Ensuring reliable material flow into your pneumatic conveying system

Previous “Pneumatic points to ponder…” columns and Powder and Bulk Engineering webinars have pointed out that, when troubleshooting pneumatic conveying system flow problems, you should first ensure that you have consistent material flow into the system before you try to find out why you don’t have consistent flow out of the system. For this column, I’ll discuss how to ensure reliable material flow into your pneumatic conveying system, a topic companies often overlook when incorporating a pneumatic conveying system into a bulk solids process. For help with this column, I consulted with expert Joe Marinelli, president of Solids Handling Technologies, who has many years of experience dealing with material flow problems.

A pneumatic conveying system’s material feed may come from an auxiliary piece of equipment such as a vibratory feeder, screw feeder, or air-activated gravity conveyor, or simply a wedge-shaped hopper on a silo above the conveying line. These feeding devices have well-defined geometries that include inlet and discharge points. What isn’t always well defined — and is often misunderstood — is how the material flows through the feeding equipment.

Flow problems

Several types of flow problems can occur when handling bulk solid materials. No flow is the most common problem, usually occurring when a gate is opened or a feeder is turned on to initiate discharge from a storage silo but the material forms an arch (also called a bridge or dome) over the hopper outlet, as shown in Figure 1a, and no material flows out. Initiating flow typically requires breaking up the arch with a force greater than the gravitational force acting on the material column in the silo using either flow aids, such as vibrators or air blasters, or by banging on the hopper wall with a sledgehammer.

A second no-flow condition, called a rathole (also called a pipe or core), forms when some material discharges from the silo’s center, but friction between the material and the silo wall prevents the material around the silo’s perimeter from flowing, as shown in Figure 1b. Once the flow channel empties out, material flow stops. A stable rathole decreases the silo’s live (or usable) capacity since material flow is limited to the narrow flow channel. The stagnant material around the silo’s perimeter can cake and solidify or spoil. A stable rathole will typically remain in place until measures are taken to break up the material and restore flow.

Erratic flow is where ratholing and arching occur in the same silo. Typically, a stable rathole develops, and when operators break up the rathole using a flow aid device, the material collapses into the hopper and forms an arch over the outlet. The operators then break up the arch and restore flow for a period of time until another rathole forms and the scenario repeats. Erratic flow can affect the material discharge rate and bulk density, and the collapsing material can even cause structural damage to the silo.

Flooding can occur if a stable rathole forms and then additional material is added to or falls into the flow channel from above. Flooding usually occurs with a fine, easily aerated material, which becomes fluidized as it falls
through the open channel and flows uncontrollably through the discharge opening or feeder.

A limited discharge rate typically occurs because of counter-current airflow. Material flowing out through the discharge or feeder creates a vacuum in the silo. Air or gas from the conveying system flows counter to the discharging material to fill the vacuum, limiting the material flowrate. A limited discharge rate is a function of a material’s ability to aerate or deaerate; material that easily entrains and holds air will be more likely to experience limited flow. The usual approach to solve this problem is to increase the feeder speed, but the rate at which material can flow through a given opening is limited, and this approach isn’t always effective.

Segregation occurs when a material composed of varying particle sizes or bulk densities — such as grain with fines or dust — separates according to those particle characteristics. The major cause of segregation is sifting, where a material’s fine particles separate by moving through the spaces between coarser particles. For example, when a material with varying particle sizes forms a pile in a silo, fine particles will typically accumulate beneath the fill point while coarse particles will roll or slide to the silo’s perimeter.

**Typical flow patterns**

Flow problems can cause downtime, equipment failure, and degraded product quality. To avoid these problems, you must understand and identify your material’s flow pattern. The two flow patterns that can develop in a bin or silo are** funnel flow** and **mass flow**.

In funnel flow, some material moves, while the rest remains stagnant. The hopper walls aren’t sufficiently steep or smooth, so the material along the wall remains in place until the material in the center of the silo has discharged. This causes a narrow flow channel to form directly over the outlet, and the first material to enter the silo is usually the last material to exit (called first-in last-out flow sequence). The major benefits of a funnel flow silo are the reduced headroom requirements and lower fabrication costs since a funnel flow silo typically uses a shallow (60 degrees from horizontal or less) pyramidal hopper or flat bottom.

In mass flow, all the material is in motion during discharge. Material slides along the hopper walls because a mass-flow silo typically uses a cone or wedge-shaped hopper that’s steep and smooth enough to overcome the friction that develops between the material and the hopper’s converging geometry. Material flows through the silo in a first-in-first-out flow sequence.

