Gravimetric fillers: Improving high-speed package filling

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Many dry bulk solids processors who use high-speed, continuous filling lines to package materials in pouches, small bags, and boxes are replacing volumetric fillers in their filling lines with gravimetric fillers. The need for long-term filling consistency, accountability, and lower material usage are just some of the factors driving this trend. After a brief look at high-speed filling lines and the differences between volumetric and gravimetric fillers, this article explains how gravimetric fillers can improve high-speed package-filling performance and how you can overcome obstacles to using the fillers in this application.

Volumetric filling equipment has long been the traditional choice for high-speed, continuous filling lines, primarily because of the equipment's low cost and simplicity. But gravimetric fillers can provide better long-term package-filling consistency, more accountability, and lower material usage in some of these applications. To determine whether a switch to gravimetric fillers makes sense for your high-speed filling line, you'll need to consider whether the fillers' advantages outweigh the equipment's higher cost and more complex operation and maintenance. First, let's examine some filling line and filler basics.

About high-speed filling lines

A high-speed, continuous filling line feeds materials or material mixtures into pouches, bags, boxes, or other small packages of up to about 1 pound. The line typically includes one or more material source, a filler (called a feeder in applications other than package filling) for each material source, a carrying-filling-sealing device, and a packaging device. In operation, material is conveyed from each material source to a filler, which feeds the material into one of several packages on the carrying-filling-sealing device. If the finished package will include multiple materials, such as ingredients in a dry soup mix, the device moves the partially filled package under subsequent fillers for additional feeding. After all materials have been added, the package is sealed and moved to the packaging device, which wraps the package with others for delivery.

The filling line typically fills multiple packages per second. As shown in Figure 1, the carrying-filling-sealing device can be either a rotating wheel (Figure 1a) that moves packages entering on one side around the wheel's perimeter, under the fillers, and toward the packaging device, or a
linear device (Figure 1b) that moves packages in a straight line under the fillers and toward the packaging device. The fillers can be volumetric or gravimetric.

**About volumetric and gravimetric fillers**
The fundamental differences between volumetric and gravimetric fillers determine how well each filler can perform in a high-speed filling line.

**Volumetric.** A volumetric filler (called a volumetric feeder in nonpackaging applications) dispenses a particular volume of material per unit time into a package. Examples are screw, vibrating pan, and belt fillers, and each is suited to different feedrates and specific material properties, including particle size distribution, bulk density, cohesiveness, and angle of repose. The filler consists of a hopper, discharge device (the screw, vibrating pan, or belt conveyor), and speed controller.
In operation, material flows from the hopper into the discharge device, which discharges a certain material volume per unit time — based on a preset discharge device speed — from the hopper into the package to be filled. The speed controller monitors and adjusts the discharge device’s speed to control the feedrate.

The volumetric filler’s few moving parts and resulting low maintenance requirements contribute to its simplicity and low cost. It’s typically easier to install in a filling line, as well, and requires less space than a gravimetric filler. But because the amount of material the volumetric filler meters into each package depends on the discharge device’s preset speed rather than an actual measurement of the discharged material, the filler can’t detect any changes in the material bulk density or discharge device efficiency.

The gravimetric filler’s ability to compensate for changes in bulk density and mixture ratios over time produces greater long-term filling consistency.

Such material bulk density changes can be caused by segregation (if the material has a wide particle size range) or a change in the ingredient proportions in a material mixture. Bulk density changes can also be caused by changing material levels in the hopper during refilling and emptying: Generally, the higher the material level, the higher the bulk density of material flowing out of the hopper.

Head pressure changes — that is, pressure changes caused by the weight of material in the hopper — can also cause some materials to flow at inconsistent rates; for instance, a floodable material will flow more quickly under less head pressure, while another material may flow more slowly under less pressure. The discharge device’s efficiency can also affect the feedrate consistency. A given discharge device can be more efficient at some speeds than at others, producing an uneven feedrate. But because the volumetric filler can’t detect any of these changes, it provides poor control of the material weight in each package.

**Gravimetric.** A gravimetric filler (called a gravimetric feeder in nonpackaging applications) measures the weight of material that’s discharged into each package. Examples are loss-in-weight (either screw or vibratory) and weigh-belt units. Each has components similar to those of a volumetric filler but also includes a weight-sensing device linked to a microprocessor controller that provides closed-loop feedrate control around a feedrate setpoint. As with volumetric fillers, each type of gravimetric filler is suited to different discharge rates and material properties.

