

Level Systems: How accurate are they?

It's the end of the month and you take your bulk material inventory. After you report to the accounting department, you get a call. Where did you get the extra material? Or worse, where did your material go? The receiving tickets and production utilization don't match with the materials on-hand. You send three different operators at different times up on the deck to verify the level measuring system and now have more confusion! The readings conflict with one another which conflict with the level measuring system. Additionally, none of the readings match the production draw. So who is right? Why don't the weights match?

When trying to account for material in a vessel many people mistakenly try to measure by the level of the material. If trying to verify the weight, there are numerous problems that can occur within the conversions that must take place from level to weight.

First there is a known amount of material delivered by a railcar, determined by a certified rail scale. The material is brought into the storage silos and eventually emptied into a certified weigh hopper that batches out in 300 pound increments for the production process. There is some material loss from the connection leakages and dust collection system, but nothing to the extent of what accounting is trying to reconcile. The automated level measurement system then becomes a target. To see why it might be the culprit, let us review how you arrived at a weight value using your level measurement system.

There are two methods to determine the weight of material in a bulk solids vessel.

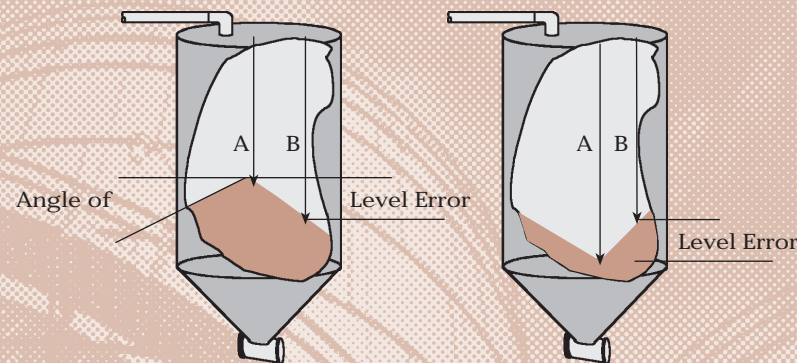
1. Find the location of the top surface of the material with a level measurement device and convert it into a calculated weight.
2. Directly weigh the material using a sensor attached to, or placed under, the vessel supports.

All weight indicators take a physical measurement from a sensor (capacitance, strain, time, etc.) and convert it into a weight value. Ultrasonic technology, pulsed radar and Time Domain Reflectometry (TDR) are measurements of how much time it takes the signal to reach the material and return to the sensor, not distance. Capacitance systems measure the difference in the dielectric constants of air and the material. Mechanical bobbers count rotations of the cable feeding mechanism. All level measurement technologies have an error associated with the way in which the sensor interacts with the surface of the material. This error is specified under ideal test conditions and is given as the limit of the technology, not the actual application. This is an accuracy of the measurement, not the weight value. In other words, the specified accuracy of a device is always better than the in-field accuracy of the whole system. Specific accuracy is a characteristic of the device rather than how it will perform as installed in an actual silo situation.

Any level measuring system locates a point on a material surface. The location of that point across the surface greatly affects the value computed for weight. This measurement must be converted to weight using several steps. First, time is converted to distance. Then distance is converted into volume. Finally, volume is multiplied by the material density to approximate weight. Each of these conversion steps introduces an opportunity for errors.

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All level measuring systems for bulk solids assume that the material is flat and horizontal. This meets the definition of level. In the real world, all bulk solids have an angle of repose. This angle is produced when the material fills into or empties from a vessel. The method of filling a vessel can produce a wide variety of shapes to the material surface. Off-center fill points, a moving tripper car, and angled or multiple fill pipes all produce multiple cones and peaks.



