How Much Is in the Silo?

How to meet accuracy expectations for bulk solids storage

V_{red} = ? r^2 H / 3 = (3.14 x 25 x 2) / 3 = 52.3 ft^3 V_{green} = Volume of 1 ft of straight wall = V_{cyl} – V_{orange} V_{cyl} = ? r^2 h = 3.14 x 56.25 x 1 = 176.6 ft^3 V_{orange} = 0.2618 (D^2 + D d + d^2) h = 0.2618 (225 + 150 + 100) 1 = 124.3 ft^3 V_{green} = 176.6 - 124.3 = 52.3 ft^3 V_{green} = Volume of 1 ft of straight wall (V_{cyl}) - V_{orange} V_{cy}l = 176.6 ft^3 V_{orange} = 124.3 ft^3 V_{green} = 176.6 ft^3 - 124.3 ft^3 = 52.3 ft^3 V_{red} = 52.3 ft^3 = V_{green} = 52.3 ft^3 **By Joe Lewis**

Storage of bulk solids in silos, bins and other vessels typically requires periodic or continuous measurement of the amount of material within the vessel. The amount of material changes as it is discharged and added. For custody transfer or critical accountability applications, the ideal solution is measuring the change in weight of the vessel using a high-accuracy load stand system. However, weigh systems are expensive and require forethought when installing the vessel itself in order to ensure proper installation and calibration of the weigh system. This is essential if the anticipated high accuracy is to be obtained.
In most cases, the high cost and forethought required for high-accuracy weigh systems cause users to opt for continuous or periodic measurement of the level of the material in the vessel. In addition, weigh systems are just not practical in some applications, i.e., very tall silos in elevator terminals, and their precision is not required in most applications.

Level Measurement Challenges

There are six commonly used types of level measurement devices. The purpose of this article is to examine the conversion of level measurement to volume and weight. Following is a list of challenges involved in determining the amount of a bulk solids material in a bin or silo with a level measurement device.
1. The density of bulk solids varies widely and can be extremely light or heavy. 2. Bulk solids can have a wide range of particle sizes and shapes from fine micron-size powders to large general diameters with sharp edges. 3. Many materials, powders especially, produce large amounts of dust during filling and discharging especially if the vessel is pneumatically filled. 4. Some materials are hygroscopic and readily absorb or trap moisture. Moisture can combine with solids to cake or clump inside a

vessel, making material flow difficult. 5. Bulk solids do not produce a flat, horizontal surface in the vessel. The material surface has an angle of repose. The angle of repose can vary for several reasons including filling and discharging and the location of the fill and discharge points. In addition, angled inlets, multiple fill points and multiple draw points can create a unique and unknown angle of repose. 6. The coarser the material, the more likely it is to clump and bridge. 7. Many vessels use pneumatic conveying systems to fill the vessel with material. This aerates the material, which creates bulk density changes as the amount of air in the material changes. 8. Some materials vary in bulk density from load to load and season to season or vary dependent on blend. This can make it difficult to accurately know the bulk density value. 9. It can be difficult to know the exact dimensions of the silo. It is not unusual to find actual dimensions varying by an inch or two (25-50 mm). These issues are just the tip of the iceberg. In addition to affecting the choice of technology for making the level measurement, they can have a major impact on the conversion of a level measurement to the volume or weight value sought.

Volume and Weight Conversion

Volume and weight values are derived through mathematical calculations based on the measured distance/level. The volume of material is calculated based on the shape and size of the vessel. Although a rectangular configuration is sometimes used, the most common silo shape is the cylinder.
As silos for bulk solids typically incorporate a conical section where the material is funneled and discharged, the determination of the volume of a cylindrical silo requires multiple calculations. The calculation to determine the volume of the cylinder that is above the cone &#151 the straight wall section &#151 can be done using the following formula: $V_{cyl} = \pi r^2 H$ In this equation, “r” is the radius of the silo and “H” is the height of the straight wall section. This is elementary geometry. For example, a 12-foot (3.66 m) diameter silo with a 50-foot (15.2 m) straight wall section yields a total volume capacity of the straight section of 5,652 ft^3 (160 m^3). The calculation of volume in the conical section is a little different but still involves fairly simple geometry using the following formula: $V_{cone} = 0.2618 (D^2 + D\ d + d^2)\ h$ In this formula, “D” is the diameter of the cone where it connects to the straight wall section, “d” is the diameter of the discharge opening of the cone section and “h” is the overall height of the cone. Determining the volume of material in the silo is simply a matter of making a level measurement and substituting that “H” or “h” in the equations. The calculation of the weight or mass of the material in the silo is then derived based on the volume calculation and the bulk density of the material in the vessel. Simple, right? Not really. The challenges involved include the following: &#149 How accurate is the distance/level measurement? &#149 How accurate are the silo dimensions? Are they based on internal or external dimensions? It is not unusual for silos to be off by an inch here or there. A one-inch error in the “H” dimension can

