Tank Scale Calibration

Choosing the Right Calibration Method

For Your Tank Scales

Because there are many calibration methods for tank scales, so you might wonder, which one is right for your operation while satisfying the quality department and requirements such as ISO9001. How can you prove that your processes are traceable and are producing best-in-class products at the lowest cost? You may also be concerned about improving safety, reducing the time that it takes to complete a calibration and potential waste of resources. In this document, we discuss the six common methods to calibrate a tank scale including pros and cons and then illustrate each method through use cases.

Content:

METTLER TOLEDO

1 **Calibration:** Definition and Business Impact

1.1 What is calibration?

Calibration is a series of tests that are performed against known standards or references such as weights to determine the accuracy of the scale. Calibration also confirms that the scale was installed correctly, has not been damaged or subjected to excessive wear and tear and that there is no interference from attached devices or accumulated product or debris. The goal of the tank scale calibration is to create the same load conditions that occur during normal operation with the help of a reference. Calibration also reveals defects in the scale, for example, due to a damaged analog strain gauge load cell or a defective cable or junction box.

Calibration also determines a device's accuracy using measurement uncertainty to confirm three important scale factors. First, calibration confirms that the scale will provide accurate measurements. Second, it confirms the device can be qualified as "fit for purpose" when its uncertainty is lower than your production tolerance. Finally, calibration provides the basis to adjust the scale if it does not provide the degree of accuracy required by the process.

There is a difference between calibration and adjustment. As defined above, calibration is a series of tests that are performed with a known standard, e.g., placing a 1,000 kg test weight on the scale. This is also called "As-Found" calibration. When the calibration process reveals unacceptable deviations, the scale can be adjusted to more closely match the known standard and the desired specification. After the adjustment, the series of tests is repeated and the measurement values recorded ("As-Left" calibration).

1.2 Calibration: The official definition

It is worth recalling the definition of calibration according to the Vocabulary of Metrology VIM 2.39 [1] which states that it is an: „Operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication."

1.3 What is the impact to your business?

Many companies are following GMP or ISO9001 to ensure high quality. ISO9001:2018 [6] section 7.6 states: „Where necessary to ensure valid results, measuring equipment shall - a) be calibrated or verified, or both, at specified intervals, or prior to use, against measurement standards traceable to international standards or national measurement standards."

Tank scales are measuring devices used in production to ensure quality under this regulation. Depending on the criticality of the production step and the risk of inaccurate measurements, the internal Quality Management System defines the calibration frequency for each scale. It may vary from monthly calibration (high criticality) to a 2-year interval (low criticality). Without the regular check (calibration), continuous product quality cannot be assured, thus placing your business goals (profitability, growth, etc.) at risk.

2 **Accuracy Requirements:** The Basis for Calibration

2.1 Accuracy, a simple two-part definition

ISO 5725-1 0.6 [6] defines accuracy as true and precise measurement results. The difference between the observed measurement value and the reference standard defines the "trueness" of the measurement. The closer the measurement gets to the reference standard, the better, or more „true" it is. Ultimately, all weight measurements are referenced to the definition of the kilogram, which is based on fundamental physical constants (newly established by the International System of Units on 20 May 2019). Even if you are weighing in pounds, the ultimate pound reference is based on this new kilogram standard. The second important component of accuracy is precision. How well can the same measurement be repeated? This is also called repeatability.

It is not enough to be "true." A measurement must also be precise (repeatable) to ensure best results and consistent quality. Let us take the example of throwing darts! Figure 2.1 shows an example of „true" results, the measurements (the dart throws) are scattered around the reference value (the bull's eye). Note that they are all surrounding the middle of the target and are evenly distributed. The player would gain a high point score and could argue that they were almost all in the center.

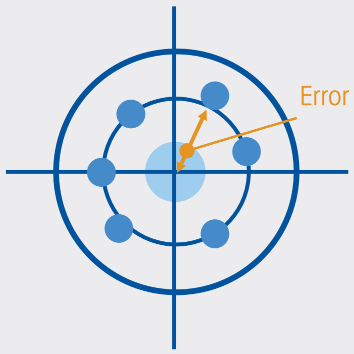

Figure 2.1 True results but they are not precise (not repeatable)

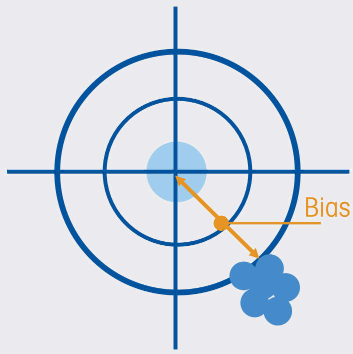

Figure 2.2 Precise results (repeatable) but they are not true

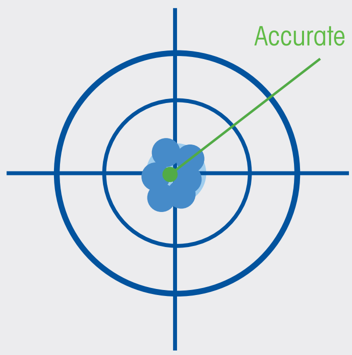

Figure 2.3 Precise and true (accurate) results

Figure 2.2 shows very precise results, as all the dart throws are very close together. One can argue that although the results are precise (repeatable), they are not true because the grouping is outside the center (not around the bull's eye). The player in this case could brag that they were pretty good but achieved a low point score. This off-center position is called bias. This bias on most weighing devices can be adjusted through a process called "span" or "sensitivity" adjustment (explained later). After this adjustment, you would expect to see the results in Figure 2.3, where the results are true (scattered around the reference) and precise (repeatable, close to each other). As with the dart game, tank scale measurement results after adjustment must be both true and precise to win the calibration game.

2.2 Six calibration methods for tank scales

Today there are six major methods used to calibrate tank scales, which are introduced and evaluated in the sections that follow. We will consider not only accuracy, but also the time, effort, cost, transport, safety and sustainability of each. The six methods are:

- Calibration with Test Weight(s)
- Weightless Calibration
- Material Substitution
- Material Transfer
- Flow Meter
- Hydraulic Calibration

3 **Uses Cases:** Four Tank Scales, Four Situations

A brief description of four use cases follows below; these use cases will be evaluated when discussing the six popular forms of tank scale calibration in the next Section to illustrate the best fit for your application.

