Abstract

Every bulk solids handling process is prone to unreliable flow resulting in a negative effect to the bottom line of the processing unit. Understanding the cause of the flow issues is the first step in troubleshooting the problem. Next, measuring the material’s flow properties is critical in providing the design data required to develop a comprehensive scientific solution. Or in the case of a new installation, the design data is required to prevent flow problems from occurring so that the new equipment works correctly from start-up. The flow property data can also provide the design parameters for a purge system to strip out residual volatiles and produce safer, higher value, and customer-pleasing products.

Introduction

The plastics industry is a growing industry and significant producers of bulk solids, such as powders, granules, pellets, and flakes. Even with all the plant experience, it is common for a plant to be dealing with bulk solids handling problems such as plugging, arching, bridging, buildup, etc. in bins, hoppers, feeders, and transfer chutes. Many plants are designed without a measurement of the flowability of the material. Further, the flowability of the material changes depending on the particle size and distribution, the moisture or volatile content, temperature, time of storage, and chemical composition.

Problems with handling solids can have a significant impact on production targets, product quality and even safety. Many of these bulk solids handling problems can be avoided by using a proven scientific approach based on the flow characteristics of the material.

This paper will discuss critical design parameters required to design a reliable storage system (i.e. purge vessel, silo, bin, hopper, etc.) to provide consistent feed to the downstream handling system.

Typical Flow Problems

Flow problems can be classified into three main categories, no-flow, erratic-flow, and uncontrolled-flow.

- **No-flow** can occur when a stable arch or bridge forms over the outlet. Sometimes vibration or external impact is used to attempt to reinitiate flow. Some material may empty out and a stable rathole forms.
- **Erratic-flow** is when the flow of the material oscillates between arching and ratholing – steady-flow is unachievable.
- **Uncontrolled-flow** can occur when a stable rathole forms and fresh powder is fed into the bin but since there is no time for the material to de-aerate, it becomes fluidized in the central flow channel. Since bulk solids handling feeders cannot hold back fluid like material, the fine powder can flood out of the equipment.

Figure 1. Typical flow problems of arching/bridging and ratholing resulting in no-flow and erratic flow conditions.

These flow problems result in a myriad of issues such as loss product, uncontrolled retention time, product degradation, and safety issues. To overcome these flow problems, the flowability of the material needs to be understood.

Flowability

The “flowability” of a bulk solid is a function of the material and the equipment it is being handled in [1]. An “easy flowing” bulk solid placed in a wrong piece of equipment can become difficult to handle; whereas material that appears to be hard to handle is placed in the correct equipment, it can flow reliably. When working on the design of a handling system, the engineer must be aware of the material flow properties and choose the appropriate equipment for reliable flow.
Flow Patterns

Material will move through a bin in one of two ways: funnel flow or mass flow. Both patterns are shown in Figure.

In funnel flow, an active flow channel forms above the outlet, with non-flowing material at the periphery. As the level of material in the bin decreases, layers of the non-flowing material may not slide into the flowing channel. When the bulk solid has sufficient cohesive strength, the stagnant material does not slide into the flow channel and a stable “rathole” forms resulting in a no-flow condition. In this stagnant region, material can gain strength over time, cake, and degrade. It also limits the live storage capacity of the bin [2] and can create cross-contamination issues between batches.

In addition to flow stoppages that occur as a consequence of ratholing, funnel flow can cause material degradation, results in a first-in-last-out flow sequence, and increases the extent to which sifting segregation (separation of large and small particles) impacts the uniformity of the discharging material. In these cases the material coming out of storage can be functionally different to what went in.

In mass flow, all of the material is in motion whenever any is withdrawn from the hopper. Material from the center as well as the periphery moves toward the outlet. A mass flow discharge pattern provides a first-in, first-out flow sequence that maximizes control of the residence time in the bin (particularly useful if a purging step is required in the surge bin), uses the full bin capacity, and eliminates ratholing and the associated problems of flooding of fine powders.

Mass flow bins provide other benefits over funnel flow hoppers. A mass flow discharge pattern will eliminate stagnant regions and diminish the effects of sifting segregation that may have occurred as a bin is filled. Mass flow also provides a steady discharge at a consistent bulk density and a flow that is uniform and controlled. For these reasons, mass flow is advantageous for material that is cohesive, fine, will degrade over time, or sifting segregation is a concern. In order to achieve mass flow, flowability tests need to be performed to provide the appropriate design basis.

Flowability Tests

There are many tests available to measure properties of the material, but not all of them are beneficial for design. Often the following tests are viewed as predictors of whether or not a material will flow well but do not provide all the information required for design [3].

- **Angle of repose** – the angle a pile will form. Best used to determine the height and volume of a pile.
- **Particle size distribution and moisture content** – while these parameters can affect flowability, i.e. fine, wet material tends to be more difficult to handle than coarse, dry ones, one can neither calculate nor infer a material’s flowability directly.
- **Flowability index** – since flowability of the material is a function of the material and the equipment it is handled in as discussed above, a relative flowability number does not provide the design parameters needed for a successful handling system.