throw off the weight calculation by 470 lbs (215 kg) with a material that weighs 50 lbs/ft^3 (800 kg/m^3). &#149 Did you use the outside diameter of the silo? This can easily result in an error of one inch in diameter. Over a straight wall height of 40 feet (12.2 m) with a silo diameter of 15 feet (4.6 m), this can result in an error of more than 3,000 lbs (1,376 kg). &#149 What about the bulk density of the material? Is it correct? Does it vary by load? The density of powders at the top of the material pile inside the silo is typically lower than that at the bottom of the pile because of packing. Bulk density inaccuracies can result in calculated weight values being off by hundreds or thousands of pounds. &#149 At what point on the material surface did the level measurement take place?

What’s Being Measured

A bulk solids level measurement device typically measures the empty space distance between itself and the material surface where it is aimed or directly below where it is mounted. For example, a smart cable-based sensor uses a weight and cable mechanism to lower a plumb bob and cable into the vessel and measure the distance of the cable until it contacts the material surface directly underneath where it is mounted. Likewise, a guided wave radar device will measure the time-of-flight of the reflected radar pulse from the material surface. Once the distance measurement is obtained, the level of the material in the silo is inferred based on the vessel height (the vessel discharge point to the mounting point of the level sensor) and the distance measurement from the sensor. Some level measurement devices, such as ultrasonic devices, do not make a direct measurement from the sensor to the material surface. Ultrasonic sensors measure the time-of-flight of the reflected sound pulse. They are unlike guided wave radar devices that use the wave guide to direct the radar pulse to the material surface and back. The sound energy from ultrasonic sensors scatters when they reflect off the material surface because of the angle of repose of the material. In this situation, the distance measured is typically based off a reflected sound pulse that has bounced around in the vessel, thereby adding slight errors in the basic distance measurement.

Level Measurement Accuracy

The measurement accuracy of a level sensor differs depending on technology and brand. Guided wave radar devices can provide a measurement accuracy of the distance measurement to within 0.8 inch (20 mm) for measurement of bulk solids. Typical smart cable-based sensors are accurate to within 1.5 inch (38 mm) for a 50-foot (15.2 m)

measurement. Through-air radar units may be accurate to 0.6 inch (15 mm) but, like ultrasonic units, need to be mounted on a swivel to align their emitted energy as perpendicular to the material surface to minimize error due to multiple reflections. Of course, the choice of technology depends on budget, accuracy and sophistication requirements. However, the overall precision of the calculated volume and weight values is another matter.

Sensor Mounting

The mounting location of the level sensor is usually controllable prior to installation and is important to the overall precision of the calculated volume and weight. The reason it's important to the calculation is due to the angle of repose. The level sensor assumes a flat surface when the calculation of the volume is done. This is not a valid assumption. However, for many applications, there is a simple solution. If the silo is filled and discharged from its center, then the mounting of the level sensor at one-sixth the diameter of the straight wall silo will eliminate the error. Consider the example of a 15-foot-diameter (4.6-m-diameter) silo that is center filled and discharged. The angle of repose will be relatively uniform with a peak at the center during filling. For this example, don't worry about the angle of repose because it will vary with the material. Let's assume it's above the transition point and the angle of repose is positive. The volume of the material in the peak, which is above the level measuring point line, is equal to the volume of the empty space below the line. See the details given in Figure 1 to review the math involved.

Conclusion

Level measurement is a viable method to monitor the amount of bulk solids in a storage vessel. However, many factors contribute to the correct conversion from level to volume and weight. Simply reviewing the accuracy statement of the sensor used is not enough and can be misleading if the sensor's technology and "specsmanship" are not understood fully. Accurate and stable information regarding vessel dimensions and bulk density is extremely important along with the mounting location chosen for the level sensor.
If the silo is not cylindrical or has off-center fill and discharge, it's best to choose a level sensor mounting location where a 1:1 relationship exists between the material above the imaginary level measurement line and the empty space below the line. It's also wise to consult a reputable and knowledgeable manufacturer for assistance.
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