3.1 Case #1: Inventory storage silo, 30-ton

Raw material for production is stored in a 30-ton silo. The purpose of the scale is to ensure that there is always enough material to complete a production run. This 30-ton silo is mounted on three load cells that jointly measure the weight of the silo contents. The silo is installed on a solid concrete foundation. Material is added through an opening on the top and removed at the bottom. Because the material is fed via a conveyor belt, no pipes are attached to the silo.

The facility pays their supplier based on raw material usage; the supplier invoices on its own weighing result. The quality and finance departments agree that calibration is necessary as a monitor to ensure the supplier is dealing fairly. The set tolerance is 1%, which means that the calibration should yield a result that is half of this value (0.5%) as a safety factor (safety factor = 2). The silo is located outdoors.

3.2 Case #2: Active ingredient mixer, 150 kg

A mixer is mounted on a stainless steel container to mix an active pharmaceutical ingredient with an excipient. The scale capacity is 150 kg. The active ingredient is 5 kg and must be weighed with an accuracy of 0.1%, which means between 4.995 and 5.005 kg. The excipient is 120 kg, and the same 0.1% accuracy applies. The tank scale is mounted in a clean room under controlled temperature and humidity conditions. The floor underneath is a steel plate on a concrete foundation. Multiple pipes are attached to the tank for material addition and removal.

3.3 Case #3: Production storage tank, 10-ton

A 10-ton storage tank holds enough material for one day's production, and it is critical that the quantity is sufficient for the upcoming production batch. The cost of the stored material is high, and the authorities are concerned about the material's environmental impact. For these two reasons, the required tolerance for the scale is 0.5% (or better). The tank scale is located indoors, but not in a temperature-controlled area. The tank is sitting on a mezzanine floor and two pipes are attached to it, one at the top for filling and one at the bottom for discharge.

3.4 Case #4: Batching tank before shipment, 5-ton

A system integrator delivers production tank scales to overseas customers. The tanks are equipped with weigh modules and terminals, and the customer requests that a functional test or Factory Acceptance Test (FAT) is performed before the scales are packed for shipment. Upon delivery and installation, the tank scales will be recalibrated before production starts.

At the system integrator the tanks are temporarily assembled on an existing concrete foundation indoors. Although multiple pipe connections are planned in the final production, these are not attached for the FAT.

4 **Calibration Methods:** A Comparison

4.1 Calibration with test weights

How does it work?

Calibration with test weights requires one or more certified weights; these are placed on (or attached to) the tank scale so that the sensors (load cells) of the tank scale are loaded.

Things to consider

These weights are available with various tolerances and grouped into classes. OIML (International Organization of Legal Metrology) and NIST (National Institute for Standards and Technology) provide reference documents for these weight classes. OIML Recommendation 111 is used globally; NIST Handbook 105 specifies weigh classes in the US.

Naturally, the better the tolerance, the higher the price. Therefore, you should consider what degree of tolerance is acceptable for your tank scale (perhaps defined in the quality system documents, or in production process description). A good rule is to use test weights with a tolerance that is three times better than your desired measurement tolerance.

You also need to keep in mind that scales used for custody transfer (buying and selling) are highly regulated, as is the calibration method allowed. The only permitted method is calibration by test weight. There are, however, some exceptions where the substitution method, covered under section C, is acceptable; the other four methods are not recognized.

Once the reference weights are placed on the scale, the sensitivity measurement (total reference weight) shall be recorded and compared to either the manufacturer's tolerance or the measurement tolerances specified by the quality department or operations. If you find that a deviation occurs, it is important to determine whether an adjustment is necessary; for example, in a validated process, it may be necessary to revalidate the process when an adjustment is made. If so, a professionally trained technician will make these adjustments. Re-application of the test load ensures that the adjustment did not compromise performance. Applying a test load three, six or ten times confirms that the scale is repeatable and that the scale is not damaged, bound by attached structures, or impeded by accumulated debris. However, a repeatability test is often omitted when calibrating with test weights. Organizing, transporting, then applying the test weights to the tank scale once can be difficult; doing it multiple times is often omitted when calibrating with weights due to the amount of time involved.

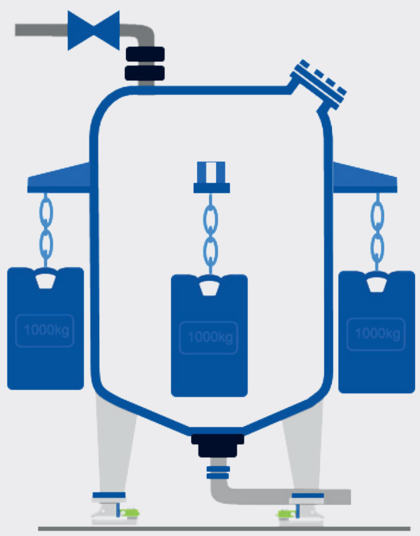

Figure 4.1

Block weights are lifted onto brackets that are welded onto the side of the vessel

The test weights used in calibration must be stored in a location that ensures they are not damaged between uses. It is industry practice to recalibrate the weights every two years for best results.

Accuracy

Of all methods discussed, test weights provide the highest accuracy. Using the appropriate class of test weight, the calibration accuracy is unsurpassable and accuracies of 0.03 to 0.01% or better can be achieved.

Organization efforts

Depending on tank scale capacity, it may be a challenge to transport a sufficient quantity of test weights to the scale. Using Case 1, the 30-ton storage silo, it would be necessary to accumulate and transport 30-ton of weights when a complete sensitivity test is performed. In smaller countries, even the availability of so many test weights is questionable, and renting and transporting them all at once is another level of difficulty. One- and two-ton weights are normally transported by a specialized vehicle with a crane. Loads above 20-tons require a separate vehicle, or trailer. In addition, the tank scale must be designed for the calibration process envisioned; this is often neglected during the scale design process. This means that a platform or brackets must be added after the fact, or another method chosen.

Estimating costs

Calibrating with test weights can result in high total cost. Test weight rental costs, transportation, and labor for handling must be added to the invoiced calibration work, and the production downtime can be substantial as well. Personnel safety must also be considered.