Rather, more useful parameter should be sought after. In order to design for the appropriate parameters, flowability tests need to run on a representative sample of material. Key tests required for design are [4]:

1. **Wall friction** – provides mass flow hopper angles using a Jenike Shear Tester in accordance with ASTM Standard D6128 [5] (also used to predict loads that are applied to the walls of the bin)
2. **Cohesive strength** – provides opening sizes to avoid flow stoppages due to cohesive arching and ratholing. It is measured as a function of consolidating pressure in accordance with ASTM Standard D6128
3. **Compressibility** – provides the bulk density of a bulk solid as a function of consolidating pressure. It is used to determine storage capacity of equipment and to calculate material induced loads. It is measured in accordance with ASTM Standard D6683
4. **Permeability** – measurement of the resistance to gas flow through the bulk solid. It is particularly important when material contains a significant...
portion of fines. The data obtained from this test is used to calculate the critical, steady-state flow rate of the material that can occur during discharge as a function of outlet size and consolidating pressure.

It is critical that the testing conditions match the processing conditions because the following variables can all affect the flowability of the material:

- Moisture content
- Temperature
- Storage time at rest
- Chemical composition, grade, volatiles
- Particle size and shape

For example, some polymers might be free flowing at ambient temperatures, but when heated to say 100°C they may block, i.e., form solid masses, and even melt at higher temperatures.

**Handling Equipment Design**

Once the flow properties are measured, then the design basis can be established.

**Storage Vessel**

When designing a storage vessel, the engineer must first establish if a funnel flow or mass flow bin/silo/hopper is required for the process requirements. Funnel flow silos are appropriate for materials and processes that have the following characteristics [1]:

1. **Coarse particles** – usually a quarter inch in size and larger;
2. **Free flowing materials** – materials which do not stick to each other;
3. **Non-degrading particles** – materials which do not cake or degrade when sitting for long periods of time without movement;
4. **Segregation is not a concern** – either the material is non-segregating or, if it does segregate, it will not affect downstream processes (for example, if operated on a batch basis); and
5. **No purging** – if the vessel will also function as a purge vessel, then the material must move down uniformly through the vessel and funnel flow is not appropriate.

Provided that the bulk material meets all five of these characteristics, a funnel flow bin is the most economical storage device. One reason is that the sloping hopper walls can be shallow, which results in savings in overall headroom for the bin. In addition, by not having particles sliding along the hopper walls, there is no abrasive wear.

However if the five criteria above cannot be satisfied, a funnel flow pattern is no longer suitable and a mass flow discharged pattern should be used.

Achieving mass flow requires:

- Sizing the bin outlet large enough to prevent arching
- Ensuring that hopper walls are sufficiently smooth and steep enough to allow flow of the bulk solid along them
- Ensuring withdrawal of material from the entire outlet area.

These requirements can be met by applying the measured properties of the material as the basis for design.

**Purge Vessel**

Resin storage vessels such as bins, silos, and tanks often double as purge vessels, in which products are purged of volatiles or polymerization reactions are controlled [6]. Many productions plants also have in-line degassing and purge columns directly after the reactors that produce the polymers. Processing the polymers by this method reduces the residual volatiles creating safer, higher quality plastics that may be used in more critical applications (like medical devices and storage containers and in higher quality product lines).

The stripping step is achieved by gas flowing counter current to the resin particles or pellets. In order to achieve reliable flow and effective purging, a mass flow design with proper gas introduction schemes are required - simply ensuring that the vessel discharges in mass flow is not sufficient. A uniform resin velocity profile must also be achieved in the purging zone, the gas must be injected such that the resin particles are uniformly exposed to it, and flow instabilities, such as fluidization, must be...
avoided. Variations in the final product may occur unless all of these factors are taken into consideration.

**Feeder Below a Hopper**

Even the most carefully designed hopper can discharge in funnel flow if the feeder does not provide uniform withdrawal of material from the entire hopper outlet.

This problem frequently comes up when a gate or valve is used at a hopper outlet in an attempt to regulate flow. In order to use a gate to regulate flow, it must be operated partially closed. This is detrimental to reliable flow because it prevents discharge from a portion of the hopper outlet, potentially resulting in a large volume of stagnant material in the hopper. Ultimately, a feeder should accomplish the following [7]:

- Provide reliable and uninterrupted flow of material from the bin above.
- Control discharge rate from a bin, achieving the required rate while preventing flooding.
- Remove material from the entire cross section of the hopper outlet in order to avoid interfering with mass flow in the bin above.
- Seal against a gas pressure gradient (in some applications).

For screw or belt feeders, this means that the capacity must increase along the length of the hopper outlet to allow material to be activated along the entire hopper area (Figure 4).

Figure 4. Comparing a constant pitch screw feeder to a mass flow screw feeder.

**Conclusions**

Reliable flow of bulk solids is possible and uniform purging is achievable in a purge vessel. The first step is to determine the flow properties of the materials being processed. Next the appropriate flow pattern must be selected for vessel design. In the case of a purge vessel, gas pressures and flow rates and their effect on solids flow must be analyzed. Using a scientific approach based on the flow properties of the materials, reliable handling systems can be designed.

**References**