incidents occurred during the 25-year period from 1980 to 2005, killing 119 workers, injuring 718, and causing extensive damage to plants and equipment.

A dust explosion requires five ingredients:

- Combustible dust such as sugar, plastic, wood, and most carbon-containing dusts
- An oxidant such as the oxygen present in the air surrounding most process areas
- An ignition source such as a static discharge, hot surface, or spark
Dispersion of the dust into the air
Confinement of the dispersed dust in an enclosed space such as a silo, dust collector, dryer, mill, or building envelope

Several National Fire Protection Association (NFPA) standards provide excellent guidance for preventing and protecting against combustible dust hazards. Prior to reviewing industry- or design-specific standards, I recommend first reviewing the more general NFPA 652: Standard on the Fundamentals of Combustible Dust. The standards detail many devices and methods for protecting your storage equipment from combustible dust hazards, including venting, containment, isolation, and suppression. These OSHA-consensus standards may be mandated by an appropriate authority having jurisdiction (AHJ), such as a plant owner, insurance provider, fire chief, or building inspector. Ignoring your plant’s combustible dust hazards or the requirements of your local AHJ can result in fines at best and catastrophic consequences at worst.

References

For further reading
Find more information on this topic in articles listed under “Storage” and “Solids flow” in Powder and Bulk Engineering’s comprehensive article index in the December 2016 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.)

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