Production downtime

For higher capacities, above two or three-tons, the downtime can be longer than one day.

Transportation

For higher capacities, the transportation can be challenging. Production areas are also often tightly packed with equipment and finding space for the test weights can be difficult. Many production areas do not permit the use of transport devices, and bund-walls and mezzanines make the task more onerous. Also, cross-contamination from the weights should be a key consideration in food and pharmaceutical industries. For that reason, many companies leave weights at the scale permanently.

Safety considerations

Safety is a key consideration when working with weights. Use a lifting device on all weight pieces over 20 kg to ensure the safety of the operator. 20 kg weights can be loaded on a calibrated weight car or robot for transportation. When lifting weights ensure that all slings, chains, brackets and other hardware are rated for the task and are sufficient to lift and hold the test weights securely. Operators must wear protective shoes to prevent injury from dropped weights. The use of round legacy weights must be avoided due to instability and unexpected, spontaneous, movement of the weights. Avoid stacking weights unless they are the modern design that includes lifting and safety features like locking geometry that allow stacking. Serialization with machine-readable tags is the best method to form a traceability chain.

Sustainability

When heavy weights must be transported long distances, the transportation effort (use of trucks, cranes, and their respective fuel costs) make the test weight calibration method less environmentally friendly.

Use cases

- Case 1, 30-ton storage silo
  Calibrating a 30-ton storage silo with test weights is not practical at all. Finding and renting so many test weights can be difficult and expensive. It is very likely that no provisions were made for the test weights on the tank scale structure. The tolerance of the silo (1%) does not require calibration with test weights either.

- Case 2, 150 kg active ingredient mixer
  The 150 kg active ingredient mixer has a high tolerance requirement (0.1% for the 5 kg active ingredient), which can likely be fulfilled only with test weight calibration. Organizing a 150 kg test weight with a high accuracy class is easy because a local METTLER TOLEDO service team would offer it. It is also likely that during the design phase provisions were made on the tank scale for calibration with test weights. Calibration with test weights is the best method for this tank scale.

Photo 4.0

Example of stackable weights with built-in safety features

- Case 3, 10-ton production storage tank
  What was said for the 30-ton silo is also valid for the 10-ton storage tank. Finding and organizing test weights is difficult, and there is likely not enough space on the tank scale itself to place the weights. The weighing tolerance, 0.5%, does not suggest that calibration with test weights is necessary.

- Case 4, 5-ton batching tank, FAT at system integrator
  In this case the tank scale is not installed in the final location; only its functionality is to be proven. For this purpose, calibration with test weights would require significant effort, so it is not recommended.

Calibration with test weights - pros	**Calibration with test weight - cons**
• Most accurate depending on the weight tolerance. Low measurement uncertainty when appropriate weight class is used. Facilitates repeatability, eccentricity tests and scale linearization. • Takes into account the effects of the entire system including measurement chain, piping and flexible support structure • Non-invasive, no product contamination risk • Traceable to national and international standards • Acceptable for Legal-for-Trade scales • Weights do not damage the environment	• Transport, lifting and storage of weights may not be practical in some instances depending on tank structure and tank access • Poor availability of weights • Time consuming • Anchor points or platform required to load weights • Safety concerns • Transport of heavy weights over long distances consumes fuel

4.2 Automatic "Weightless" Calibration

How does it work?

Most industrial weighing companies offer a theoretical "automatic calibration feature" that attempts to minimize bias at installation (Figure 4.2) by electronically adjusting scale sensitivity based on sensor sensitivity. It is simply entering or reading the sensor (load cell) sensitivity data into the weighing terminal and adjusting the displayed weight value accordingly. At METTLER TOLEDO, weightless calibration is called CalFree™ (for analog load cells) or CalFree Plus™ (for POWERCELL® load cells).

The benefit of this weightless function is the time and effort saved when installing the system because this method can be completed within minutes and does not require you to obtain, transport and position reference weights. However, weightless calibration cannot mimic the scale in operation, you must consider following this procedure with another calibration method that confirms repeatability for more accurate results.

After the initial use of weightless calibration, there is no additional benefit applying the method again, it will not pass a quality or regulatory inspection or audit (that requires comparing the scale measurement to a reference).

Things to consider

The downside of this method is that it is theoretical; the adjustment is based on sensor sensitivity without consideration of scale design or installation. In other words, weightless calibration cannot detect system or installation errors, wrong settings, interference from attached devices, nor will it detect problems with the scale, foundation or structure. Consider the case of pipes attached to the tank scale because they can dramatically alter the sensitivity of a scale. It is impossible to include this effect in the sensor (load cell) sensitivity data measured at the manufacturer's facility.

This method does not test the repeatability of the scale, meaning that if you expect a high degree of precision (see Section 2), you must turn to other methods. Weightless adjustment can be used at the initial installation to reduce time and prove that the tank scale terminal, or transmitter is working, but calibration must be confirmed by another method such as weights or material build up.

Accuracy

It is difficult to assess the accuracy of the weightless (or electronic) calibration method, since it is not calibrating the installed tank scales with attached devices (e.g., pipes), but it is almost certainly method yielding lower accuracy. In the ideal case (tank scale on solid foundation, no pipes attached) the accuracy can be as good as 0.1%, but for most cases it is 1 – 2%. If the load cell sensitivity data is entered manually into the scale terminal, then it is prone to human errors such as typos as well.

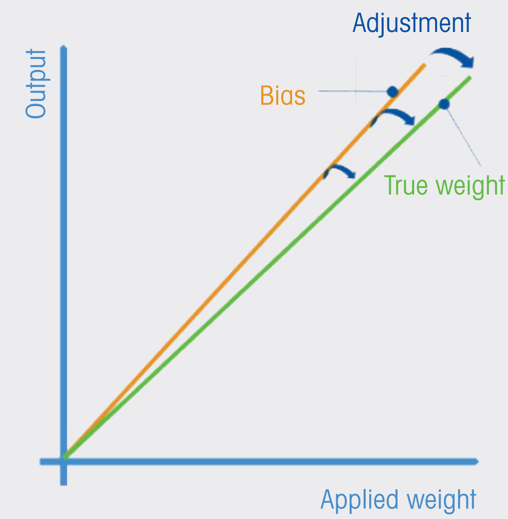

Figure 4.2

Weightless calibration can adjust the slope of the sensitivity to a more ideal position but is not considered a calibration

Organization efforts
This method has no organizational effort, as it can be done in a matter of minutes and in fact can be done remotely before the equipment is installed.

