Understanding powder behavior is essential for optimizing bulk solids production processes and developing high-quality products. This article introduces the challenges associated with predicting powder flowability and discusses how understanding powder behavior can benefit process performance. [Editor’s note: While this article discusses powder behavior, the same principles apply to bulk solid materials generally.]

Powders are integral to a wide range of industrial manufacturing processes. Whether as raw or intermediate materials or as final products, powders contribute to approximately 75 percent of all manufactured goods. However, despite their usefulness and ubiquity, powders continue to present handling challenges during product development, manufacturing, and quality assurance. We often label a powder as difficult-to-handle, when a more accurate description would be to say that we simply don’t fully understand the material’s behavior.

Powders perform differently, depending on how they’re formulated and manufactured and on the environment to which they’re subjected. While this performance variability can make powder behavior difficult to predict, it’s ultimately what underpins the value powders bring to manufacturing processes.

Factors that affect powder behavior

A powder is more than just individual particles; it’s a bulk assembly that contains solid particles, gas (typically air) and liquid (typically water), as shown in Figure 1. The properties of each of these phases (solid, gas, liquid) and the interactions between them determine the powder’s behavior. This means that powder behavior is influenced by several variables and an array of potential interactions as well as by external process factors, as shown in Figure 2. As a result, powder behavior is too complex to be accurately predicted by measuring the material’s physical properties alone.

A common misconception is that powder behavior can be described just by understanding the material’s flowability and that flowability is a discrete property that can be quantified with a single number. Neither of these assumptions are correct, however; a material’s flowability can vary depending on a number of circumstances.

For example, loosely packed flour will flow freely from a glass jar when the jar is tipped over, but if the jar is first tapped several times on a hard surface, the flour will consolidate and resist flow even when the jar is held upside down, as illustrated by Figure 3. Dry sand, however, doesn’t consolidate and will easily flow from the jar both before and after tapping. As this example shows, a material’s flowability often depends on other characteristics specific to that material.
Material characteristics and factors that affect powder behavior include:

**Flowability.** Some materials tend to flow well through a process, while others tend to bridge, block, or flow intermittently.

**Compressibility.** Some materials are very stiff and don’t compress, while others consolidate under compression, resulting in a large increase in bulk density.

**Adhesivity.** Some materials tend to stick to process equipment, while others slide easily over surfaces.

**Permeability.** Some materials allow air to easily pass between the particles, while others block airflow. This can be critical during processing and in some final product applications.

**Electrostatic charge.** Some powders may become electrostatically charged during handling and processing, which can change the material’s flow behavior.

**Moisture content.** Most powders experience a change in behavior if humidity or water content increases or decreases, but the extent of the change varies depending on the material.

**Friability.** If a material’s particles are friable or weak, mechanical stress can break or damage the particles during handling and processing, changing their size and shape and potentially affecting the powder’s behavior.

**Flowrate.** Powders may behave differently depending on the flowrate (or shear rate). Flowrate can particularly affect operations such as mixing and blending.

**Fluidization potential.** Certain powders have a tendency to fluidize and retain air, resulting in fluid-like behavior and often causing flooding or poor in-process flow control.

These are just a few of the factors affecting powder behavior. Adding to the complexity is that material properties are frequently independent and unrelated, so two powders may be equally compressible but exhibit very different flowability, while two other powders may flow the same but have different permeability.

**Mechanisms of particle interaction**

We can gain further insight into bulk powder behavior by understanding how particles interact and move relative to one another. If we understand the mechanisms of particle interaction, we can often engineer those mechanisms to our advantage, which can provide great benefits for both product development and process optimization.

Mechanisms that restrict interparticle movement include:

**Friction.** As shown in Figure 4a, particles with a smoother surface will generally have a lower frictional interaction and flow more easily than those that are rougher, assuming all other features are identical.

**Mechanical interlocking.** Certain particle shapes can encourage the particles to mechanically interlock with one another and resist flow, as shown in Figure 4b.

**Interparticle forces.** Interparticle forces, as shown in Figure 4c, can cause cohesion between contacting particles and particles in close proximity to one another, inhibiting flow.