In a loss-in-weight filler’s operation, for instance, a feedrate setpoint is first input to the microprocessor controller. Material then flows from the hopper into the discharge device, which discharges the material into a package as the weight-sensing device takes continuous discrete measurements of the loss in weight of material in the hopper. The weight-sensing device sends these weight signals to the microprocessor controller, which calculates the hopper’s loss in weight per unit time and uses this information to correct the discharge device’s speed within a narrow accuracy range around the feedrate setpoint. This provides closed-loop feedrate control.

**Long-term filling consistency measures the fluctuation in the material weight (or in the ratio of the weight of different ingredients) in each package for longer periods.**

Such closed-loop control allows the filler to detect and compensate for changes in the material bulk density (whether due to segregation, changes in a mixture’s ingredient proportions, changing hopper levels, or other factors), head pressure, and discharge device efficiency. Because the gravimetric filler includes a weight-sensing device and microprocessor controller, it also is more complex, typically requires more room in the filling line, and has a much higher capital cost than a volumetric filler.

**How gravimetric fillers can improve high-speed filling performance**

To understand how a gravimetric filler can improve your high-speed filling line’s performance, it’s helpful to compare volumetric and gravimetric fillers in terms of several performance criteria. These include short- and long-term filling consistency, throughput rate, accountability, material usage, and waste control.

**Short- and long-term filling consistency.** Evaluating short-term filling consistency requires measuring the fluctuation in the material weight (or in the ratio of the weight of different ingredients) from package to package over short periods. To do this, you can weigh material in each of a series of contiguous packages (or, in the case of a material mixture, you can classify the mixture into individual ingredients and then weigh each of them) and evaluate the material to determine how consistently each package is filled. After this, you can periodically remove a package during normal filling operation and compare the data from the contiguous samples with data for each periodic sample to determine how much the filling consistency fluctuates over the short term. Typically, these short-term results show similar filling accuracy and deviations for both volumetric and gravimetric fillers, with the gravimetric filler showing only marginally better filling consistency.
For instance, a filling line running at 600 packages per minute fills 10 packages per second. Because bulk density and mixture ratios won't fluctuate much in 1 second, the volumetric filler is able to provide about the same filling consistency as the gravimetric filler in this period. However, the gravimetric filler can overreact to minor 1-second fluctuations by speeding or slowing feeding too much, which can reduce the filler's short-term consistency.

Figure 2a plots results — the material weight in each package (called the sample weight) — collected from two short-term filling line runs in a total 3-second time span at a 600-package-per-minute filling speed. In one run, 30 consecutive packages were filled by a volumetric filler, and in the other, 30 were filled by a gravimetric filler; all other conditions were identical. The results, with each data point representing one sample's weight, are tabulated in Figure 2b, which shows that the volumetric and gravimetric samples had similar accuracy and repeatability, but the volumetric results show a decreasing weight trend. Because the volumetric filler can't compensate for bulk density changes, a decreasing bulk density may be causing the weights to decrease over time. But because the time span is only 3 seconds and the weight decrease is relatively small, these short-term results indicate that the volumetric filler's results are slightly better.

Long-term filling consistency measures the fluctuation in the material weight (or in the ratio of the weight of different ingredients) in each package for longer periods —
from run to run, cycle to cycle, day to day, month to month, and so on. Measuring long-term consistency requires the same techniques as for short-term consistency and is especially useful for evaluating filling performance during special runs (such as for a customer’s special orders), problem runs (such as to diagnose and fix filling-line problems), and filling-line cycles (such as refill, startup, and shutdown cycles). The gravimetric filler’s ability to compensate for changes in bulk density and mixture ratios over time produces greater long-term filling consistency — with greater accuracy and repeatability and less fluctuation in package weight — than the volumetric filler can.

Reviewing Figure 2’s short-term results along with results for two more short-term runs, as shown in Figure 3, reveals the gravimetric filler’s better long-term filling consistency. Figure 3a’s data points represent the sample weight for each of 30 packages for three consecutive short-term runs (including that plotted in Figure 2a) for each of the two fillers; this gives a total of 90 samples per filler. The data was collected over a 9-second time span, again at a 600-package-per-minute speed. The results are tabulated in Figure 3b.