Estimating costs
Very low costs are involved with this method; it is only the time to enter the sensor sensitivity data into the terminal.
Production downtime
It is a very fast method, and it is used at time of installation, so there is no production downtime.

Transportation
There are no associated transportation costs.
Safety considerations
There are no equipment or human safety considerations involved. However, the consequential risks (high measurement uncertainty) based on potentially poor measurements resulting from this method shall be considered.

Sustainability
Fast method, no transportation, etc. involved. This is the most environmentally friendly method.

Use cases

- Case 1, 30-ton storage silo
  The electronic or weightless calibration can be used when the storage silo is installed to check the functionality of the terminal, but keep in mind the accuracy limitations. Since the storage silo is on a solid foundation, and no pipes are attached, the electronic calibration will work. However, if regular calibration is needed in the future, another method should be considered.

- Case 2, 150 kg active ingredient mixer
  For this tank scale, the weightless calibration cannot meet the required accuracy; therefore it is not recommended.

- Case 3, 10-ton production storage tank
  Upon installation, the weightless calibration serves as a functional check of the weighing terminal. Later on, to cover the effect of connected devices on scale sensitivity, another calibration must be performed.

- Case 4, 5-ton batching tank, FAT at system integrator
  The weightless calibration can be used at the system integrator's facility to prove basic functionality (FAT). When the tank scale is delivered and installed at the final location, a formal calibration should be performed. Only in this case will be the effect (potential inaccuracies) of pipes, pumps and foundation be accounted for in the calibration.

Weightless calibration - pros	Weightless calibration - cons
• Fast startup for tank designers and control system integrators • Helps speed up installation/commissioning • Very fast • Low cost • No material contamination risk • Environmentally friendly • Available on most weighing devices • Ideal for large storage tanks and silos	• Not recognized as calibration by any legal or quality organizations. • No traceability to a national or international standard • Opens user to risks in quality management if no other approach is employed • Does not confirm system performance • Does not test trueness and repeatability; therefore, not accurate • Improper use or operator mistakes force errors into the system • Not useful after initial use

4.3 Material Substitution

How does it work?

Material substitution has been used traditionally in instances where not enough test weight is available. This method relies on the use of a small amount of test weights and a stable material that may be added to the scale. Material substitution is recognized by many authorities for scales with over 20-ton capacity because availability and handling of such large amounts of test weights is difficult and expensive.

In the first step, the tank is loaded with known test weights as shown in Figure 4.3. In this example, we took 4,000 kg of test weight and the scale is adjusted at 4,000 kg. In the next step the weights are removed and the substitute material is added until the scale reads 4,000 kg as shown in Figure 4.4. Then weights are reapplied as shown in Figure 4.5 and the scale is adjusted at 8,000 kg.

This process, the loading of weights, adjustment of the scale, removal of the weights and filling of substitution material, is repeated until the capacity of the vessel has been reached when the final adjustment is done. E.g., to reach the full capacity of Use Case 1, the 30-ton storage silo, eight substitution steps using 4,000 kg test weights are required to adjust the scale at full capacity.

Things to consider

In many industries, some form of purified water is used in production, and it is used for calibration to avoid contamination. This is costly, especially if it is WFI (Water For Injection). If mains water is used, the tank may need cleaning and drying before production can restart. The mains water used may be recycled or disposed of once it is treated for disposal.

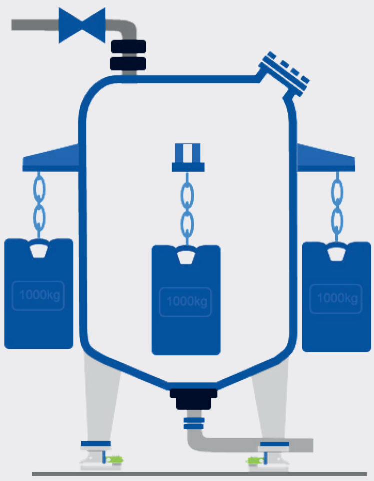

Figure 4.3

First step of material substitution: apply weights. Here the indicated weight is 4,000 kg

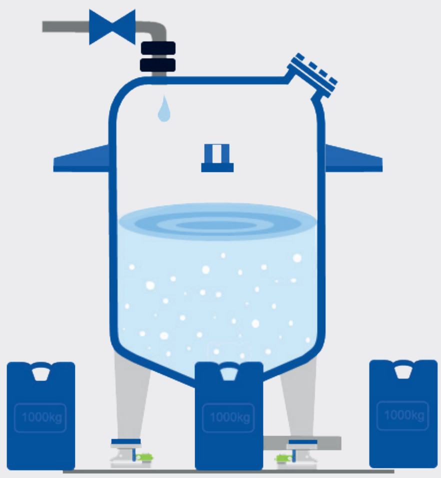

Figure 4.4

The second step of material substitution: water purified for injection is added until the indicated weight is 4,000 kg

Figure 4.5

Weight is loaded again. The accumulated weight should be 8,000 kg

When water cannot be used as substitution material, another material must be used (e.g., oil or alcohol).

As noted above, for scales used in Legal-for-Trade applications, calibration by material substitution is allowed in certain circumstances but with restrictions on the number of substitutions that can be made.

Accuracy
The accuracy of material substitution calibration depends on the accuracy class of the available test weights, the repeatability of the scale and the number of substitution steps. The higher the number of steps, the lower the achievable accuracy due to accumulated measurement uncertainties. The typical accuracy achievable with the material substitution method varies between 0.03 and 0.5%.

Organization efforts
Test weights, substitution material and a means for loading/unloading are prerequisites. The benefit is that less weights are required compared to calibration with test weights. The substitution material must be available in quantities to fill the tank to capacity (or to the desired calibration load). Furthermore, the cleaning and drying of the tank before and after the calibration must be organized, if required.