**Liquid bridging.** Moisture in the material can create a bridge or capillary bond between particles, as shown in Figure 4d, reducing particle independence and inhibiting flow.

All these mechanisms act to restrict interparticle movement, and, generally, the stronger their influence,
the less likely the powder is to flow freely. Ignoring that particles in motion will have inertia, the primary — and often the only — motivating force acting on loosely packed particles is gravity.

Powders with high levels of cohesion, interlocking particle shapes, and high surface friction will still flow if the gravitational force acting on the particles is sufficient to overcome these mechanisms. Materials with large or dense particles tend to flow better than materials with very fine or light particles because each individual particle’s mass is relatively high, so the gravitational force acting on each particle is greater compared with very fine or light particles.

While powder behavior is influenced by all the mechanisms of particle interaction, including gravity, the level of influence of each depends not only on the material’s properties but also on the environmental and process conditions imposed by the application.

The process environment

For most processors, powder behavior isn’t just a subject of academic interest, it’s a daily challenge. Depending on the application, manufacturing processes subject powders to various stress regimes and environmental conditions in a range of unit operations, including:

- Hoppers
- Feeders
- Blenders and mixers
- Granulators
- Dryers
- Conveyors
- Mills
- Extruders
- Fillers
- Compression processes (such as tableting or pelletizing presses)

Intentionally aerating a flow-resistant powder during processing can help induce flow in some applications.
Developing an optimized process requires understanding the powder’s intrinsic characteristics, understanding the demands of the process, and ensuring that the two are compatible. If the material isn’t compatible with the process, then either the material, the process, or both will need to be modified to achieve an efficient operation and ensure a high-quality product over the long term.

**Powder processing challenges**

As the list of unit operations in the previous section shows, powders are frequently subjected to storage, transportation, and handling before and during processing. In storage, a powder can consolidate or cake and become more resistant to flow. When aerated — by discharge from a hopper, for example — the particles become separated by air, which reduces resistance to flow. Inducing flow with a consolidated powder requires around 100 times more energy than with a typical aerated powder, and may require more than 1,000 times more energy than with an easily fluidizable powder.

To help minimize problems later in production, powder properties should be considered from the earliest stages of plant design and product formulation. Employing appropriate handling techniques can improve the likelihood of success when handling notoriously challenging powders. Also consider how any changes to an existing manufacturing plant may influence process performance.

Sometimes blockages, bridging, weight variability, and agglomeration may begin to occur even with no apparent change to processing conditions. This is frequently caused by changes in the raw material supply. Specifying raw materials is a critical part of production management, and quality control is important in determining whether a new batch or formulation will process the same as previous batches or formulations.

For example, a powder processor may change material suppliers to reduce costs. The processor may specify the same material in terms of composition, purity level, particle size, bulk density, and moisture content, but when the new material arrives, the process performs poorly even though the powder matches the specifications. Frequent blockages occur, flow rates are compromised, and the final product fails to meet quality standards.

The problem is typically that the material specification didn’t adequately define the characteristics required for a material to perform well in the process. Some other property (or properties) not included in the specification is influencing the material’s behavior in the application. Defining measurable parameters that relate to how the material will perform in your specific application is essential when selecting a powder. Particle and chemical properties alone are often unable to achieve this.

Understanding your powder’s behavior requires comprehensive testing and characterization of the material’s flow properties, determining which variables are important in your specific application, and establishing a robust database of process-relevant data for comparing powders. If possible, develop a design space for determining material compatibility so that new materials can be specified and new formulations can be optimized to meet your application’s criteria. Materials can then be tested before entering a process or at various stages throughout a process, such as just upstream or downstream from a particular unit operation.

While powders can be challenging to process and measure, they deliver an array of industrially useful behavioral properties. Ensuring that your powders and processes are compatible will help you to fully take advantage of those properties and provide high-quality products over the long term.

**References**

For further reading

Find more information on this topic in articles listed under “Particle analysis” in Powder and Bulk Engineering’s 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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