The sample weights for each 30-package set in Figure 3 are similar to Figure 2’s short-term results. But when the three sets are taken together as a single test, the 90 sample weights for each filler in Figure 3 show that the volumetric filler’s performance wasn’t as accurate or repeatable over the long term. If the long-term performance tests had been
run over several hours or days, as is more typical for filling performance tests, the long-term data could show even poorer results for the volumetric filler.

Using a gravimetric filler can dramatically improve long-term filling performance because the filler adjusts its output to produce the same mean sample weight for the packages. This ability to adjust weights reduces the range of weights in the packages, allowing tighter control of the filling process. Because this gives the operator more confidence in achieving a tighter weight span in the filled packages, the operator can also reduce the package target weight (or setpoint) to reduce material costs.

In cases where the gravimetric filler has poor short-term performance and this will be a serious concern, the filler’s long-term performance may not provide enough compensation for making the switch to gravimetric filling. In many cases, however, a filling line can handle the gravimetric filler’s slightly worse package-to-package weight fluctuations if the filler greatly improves the long-term weight fluctuations and produces an overall process improvement. Tests of gravimetric fillers at the filler manufacturer’s plant or a trial run with fillers temporarily installed in your plant can help you evaluate short- and long-term filling performance.

**Throughput rate.** Providing higher filling throughput rates to meet peak demand or to minimize operating costs while maintaining product and package quality is important to many bulk solids processors. Increasing the throughput rate requires increasing the filling line’s speed. While both volumetric and gravimetric fillers can handle high filling speeds, the faster a volumetric filler is, the more evident its package-to-package weight fluctuations become. In addition to comparing the number of packages filled in a given time period by each of the fillers, consider how a higher throughput rate will affect the filler’s long-term filling consistency.

**Accountability.** The gravimetric filler provides accountability by collecting data about filling and filling trends in real time to help your control system monitor the package-filling process and control the filling line. The filler’s microprocessor controller typically calculates and accumulates this filling data, then provides it to your filling line’s control system or — to integrate filling with other operations — your plantwide control system. This level of accountability provides a higher level of filling control. The volumetric filler has only a speed controller, so it can provide no accountability to the control system and provides much less filling control data.

The gravimetric filler’s accountability provides multiple benefits. Data provided by the filler can be used to monitor how much material is used over the short and long terms, which helps control your material inventory. The filler can also provide data for monitoring how well actual mixture ratios in your filled packages compare with the specified mixture ratios. By providing real-time data about problems with the material supply, the filler itself, or other filling line components, the filler also allows the operator to quickly detect and correct problems before they result in wasted material or packages. The gravimetric filler can also report data to a maintenance technician to aid equipment troubleshooting.

**Material usage.** A successful filling line will consistently deliver the specified amount of material — within a narrow accuracy range — to each package, thus delivering what your company promises to its customers while minimizing your material costs. In many plants, a relatively expensive material is mixed with other, less expensive materials before being fed into a package. In such a case, it’s easy to see why the minimum amount of material should be delivered to the package: Overfilling could drastically increase material costs.

To determine whether your filling line’s material usage and associated costs are excessive, you need to compare the material usage rate at regular intervals and over the long term to the filling line’s average target consumption (the amount of material you expect the filling line to use based on achieving your specified, or target, package weight and throughput rate). Because the gravimetric filler more tightly controls filling consistency and thus minimizes the upper and lower limits of acceptable filling accuracy, it allows you to establish a narrower filling accuracy range and thus reduce long-term material usage.

**Waste control.** Filling waste can be material, packages, labor, or any other resource that’s consumed by your filling line but doesn’t go into the final filled package. For instance, any package that doesn’t contain the correct material weight can be rejected by a downstream checkweigher. Other material and packages can be wasted at startup before the filling line is operating correctly and at full speed. Breaks in the material supply or package supply can also result in wasted material and packages. Labor to clear an equipment jam or blockage is another form of waste.

Controlling waste helps maintain filling efficiency and throughput and reduce filling costs. In the short term, the gravimetric filler wastes more material and packages at
startup and at feedrate changes before reaching the feedrate setpoint than the volumetric filler. Over the long term, however, the gravimetric filler provides better control of the process by responding quickly to material supply breaks, jams, and other problems.