Estimating costs
Test weight rental and transportation costs, substitution material cost, cleaning and drying, recycling, or disposal of the substation material all add to the total cost of calibration. Labor cost and production downtime also contribute to the total cost.

Production downtime
Depending on the tank scale capacity, the efficiency of the weight-lifting method and the number of substitution steps, the production downtime can be quite lengthy, counted in days rather than hours. In many cases, the material flowrate is low compared to scale capacity, making the procedure very time consuming. In the event cleaning and drying is needed, production downtime is even longer.

Transportation
Multiple parts must be transported, including test weights and substitution material, which create a logistical challenge.

Safety considerations
All safety considerations mentioned under calibration with test weights apply here (see Section 4.1). In addition, when cleaning and drying tanks, workers must closely follow safety guidelines; including the use of ventilation, protective equipment and breathing apparatus to avoid contact with hazards.

Sustainability

Transportation, cleaning of the tank, and recycling/disposal of the substitution material can make this calibration method environmentally unfriendly, depending on the characteristics of the effluent.

Use cases

- Case 1, 30-ton storage silo
  The availability of test weights defines the number of substitution steps. Typically, only one or two-ton test weights can be loaded on the scale. This creates a high number of substitution steps and renders the material substitution method impractical for many 30-ton storage silos.

- Case 2, 150 kg active ingredient mixer
  The tank scale capacity is relatively low, allowing load up to full capacity with test weights. Therefore, this method is generally not used for tanks under 2,000 kg.

- Case 3, 10-ton production storage tank
  For this tank scale the full capacity can be reached in four to five substitution steps, so the method is definitely worth considering.

- Case 4, 5-ton batching tank, FAT at system integrator
  The full capacity can be reached in two-to-three steps; however, the efforts are high just to prove that the tank scale is displaying weight values. For that purpose, another method (e.g., electronic calibration) is sufficient until the system is installed and another calibration method is selected.

Material substitution calibration - pros	Material substitution calibration - cons
• Effective method for high-capacity vessels when not enough test weight is available • It is recognized by authorities for certain scales at capacities of 20-tons and above (Legal-for-Trade applications) • Accuracy is enough for many processes depending on the measuring and production tolerances • Tests the entire system and is effective to verify the effects of piping and other objects attached to the scale • The first step of the process is traceable because certified (traceable) weights are used	• Inert material can be expensive and must be transported to the scale • Loading of the inert material can be cumbersome • Recycling or disposing of the substitute material and associated documentation can be expensive • Time required for the entire test • Repeatability testing is not as easy as using weights alone unless repeatability tests are performed with the known weights. This, however, will only test the scale at a lower capacity and not eliminate the possibility of errors at full scale capacity. • Accuracy of the method is dependent on the repeatability of the scale and the number of substitutions required

4.4 Material Transfer

How does it work?

The material transfer method relies upon a reference scale to weigh material which is then transferred to the scale to be calibrated. Ideally, the material would be weighed on a recently calibrated adjacent scale and transferred in a single step. In practice, the material is often weighed in a truck on a truck scale and then transported to the test site for calibration. This method is faster than calibration by test weight or material substitution but depends on the accuracy of the reference scale and complete transfer of the weighed material.

Things to consider

As with the material substitution method, the material must be compatible with the process equipment and then treated and disposed of. The transfer system and the calibrated tank must be cleaned following the transfer once the material is discharged. With this method, it is difficult to perform repeatability tests, which makes it a less accurate form of calibration.

Accuracy

The accuracy of material transfer calibration depends on the accuracy of the reference scale used to weigh the transferred material, and on the completeness of the transfer process (e.g., how much residual material remains in the transfer equipment, pumps, hoses, etc.). In many cases, a truck is used to transfer the material from the reference scale (the truck scale) to the tank scale to be calibrated. In this case, the reference weight can be adjusted for the fuel consumption between the first and second weighments of the truck. Accuracy will suffer if the reference scale capacity is large compared to the scale to be calibrated. Likewise, if the material must be weighed and transferred in several drafts, accuracy may suffer. In practice, typical accuracies are 0.5 –1%.

Organization efforts

The transferred material must be organized, weighed and transported to the tank scale location. Equipment is needed to transfer the material to the tank completely. After calibration cleaning and drying of the tank and transfer system is likely needed.

Estimating costs

The cost of the transferred material, the transfer equipment, material recycling/disposal and tank cleaning and drying should be considered in addition to labor costs.

Production downtime

The tank scale is not operational during the material transfer, emptying and cleaning of the tank. Depending on tank scale capacity, the downtime varies between a few hours and a few days.

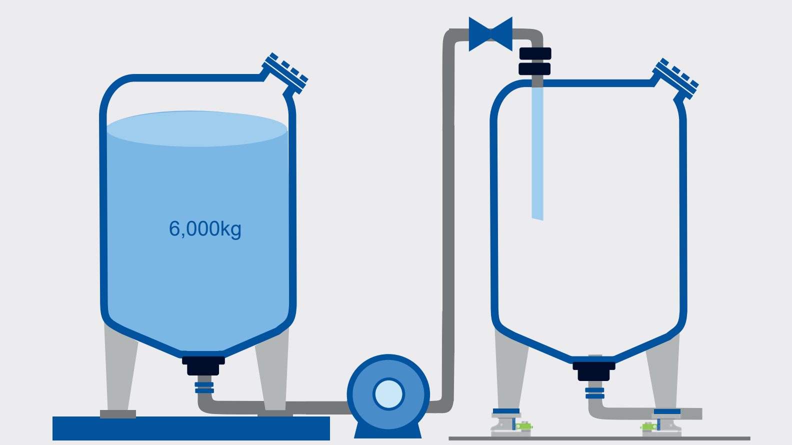

Figure 4.6

A known weight is being transferred from one scale (the reference scale) to the tank scale to be calibrated

Transportation

The transferred material must be transported to the tank scale.

Safety considerations

With this method no heavy weights are lifted, so it is safer than the calibration with test weights or material substitution. Of course, general workplace safety rules must be followed.

Sustainability

The transportation and material recycling or disposal must be considered when the method's sustainability is determined. The environmental load can be high depending on the amount of material used and disposed of. Fuel consumption must also be considered when the material is transported by truck.