While a funnel-flow silo may cost less and require less headroom than a mass-flow silo, funnel flow isn’t suitable for all materials. Coarse, free-flowing materials, such as plastic pellets will flow well in a funnel-flow silo, but cohesive materials and fine powders tend to bridge or rathole. A rathole can’t form in a mass-flow silo since all the material moves during discharge. Mass flow doesn’t prevent arching, however, so a mass-flow hopper outlet must be large enough to prevent arching over the discharge opening.

Materials that degrade or spoil aren’t suitable for funnel flow because some of the material remains stagnant in the silo, which can affect product quality or safety. The first-in-first-out flow of a mass-flow silo minimizes the material’s residence time, preventing degradation.

Mass flow is also more suitable for applications where particle segregation must be avoided. While sifting segregation may still occur inside a mass-flow silo, fine and coarse particles are desegregated at the hopper outlet since all the material flows in unison.

**Material flow properties**

Bulk solids flowability is a science, and today’s technology has taken the guesswork out of hopper and feeder design. The field of bulk solids handling was developed mainly through the work of Andrew W. Jenike, who pioneered bulk solids flow theory in the 1950s. Jenike developed a scientific approach to studying bulk solids storage and flow properties that’s still relevant today. In fact, the Jenike shear test is now the American Society for Testing Materials (ASTM) standard in the US and Europe for determining a bulk solid material’s flow properties.

**Flow property tests** measure a material’s cohesive strength, wall friction properties, compressibility, and permeability. These tests can identify how a material will flow in a particular hopper or feeder geometry to either confirm the validity of a proposed design or identify a flow problem in an existing bin or silo.

Cohesive strength is a physical, chemical, or electrical bond between particles. Many bulk solids will flow like a liquid when poured from a container. Under these conditions, the material has no cohesive strength because air is entrained between the particles, reducing interparticle friction. However, if you squeeze a handful of the material, removing the entrained air, the particles may gain enough cohesive strength to retain the shape of your hand.

Cohesive strength is measured using a bench-scale testing device called a
direct shear tester, as shown in Figure 2. The device measures the material’s cohesive strength as a function of applied consolidation pressure. The operator places a material sample into a shear cell on the device, which then applies a compressive load to consolidate the material and simulate the pressure the material would be under in a storage vessel. Once material in the shear cell is consolidated, the device applies a shear (or lateral) load to the material to simulate flow conditions in a vessel. Shearing the sample to failure determines the material’s cohesive strength at that particular consolidation pressure.

By repeating this procedure at different consolidation pressures, you can understand the relationship between consolidation pressure and cohesive strength for that material. This relationship can be plotted on a graph and is called a flow function. The testing process is fairly straightforward but requires time to simulate the range of pressures acting in a storage vessel.

The test procedure also allows the operator to simulate several other conditions that affect a material’s flowability, including the sample’s moisture content and particle size and the effects of temperature and storage time.

Wall friction values are expressed as a wall friction angle (or coefficient of sliding friction). The higher the wall friction angle, the steeper the hopper walls need to be to ensure mass flow. The shear tester determines the wall friction angle by measuring the force required to slide a material sample across a stationary surface. For a given material and wall surface, the wall friction angle isn’t necessarily constant. The value often varies depending on the normal pressure (pressure perpendicular to the stationary surface), with the wall friction angle usually decreasing as the normal pressure increases.

Compressibility describes a material’s range of bulk densities as a function of consolidation pressure. A bulk solid material’s bulk density is an essential value when analyzing the material’s flow properties, and a material will exhibit a range of bulk densities depending on the amount of consolidation pressure being applied. In a silo, the consolidation pressure varies depending on location in the vessel and the height of the material column above that location. Compressibility values are used for calculating hopper angle, discharge outlet size, and feeder and silo loads.

A bulk solid material’s permeability is determined by passing air or another gas through a representative column of the material. While regulating the pressure drop across the material bed, the tester measures the rate at which the gas flows, allowing the material’s permeability to be determined as a function of bulk density. Permeability values are used to calculate discharge rates through various outlet sizes in a mass flow silo so the silo outlet can be modified to achieve the desired discharge rate.³

Gravity flow

Achieving gravity flow is typically the best approach to vessel design since gravity-powered discharge is efficient, cost-effective, and reliable. To achieve gravity flow, you must evaluate your material’s flowability. Using the material’s wall friction values, compressibility, and flow function data along with Jenike’s

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References

For further reading

Find more information on this topic in previous “Pneumatic points to ponder…” columns or in articles
listed under “Pneumatic conveying,” “Solids flow,” and “Storage” in Powder and Bulk Engineering’s article index in the December 2015 issue or the Article Archive at PBE’s website, www.powderbulk.com. (All articles and columns listed in the archive are available for free download to registered users.)

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