{ Figure 1 } Errors due to measurement locations

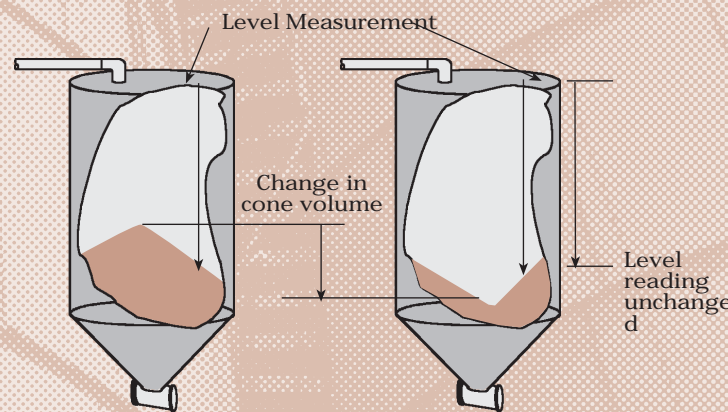
A very large vessel with multiple draw points produces multiple funnels in the material surface. Some of these shapes can be extremely irregular with multiple high and low points. In some cases, the level on one side of a vessel can be 30% to 50% different in height than the other side (difference between points A and B in Figure 1). Vessels designed for mass flow usually produce an almost level surface when emptying but possess a cone shape on filling. This non-level material surface can produce a significant error in the conversion to weight reading.

The conversion from distance to volume is one of the biggest sources of error. The claim that a level system can make a direct conversion from a level to weight reading is misleading. A level system must first make a conversion to volume using the vessel height and cross section dimensions. Even manual conversion tables have three columns: one for taped distance (airspace), one to convert to volume, and one for weight (based on a fixed density). If a weight conversion is done using only one linear distance (a high and low point), the actual percentage of error in the weight value can be as high as 10% (+/- 5%) due to the shape of the pile.

Assume the level system is located near the wall of the vessel and detects a point directly below the sensor in a round vessel of radius R. The amount of material in the filling or emptying cone shape is a function of the silo cross section and the angle of repose of the material for funnel flow vessels. The material cone volume is $V_C = 1/3 \pi R^3 \tan(A)$ where A is the angle of repose of the material. The maximum amount of change in volume from cone up to cone down is 2V. The total volume of

the vessel ignoring the cone is $V_T = \pi R^2 H$, where H is the height of the vessel. The error percentage of the missing material is $2V/V_T = 2/3 (R/H) \tan(A)$. For material with an angle of repose of 45 degrees $\tan(45) = .707$. For a typical bin of 12 foot diameter (R=6) and 50 foot height, the error would be 5.6%.

As the sensing point is moved from the wall towards the center, the error will decrease and then increase again. A measurement at the center will produce the same error as the edge. The theoretical minimum error location would be where the volume of the cone from the measurement point to the center equals the volume of a ring of missing material around the outside wall. This only works when the material shape is a perfect cone on both filling and emptying. For irregular material surfaces that develop in real vessels the minimum error point is unknown. See Figure 2.



{ Figure 2 } Errors due to material shape

All linear volume conversions assume the vessel shape is a cylinder, yet most bulk vessels do not have flat bottoms. Non-linear conversions of distance to weight must account for the variation in the vessel and particularly the shape at the bottom. Cones, square, pant-leg, and internal mass flow devices can produce significant level to volume conversion errors when the level is low in the vessel.

Using the wrong bulk density when converting from volume to weight is another major source of error. The published specifications for material bulk density can vary by as much as 50% from the actual values. Published bulk density is an average. In the case of flour, it varies from season to season, year-to-year, dependent on the wheat crop and blend. Pneumatic conveying aerates the materials so it changes level as it compacts down with time. In one known application, a 60 foot flour silo has been observed 3 feet (5%) level overnight from settling. Another company uses 57 lbs./ft. as a standard for all level to weight conversions for corn, even though the actual measured values run from 42 lbs./ft. to 72 lbs./ft depending on moisture content and processing steps. This is +/- 26 %!

Total error to make a level measurement into a weight value is the sum of the errors. $E_T = \text{measurement error} + \text{volume conversion error} + \text{material density error}$. Worst case for the above example would be $E_T = 1\% + 5.6\% + 26\% = 32.6\%$. For a more typical case in actual use the probable error is $E_T = 1\% + 3\% + 4\% = 8\%$.

Considering all the opportunities for errors, obviously the best method of determining the weight of material in a vessel is to weigh it. Often a level technology is mistakenly used to determine weight. The moral of the story is: If you must account for weight or process by weight you should be measuring by weight. Many vessels with level systems have the support structure (legs, gussets, skirts, etc.) to allow for a weighing system to be installed with such equipment as the robust Load Stand II, high accuracy LD3 load cell, or bolt-on weight sensors such as the L-cell. When using a weighing system there is only a single conversion needed and much higher accuracies achieved with these instruments. You are measuring weight with a weighing technology and the volume/material density conditions inside the vessel are irrelevant. After all, weight is weight and always will be.

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