Use cases

- Case 1, 30-ton storage silo
  The material transfer calibration method is well suited for the storage silo. If the material can be brought to the silo in one batch, e.g., by a truck, then the silo can be calibrated in one run. The required 1% weighing tolerance can be achieved with this method.

- Case 2, 150 kg active ingredient mixer
  Material transfer is not the right calibration method for this tank scale, as the accuracy is not sufficient. Even if the accuracy was sufficient, the cleaning of the tank after the material transfer would need to be thorough.
  Figure 4.6 A known weight is being transferred from one scale (the reference scale) to the tank scale to be calibrated.

- Case 3, 10-ton production storage tank
  The required accuracy for this tank scale is 0.5%, so the material transfer calibration is a suitable method. Care must be taken that the reference scale has a good accuracy (e.g., a floor scale with similar capacity, as a truck scale might not work), and there are no remains in the transfer system (in the pump, pipes, etc.).

- Case 4, 5-ton batching tank, Factory Acceptance Test (FAT) at system integrator
  It is a good calibration method for this factory acceptance test. The five-tons of material can be pumped relatively quickly (depending on the pumping rate), and the functionality of the scale is proven under similar conditions to normal operation. Keep in mind, though, that piping influences of the final installation onsite are not considered during the Factory Acceptance Test (FAT)

Material transfer calibration - pros	**Material transfer calibration - cons**
• Effective method for high-capacity tanks when test weights are not practical and a sufficient scale is available • Accuracy is sufficient for many processes • Tests the entire system and is useful to verify the effects of piping and other objects attached to the scale except during an FAT	• Material may be expensive and must be transported • Some material may be left in the transfer system resulting in error • Loading/unloading of the material may be difficult • Recycling/disposing of the material and associated documentation may be expensive • Time to complete the entire test • Repeatability testing is not practical • The accuracy of the reference scale must be higher than the scale to be calibrated. In many cases, a truck scale has a fixed higher readability (lower resolution) than a tank scale making it an undesirable choice as the reference scale. • It is not recognized for Legal-for-Trade scales

4.5 Calibration with Flow Meter

How does it work?

Flow meters can be used to calibrate tank scales. A known rate of flow through a flow meter over a defined time is equated to an absolute weight value. Like other methods (material substitution, material transfer), water is often used to fill the tank scale to be calibrated. This method can require hours and sometimes days to complete a calibration, depending on the size of the flow meter and capacity of the tank. This means that during the calibration cycle the tank cannot be used for production until it is filled, emptied, cleaned and dried. This method depends on an accurate flow meter, consistent material, temperature, and constant flow. This method is not recognized for calibration of legal-for-trade scales. The primary reason this method is chosen is convenience; this method works when other methods prove impractical.

Things to consider

Flow meters can be used only with liquids and special attention must be paid to the liquid (e.g., its temperature and tendency to foam or form bubbles). The selection of the flowmeter type is important, as is its operation for optimal performance.

Similar to other methods in which material is filled into the tank, care must be taken to avoid tank contamination and how the material will be recycled or disposed of to avoid contamination of the environment. The cost of water becomes a significant factor in industries using treated water, which is typically also used for calibration to avoid contamination.

Repeatability is typically not tested with flow meter calibration because of the cost of material and labor and the resulting production downtime.

Accuracy

Typical accuracies achievable in the field are between 0.5 and 1%, rather closer to 1%. Although much better accuracy figures can be found on flow meter datasheets, those are only valid under laboratory conditions (well-controlled temperature, relatively low flow rates, etc.).

Organization efforts

A calibrated flow meter must be available, along with the quantity of material required for the calibration. The required production downtime must be planned, along with the cleaning crew where that will be required.

Estimating costs

The material used for calibration can be a substantial cost, e.g., in the pharmaceutical industry where typically purified water, oil or alcohol must be used with costs starting at 1 USD (or EUR)/liter. For a 10-ton tank scale, the material cost alone could be 10,000 USD. If something goes wrong during the filling process and the calibration must be started again, costs escalate. Normally this process is supervised by a maintenance technician who must remain on-site during the entire process, which has been known to last up to a week. It is important to note that not only the tank must be cleaned but the flow meter and piping as well.

Production downtime

If purified water is not used, then downtime must be planned for the cleaning operation before and after the calibration, not to mention the calibration time itself. Altogether, this can take a week or even longer for high-capacity tank scales in very clean, high-risk operations.

Transportation

The material must be transported close to the tank scale with the flow meter. The recycling and disposal of the calibration material might require additional transport. In some cases, a water purifier is installed on-site, but availability is still an issue, as other departments might require water at the same time.

Safety considerations

With this method it is not necessary to lift heavy weights, making it safer than calibration with test weights or material substitution. Of course, general workplace safety requirements must be fulfilled.

Sustainability

Similar to the material transfer method, transportation and material disposal are considered when the method's sustainability is considered. The environmental impact can be high depending on the amount and type of material used and recycled or disposed.

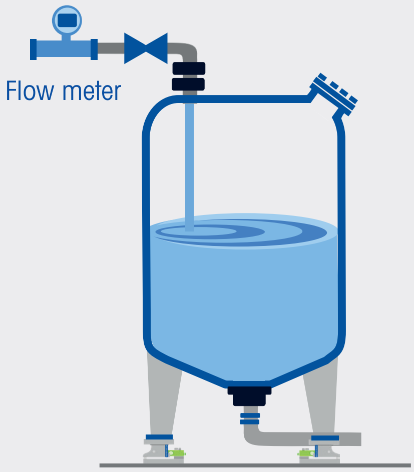

Figure 4.7

Inert liquid is added over time until the expected quantity is filled

Calibration with flowmeter - pros	Calibration with flowmeter - cons
• Effective method for high-capacity vessels when not enough test weight is available • It is not recognized for Legal-for-Trade scales • Accuracy is adequate for many processes depending on the measuring and manufacturing tolerances • Tests the entire system and might verify the effects of piping and other objects attached to the scale • It is usually safer for the maintenance personnel due to low interaction with the system	• Inert material is expensive and must be transported in select cases • Flowmeters are generally less accurate than scales and must be sent out for calibration regularly • Loading of the inert material in the tank poses a contamination risk • Disposing of the material and associated documentation • Time for the entire test - this is usually the calibration that takes the longest time to complete • Repeatability testing not possible • Some processes cannot use water, so instead more expensive materials like oil, glycerin or alcohol must be used • Can be used with liquids only

Use cases

- Case 1, 30-ton storage silo
  With careful preparation and execution, the flow meter calibration can fulfill the 1% accuracy requirement. Calibration with a flow meter is one of the methods considered when such a high-capacity tank scale must be calibrated.

