MEASURING BULK DENSITY OF GRANULAR MATERIALS CONTINUOUSLY IN-PROCESS

Many of the products that we purchase every day, such as dog food, cat litter, or breakfast cereals, are packaged by volume but sold by weight. Implicitly, this means that for many dry bulk products the bulk density — or rather, the bulk density’s consistency — is very important to consider when manufacturing these materials. This article explains how continuous bulk density meters can provide this information for in-process materials.

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When purchasing a 40-pound bag of dog food, customers expect 40 pounds of dog food even if the bag is overflowing with product. Moreover, they expect a full bag of dog food, even if at half full the bag weighs more than 40 pounds. These customer expectations mean that an important part of modern manufacturing is a product’s bulk density measurement, but what is bulk density, what affects it, and what are some effective ways of measuring it in-process?

The simple answer is that bulk density is a measurement of mass per unit of volume. The answer becomes more complex as you begin to examine the factors that affect bulk density and the points within a process where bulk density can be measured.

Particle size affects bulk density because the smaller the particle size, the more closely packed — and, thus — the more dense the material volume can become. The shape of particles also will affect bulk density as shape affects individual particles’ ability to nest with other particles. Some particles can have the same relative shape and size but can have drastically different weights. Expanded plastic pellets or dried coffee beans (not green) are great examples of this phenomenon. Some materials are hygroscopic and will pull water from the atmosphere, which can dramatically change a material’s bulk density. A material’s surface friction or static charge also can affect — although minorly — its bulk density.

The state of the material while in-process is the final thing that can affect bulk density and its measurement. Bulk density classes or characterizations are derived from a material’s state in-process. The more commonly identified bulk density classes include aerated, vibrated (or tapped), and poured.

**Aerated bulk density** is the bulk density of a material when it has been aerated. Typically, but not always, aerated bulk density measurement is a function of particle size. Small, lightweight particles, for example, lend themselves to easily being aerated. The measurement of aerated bulk density can be important to know for various reasons, including the proper sizing or analysis of pneumatic conveying systems.

**Vibrated (or tapped) bulk density** is the bulk density of a material as the vessel that’s being filled with the material is being vibrated. As the individual particles are vibrated and shift, they nest closer and closer together, thus making the contained material more dense. This measurement results in the highest bulk density for a material. While materials are often tapped or vibrated in-process, especially when filling containers or during packaging, rarely is the vibrated or tapped bulk density actually measured in-process.

**Poured bulk density** is the density of material as it’s poured into a volume or container. Pouring causes a relatively loose structure in the material and results in a lower bulk density. In practical terms, the poured bulk density is a close approximation of the material’s bulk density as it moves through a process, flowing through conveyors, dropping via gravity, or emptying from tanks or containers. When a material is moved in this manner, the bulk density of the entire stream could be considered its poured bulk density.
**Sampling and measuring in-process material bulk density**

Generally, while aerated and vibrated material bulk densities are important to know, these measurements aren’t taken while the material is in-process — partly because both methods require external stimuli to facilitate the necessary aeration or vibration. Poured bulk density, due to its ease of measurement, is the in-process measurement of choice.

Because bulk density isn’t a first principal measurement (not measured directly), it’s typically calculated based on various other measurements. For instance, bulk density meters typically measure mass and volume and calculate bulk density using these two values.

Two main ways of measuring material bulk density in-process include static (or sampling) measurements and continuous (or dynamic) measurements. For static bulk density measurement, material is sampled using a known sample volume, the sample is weighed, and the two values of mass and volume are used to determine bulk density. For continuous bulk density measurement, mass and volume measurements must be taken while the material is flowing and not when the material is at rest. In other words, while the formula for calculating static bulk density is density = mass/volume, the formula for calculating the flow of bulk density is density (flow) = mass (rate)/volume (rate).

**Static bulk density measurement.** The most common in-process measurement method is a static measurement and involves sampling the material and measuring bulk density external to the process. This measurement usually involves using a collection device like an automatic or inline sampler, which is inserted into the material stream to collect the sample and then pulled from the stream. For some processes, the material sample is sent to a laboratory, which calculates the bulk density. While extremely accurate, this method incurs excess cost because outside analysis is required. Results also can be delayed for hours, meaning the feedback can’t immediately be used to compensate for processing errors or as a signal that upstream equipment is malfunctioning.

Some sampling devices will measure bulk density and don’t require that material be sent out for analysis. These devices can maintain a high degree of accuracy while saving time by eliminating the need for lab analysis. These sampling devices use a variety of methods to maintain sample consistency such as minimizing the collection vessel opening and standardizing leveling techniques. With volumetric consistency ensured, material within the collection device can be weighed and the density calculated. Some units can measure bulk density as often as twice a minute. While quicker than lab analysis, this method will still result in delayed response times of up to 30 seconds. Also, because sampling devices don’t sample the entire material stream, they presume that the stream is homogenous over the entire 30-second measurement cycle.