**Overcoming obstacles to using gravimetric fillers**

Despite the gravimetric filler’s long-term benefits in high-speed filling applications, it can present some drawbacks. These include the filler’s greater space requirements, more complex operation and maintenance, filling inconsistency after startup and feedrate changes, and higher capital cost. The best way to overcome these obstacles is to apply the gravimetric filler in cases where you can reduce costs by controlling package weights, thus reducing material usage and preventing waste, and where you need more detailed filling data for better accountability. The following information provides details about these obstacles and explains how you can overcome them to gain the benefits of gravimetric filling.

**Greater space requirements.** The gravimetric filler is generally larger than the volumetric filler, and the hoppers and other equipment supplying material to the gravimetric device are often larger than those for the volumetric filler. The gravimetric filler’s material supply equipment also can have a more complex layout. This can make it difficult to group the fillers closely together and can make it more difficult to operate and service them after installation. One way to avoid these problems is to discuss the new equipment’s space requirements with your operators and maintenance technicians and invite their input. This will allow them to point out their operating and maintenance needs and contribute to layout solutions before the equipment is installed.

**More complex operation and maintenance.** Gravimetric filling represents a real paradigm shift from volumetric filling, and switching from using volumetric to gravimetric fillers requires a big step up in operation and maintenance complexity for your operators and maintenance technicians. The procedures they used with the volumetric device are often eliminated or greatly changed after the gravimetric filler is installed. The gravimetric filler’s more complex electrical connections and its sensitive weight- and speed-sensing components make filler installation, calibration, operation, cleaning, and troubleshooting (either of the filler or the filling line) more difficult.

To overcome these obstacles, involve your operators and maintenance technicians in the switch from volumetric to gravimetric filling and carefully train them to understand how the gravimetric filler’s components and operation differ from those of a volumetric filler. They need to understand how to operate and maintain the filler to prevent damage to its weight- and speed-sensing components. In a filling line that adds multiple materials to each package, you can also initially use gravimetric fillers for only your key materials, reducing the impact of switching to all gravimetric fillers.

**Filling inconsistency after startup and feedrate changes.** Because a continuous filling line for small packages typically runs at high speed, it’s important for each filler in the line to deliver the correct amount of material as soon as possible after the line is started up or the feedrate is changed to prevent wasted material and packages. This is even more important if the line is often stopped and started or if the feedrate setpoint is changed frequently. The gravimetric filler’s microprocessor controller traditionally uses a simple proportional-plus-integral-plus-derivative (PID) control algorithm to ramp up the feedrate until it reaches the feedrate setpoint and achieves good feedrate control; depending on the gravimetric filler’s type and the algorithm’s tuning, the feedrate can be inaccurate as long as 30 seconds after startup or a feedrate change.

The feedrate just after startup of a gravimetric filler controlled by a PID algorithm is shown in Figure 4a. As the figure shows, the feedrate is slow to come to the feedrate setpoint. By the time good feedrate control is achieved, a
large amount of material and many packages have been wasted. While tuning the control algorithm can improve the filler’s startup performance, this can also reduce feedrate control during normal filling operation.

One solution is to select a gravimetric filler whose microprocessor controller uses two independent algorithms for feedrate control. In this case, a startup algorithm jumps to a calculated setpoint, then a second, more traditional PID algorithm takes over, maintaining the setpoint, as shown in Figure 4b. The calculated setpoint the startup algorithm jumps to is typically determined by feedrate values and tendencies the filler’s controller has learned during normal filling operation. The two algorithms enable the filler to jumpstart feedrate control without sacrificing good long-term control during normal filling.

**Higher capital cost.** The gravimetric filler is typically much more expensive than a volumetric one. The gravimetric unit’s weight-sensing device and microprocessor controller add to its cost, and these complex components can require more spare parts. Your operators and maintenance technicians will also require more training to handle the gravimetric filler’s complexity.

But as long as you apply gravimetric fillers appropriately, you can expect a relatively fast return on your investment. The more costly your material is, the less consistently your material flows, the more critical your packaged product’s mixture ratio is, or the more packages your current filling line’s checkweigher rejects because of filling inaccuracy, the faster your switch to gravimetric fillers will pay for itself.

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**For further reading**

Find more information on package filling and gravimetric filling equipment in articles listed under “Bagging and packaging,” “Feeders,” and “Weighing and batching” in *Powder and Bulk Engineering*’s comprehensive “Index to articles” (in the December 2001 issue and at www.powderbulk.com).

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