- Case 2, 150 kg active ingredient mixer
  Due to the high accuracy requirements, calibration with flow meter is not a viable option for this scale. In addition, pumping material into the tank and then disposing of it would create contamination risk.

- Case 3, 10-ton production storage tank
  The required accuracy for this tank scale is 0.5%, which is at the lower end of the flowmeter calibration method's accuracy. It is likely, that this method will not be sufficient to fulfill the requirements when you consider a safety factor.

- Case 4, 5-ton batching tank, FAT at system integrator
  This method is well suited to calibration for factory acceptance test. The five-tons of material can be pumped relatively quickly (typically in a few hours, depending on the pump speed and volume), and the functionality of the scale is proven under conditions similar to normal operation (the scale is loaded with material inside the tank).

4.6 Hydraulic Calibration using Traceable Standards

How does it work?
METTLER TOLEDO's RapidCal™ Calibration system is a pull-down hydraulic calibration system. RapidCal creates the same load conditions that occur during normal weighing operation and accounts for product weight and attachments (pipes). The tank structure is pulled down against firm anchor points mounted to the foundation. Other hydraulic calibration methods lift the tank during calibration, thus unloading the sensors (load cells). This lifting of the tank introduces a serious and unnecessary tipping hazard during the calibration. The whole tank scale (and it must be filled up to full capacity!) is supported only by hydraulic jack-up cylinders that pose a safety risk to your facility. Furthermore, lifting the scale is not an accurate calibration method, as it does not account for piping influences.

METTLER TOLEDO's hydraulic calibration method ensures accurate calibration without the significant safety concern. RapidCal allows in-place calibration without a lot of heavy equipment that poses safety concerns for the persons who perform the calibration. It uses traceable, high-accuracy reference load cells that measure downward force. Tanks do not need to be full as with other hydraulic methods.

Moreover, like test weight calibration, RapidCal is non-invasive; the calibration equipment is attached to the outside of the tank scale only. The tank remains part of a closed system with no danger of introducing contamination, no need to clean the tank before or after calibration, and no material to be treated and disposed of after calibration. As with test weight calibration, lugs must be added to the side of the tank or vessel, and anchor points must be added to the floor or sub-structure. These lugs can be added to the tank during manufacture or can be retrofitted later, although the former is preferable.

This calibration type is beneficial in areas where tanks are very close together, inside a bund wall or on a mezzanine where it difficult or impossible to gain access with test weights.

Things to consider
This method is quite accurate for production environments. The measurement uncertainty for this type of calibration is documented and a calibration certificate issued. This certificate can be used in quality systems as evidence that the tank scale was adequately calibrated and is traceable. Note that RapidCal is a new technology and not approved for Legal-for-Trade scales at this time.

The required anchor points for this calibration method can be designed-in during the initial tank scale and foundation design; in most cases it is possible to upgrade existing tank scales. It is best to work with the original tank and facility designers to make this upgrade based on drawings from METTLER TOLEDO.

Accuracy
METTLER TOLEDO's RapidCal calibration method provides 0.1% accuracy throughout the calibration range 1 – 32-tons, covering most accuracy requirements and tank scale capacities.

Organization efforts
Compared to other calibration methods, organizing a calibration with hydraulic equipment is relatively easy. An appointment can be scheduled with the trained service team for a time when the tank can be withdrawn from production and is largely empty. Transportation of the equipment, installation on the tank scale and the calibration itself are performed by the technicians, leaving the tank in the same condition it was found in and ready to reenter production.

Estimating costs
Beside the invoiced calibration and the relatively short production downtime, no other costs are involved.

Production downtime
A typical hydraulic calibration process can be completed in a matter of hours (2 – 3 hours) and perhaps faster when tank scale surroundings provide clear and easy access for the technician.

Transportation
The calibration equipment can be transported in a large car, SUV or pickup and readily moved into position in its wheeled cases.

Safety considerations
Access to the area around the tank must be prohibited during the calibration process. Since hydraulic equipment is used, all relevant safety regulations must be adhered to.

Sustainability
The hydraulic equipment is hand operated and weighs a fraction of the weight of a conventional test-weight vehicle; only the fuel for transport needs to be considered. This calibration method has a very small environmental footprint, and the system can be used for many years.

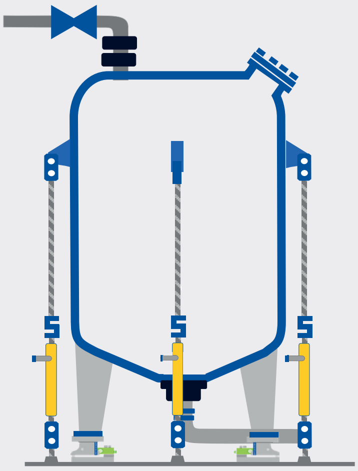

Figure 4.8

METTLER TOLEDO's hydraulic tank scale calibration method, RapidCal™

Use cases

- Case 1, 30-ton storage silo
  If the anchor points are available, the hydraulic calibration method is the most suitable way to calibrate this silo. Downtime is short, and calibration to scale capacity and accuracy requirements can be fulfilled without difficulty.

- Case 2, 150 kg active ingredient mixer
  For this tank scale hydraulic calibration is not suited. The tank scale capacity is well below the range where hydraulic calibration technically makes sense. This tank is better calibrated using test weights.

- Case 3, 10-ton production storage tank
  When anchor points are available, the hydraulic calibration is the most suitable method to calibrate this tank scale. The accuracy requirement is met and the piping effects are compensated for in the calibration. The customer benefits from very short downtime and a calibration process that is certified.

- Case 4, 5-ton batching tank, FAT at system integrator
  The hydraulic calibration can be used for the factory acceptance test; however, the tank scale must be firmly installed (e.g., bolted) to the foundation. This form of calibration tests the tank as specified and confirms acceptance to a traceable standard.