**Continuous bulk density measurement.** Continuous bulk density measurement devices can measure the entire flow stream. They typically consist of a continuous flow measurement device as well as an integrated feeding device that can modulate and control the flow path size and, thereby, the flowrate. By controlling the flowrate, continuous bulk density measurement devices can accurately measure the full flow of material mass (rate) and, based on the size of the flow path, be able to accurately determine the volume (rate) at the particular mass (rate). The result is a continuous bulk density measurement for the entire flow of material.

**Practical applications for continuous bulk density measurement**

Measuring the entire flow of material rather than sampling flow portions can offer tighter bulk density control. Material can be either accepted or rejected based on the near instantaneous output that continuous bulk density measurement devices offer. The feedback also can be used to perform checks on upstream equipment or on process procedures.

These devices also can store records of accepted versus rejected material. The typical repeatability of continuous bulk density measurement devices can
be as good as ±1.0 lb/ft³. The measurement accuracy depends on the reference measurements used. For calibration on the same material, accuracies of the continuous bulk density can be as good as ±1.0 lb/ft³.¹

**Flow from a bin or hopper**
If positioned after a large holding tank, silo, or bin of stored material, as shown in the diagram in Figure 1, a continuous bulk density measurement device could maintain the material flow’s bulk density within a specified range. The device would maintain a specified flowrate with specified upper and lower bulk density limits. A high and low alarm would be set based on those limits. As the silo discharges material, the continuous bulk density meter outputs material with the accepted bulk density. As out-of-spec material passes through the meter, the material triggers an alarm that actuates a downstream diverter that directs the off-spec material to an alternate bin or location. When the material flow’s bulk density returns to within specification, the alarm shuts off and the acceptable material is diverted back to the proper locations.
In this type of an installation, both the accepted and rejected material amounts are known. Since response time is nearly instantaneous, most continuous bulk density measurement devices can ensure that nearly all rejected material is kept separate from accepted material. Unfortunately, because the material being measured is held in a storage tank or silo, these meters’ ability to alert operators to upstream process disturbances is diminished. Determining when the out-of-spec material was originally produced would be nearly impossible.

**Dynamic flow in-process**
For situations where material isn’t stored but is, instead, in-process, a continuous bulk density meter would require the addition of a maintained-level hopper. A maintained-level hopper is a small hopper that, with the assistance of level-sensing technology, will maintain the material level within the hopper. When installed in this type of application, as shown in the diagram in Figure 2, a level setpoint for the hopper is established. The system changes the continuous bulk density meter’s flow setpoint to maintain the hopper’s material level. Though the bulk density meter isn’t controlling or maintaining the flowrate, the meter still outputs an accurate bulk density measurement, even for erratic flowrates. In such installations, the hopper could be sized to maximize bulk density feedback speed (smaller hopper volume) or to maximize the smoothing of the flow signal. For example, the larger the hopper, the less likely the hopper level will go down far enough to require the bulk density meter to change its flow setpoint, meaning that the flow signal will be more consistent. Similar to the previous example, amounts of both the accepted and rejected material are known, but because the hopper size can be greatly reduced, the ability to signal upstream process disturbances is greatly increased.

**Substituting continuous for static measurement**
While continuous bulk density measurement devices will control the material flowrate going through them, controlling that flowrate isn’t practical or even possible for some processes. In such instances, the devices can be used similarly to sampling or static measurement devices by diverting material from the main material stream. In this case, however, rather than sampling a discrete volume of material, a continuous stream of diverted material is measured and then diverted back to the original material stream. In such a case, only a fraction of the full material flow is measured. Due to the small amount of “stored” material, or the material amount that collects above the continuous bulk density device, the bulk density feedback received from the device is fairly indicative of the current upstream process conditions and can, thus, be used to make determinations about them. See Figure 3.

The rejection command for out-of-spec material could come in less than a second, which would minimize the amount of out-of-spec material passing into the process. Unfortunately, since the bulk density of only a fraction of the material is being measured, neither the total amount of accepted or rejected material is known. Since many continuous bulk density meters measure the flowrate of the material passing through them, a meter installed in this configuration wouldn’t give you a real-time indication of the material flowrate either.

**Measuring blended bulk densities**
For processes that measure bulk density, one of the by-products is volumes of out-of-spec material. This material could be considered waste, or it could be blended back into the main process. One such application would be during the packaging process.

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**FIGURE 3**
Variable material flow
Continuous bulk density meter
Flow setpoint
Bulk density limits
High-speed diverter and alarms
Accepted material
Rejected material
two continuous bulk density feeders, as shown in the diagram in Figure 4, the accepted and rejected material can be reblended for packaging. A bulk density controller would determine the flow setpoint for each of the two material flows, which, when blended, will maintain the bulk density setpoint. With the bulk densities controlled, each of the resulting packages would be filled to its proper weight and volume.

References
1. When compared to a vibrated bulk density with the number of samples taken large enough to give the true sample bulk density (SBD) of the lot.

For further reading
Find more information on this topic in articles listed under “Weighing and batching” in Powder and Bulk Engineering’s article index in the December 2018 issue or the Article Archive in PBE’s website www.powderbulk.com. (All articles listed on the archive are available for free download to registered users.)

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