Hydraulic calibration - pros	**Hydraulic calibration - cons**
• Very accurate - facilitates both sensitivity and repeatability tests • Traceable to national and international standards through use of recognized precision components • Comes with an accuracy certificate including a statement of measurement uncertainty • Completed typically in 2 – 3 hours • Takes into account the effects of the entire system including measurement chain, all attachments including piping and (flexible) support structure • Easy transportation • Non-invasive, no product contamination risk • Lower contamination risk outside the tank in areas such as pharmaceutical production • Does not damage the environment	• Not recognized for Legal-for-Trade scales; otherwise good for all industrial applications • Requires aligned anchor points on the tank and on the foundation or support structure

5 **Calibration Methods:** Expected Results

Each method discussed has both pros and cons based on the case. The most important factor to consider is the measurement uncertainty specified for each method. Below is a table that provides the calibration uncertainty in percentages that allows you to compare the methods based on expected results. We have included dependencies that negatively affect these percentages if they are not minimized.

Reducing the time to calibrate leads to cost savings and higher productivity.

The time it takes to complete a calibration must be a key consideration due to production down-time and labor costs for the duration of the calibration and cleanup. Less time for the process allows for better up-time and allows you to calibrate more frequently if required.

Weightless calibration is the fastest method but not recommended for production equipment. In certain cases (e.g., for high-capacity storage silos, installed on firm foundation, and no pipes attached) this can be a good way to install the tank scale. However, it is not a true method of calibration.

Calibration with test weights is the best method when accuracy is paramount. Hydraulic calibration is the winner when calibration time and maintenance of uptime is considered, and, like weights, it is non-invasive in contrast to other forms of calibration.

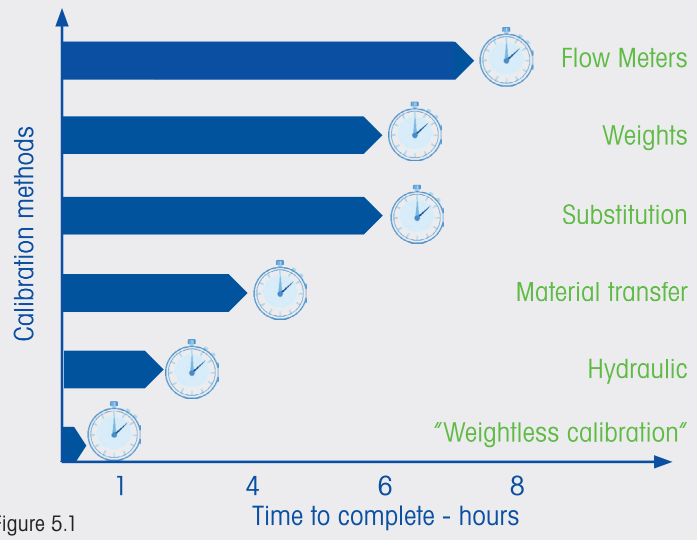

Figure 5.1

Comparing time for calibration

Reducing the time to calibrate leads to cost savings and higher productivity

6 **Summary:** Calibration Considerations

Each of the above methods has advantages and disadvantages, such as quality of the result, cost, downtime and safety. You should choose the method that best fits your individual situation, including the type and capacity of tank you use and available logistics.

Below is a summary of the key considerations when selecting a tank-scale calibration method:
- Expected accuracy of the calibration method: Does the method support your process measurement goals?
- Traceability including a calibration certificate with statement of uncertainty as a proof of "fit for use": Is this helpful for your process quality or for meeting regulatory guidelines?
- Personnel: Are qualified personnel available to perform the selected method?
- Frequency: Will the method support your requirements and associated risks?
- Weights and measures requirements, if any: Will the method support Legal-for-Trade standards, if your application requires compliance?
- Costs and environmental impact: Will equipment required to move test materials be ready, and will it use resources?
- Accessibility of the scales: Is there enough space surrounding the tank scale (for external methods)?
- Risks of the procedures: Are the safety of the process and personnel optimized?
- Cleanup: Is the tank contaminated with inert materials that must be cleaned out and disposed of?
- Environmental impacts: Is recycling and disposal of inert materials including environmental impact and documentation required?
- Downtime and opportunity cost: How much time is required to complete the process (and clean and dry the tank, if required)?
- Materials: Are the materials required to perform the calibration available?

	Weights	**Weightless**	**Substitution**	**Material Transfer**	**Flow Meter**	**Hydraulic pull down e.g. RapidCal**
Calibration Uncertainty %	0.01 – 0.03%	Typ. 1 – 2% (in ideal case 0.1%)	0.03 – 0.5%	0.5 – 1%	0.5 – 1%	0.05-0.1%
Dependencies	Weight tolerance varies depending on weight class	-	Weight tolerance and material stability	Source scale and material remaining in transfer system	Quality of the flow meter/ consistency of material used/ temperature	System alignment/qualified equipment
Legal for trade	Yes	No	Sometimes	No	No	No
Traceable method	Yes	No	No	No	No	Yes

It is important to remember that weightless or electronic calibration will not confirm that the scale operates according to your specifications because it does not test the system as used and does not assess problems that can occur due to poor installation, damage, attached devices, or weak structures/foundations, and it will not reflect problems resulting from spilled materials or waste that block free movement of the tank scale.

Internal calibration methods like material substitution, material transfer and flowmeter are valid methods, but they are not traceable, and they are invasive. The latter makes them less attractive to many operators who must pay for the pure and inert materials that must be disposed of afterward calibration is complete.

If you are looking for high accuracy and traceability, test weights are perfect as long as transportation resources and operator safety are taken into account.

If you are looking for accuracy and traceability and would like to reduce losses caused by production downtime and potentially the costs of gathering and transporting a high amount of test weight, hydraulic calibration is likely the best choice.

Both test weights and hydraulic methods allow you to test trueness, linearity and repeatability; moreover, they are non-invasive and do not require cleanup afterwards.

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Further Reading:

White Paper: "ISO9001:2015 and Weighing – Managing Risk and Quality".
METTLER TOLEDO ©05/2017

Webinar: „Optimize calibration efforts with risk-based analysis", April 2017,

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