Weighing Guideline



Successful Integration of Weighing

For Tanks, Vessels, and Reactors

METTLER TOLEDO

Contents

1 Executive Summary 5

2 Weighing – The Most Versatile Technology 6

3 Typical Process Scales 7

4 Select a Suitable Batching Process 8
Introduction 8
Simultaneous Batching 9
Sequential Batching 9
Accumulative Batching 9
Summary 10

5 Understand Technology Basics 12
Magnetic Force Restoration 12
Strain Gage 13
PowerMount™ 14

6 Select the correct Weighing Sensor/Scale 15
Single-Point Load Cells 16
Bench and Floor Scales 17
Compression Load Cells and Weigh Modules 18
Tension Load Cells and Weigh Modules 20

7 Tips for Scale Design and Installation 21
Piping 21
Structural Support 22
Weighing Portable Tanks 23
Sensor Capacity 23
Calibration 24

8 Influence of Material and Feeder on Accuracy 26
Materials 26
Feeders 26

9 Speed versus Accuracy 27

Contents

10 Control Your Process 28

Filling Process 28
- Fast & Fine Feed 29
- Spill 29
- Jog 29

Control 30
Terminals 32
- A/D Conversion and Filtering 32
- Digital I/O 33
- Connectivity 33
- IND780batch 33
- IND780Q.iMPACT Controller 34

11 Chemical Reactor Vessels 35

Reactor Types and Applicability of Weighing Technology 35
Dead Load 36
Multiple Fluid Systems 37
- Heating/cooling Fluids 37
- Atmosphere 37

Temperature 38
Vibration 39

12 Certification Requirements 40

13 References 41



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Why Read this Guideline?

The guideline addresses end-users who plan on purchasing process tanks and vessels, as well as machine builders, helping them to assess their current process equipment and to evaluate alternative solutions.

For end-users, the guideline provides an overview of the more common terminology and technologies and especially the advantages and disadvantages of each. This will allow informed dialogue with potential vendors and be useful in creating professional requests for quote.

Machine builders can gain useful information to optimize the performance of their process equipment. It also helps explain the relationship between speed and accuracy and other factors which influence overall performance of process scales.

Executive Summary

Controlling processes by weight has many advantages compared to volumetric methods, including accuracy and its facilitation of statistical process control and traceability. A huge variety of materials are processed including liquids, gases, and solids, and there is almost no end to the variety of processes to which they are subjected. Weighing is the one universal technology that can be used regardless of the material. METTLER TOLEDO, with its broad range of globally approved products and three weighing technologies, can meet the challenge of just about any process control requirement you may have.

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Weighing – The Most Versatile Technology

In many process industries, tanks or chemical reaction vessels are at the heart of the manufacturing operation. Accurate material transfers to/from them are important, if not critical, in maintaining product consistency, quality, and regulatory compliance. In addition, a scale can aid greatly in manufacturing efficiency by, for example, reducing material usage and scrap and maintaining accurate inventories.



Figure 1: Typical Tank Scale



Figure 2: Through-floor Tank Scale

Tanks and vessels can use flowmeters or weighing scales to control filling/emptying. Volumetric flowmeters suffer from a number of problems that can be avoided by weighing. Here are some advantages of weighing:

- Weighing technology is universal in that the same scale can be used to weigh liquids, solids, or gasses or any mixture of these.
- Unlike most flowmeters, weighing scales are unaffected by changes in material properties such as density, viscosity, entrained gasses, and foaming.
- The weighing equipment is not in contact with the material, so there is no degradation in performance due to corrosive or abrasive materials.
- A tank scale always tells you directly the mass of material present at any time; it does not depend on the computation of a value based on flowrate, time, and density for all individual material inputs and outputs. If the flowrate is erratic or stops unexpectedly, there is no uncertainty about the weight contained in a tank scale.
- Weighing is more accurate and can operate in a smaller tolerance band.
- Weighing can be used in commercial (legal-for-trade) applications if required.
- Weighing equipment can be calibrated and checked in-situ; there is no need to send the equipment away for costly calibrations.

Weighing, of course, has some limitations and these will be discussed below. This guideline is focused on small- to medium-sized process tanks and vessels and how weighing technology can be applied successfully to them. Process tanks and vessels are typically associated with the handling of liquids, but gases and solids may be added as well; however, the output is usually a relatively free-flowing liquid or slurry.

Typical Process Scales

Figure 3 illustrates a typical tank scale in which the tank sits on weigh modules connected to a terminal. The terminal monitors the tank weight and controls the filling valves. Such a scale is referred to as a weigh-in or gain-in-weight scale, and is typical of that used for batching operations. A tank scale can be stand-alone as shown, or it may be integrated in various ways into a larger system that includes, for example, a Programmable Logic Controller (PLC).

Figure 4 is identical except the terminal controls the discharge valve. This is referred to as a weigh-out or loss-in-weight scale. Here, the scale might be used to provide a certain weight of material as quickly as possible to fill containers, or it might provide material at a controlled flowrate to a downstream process.

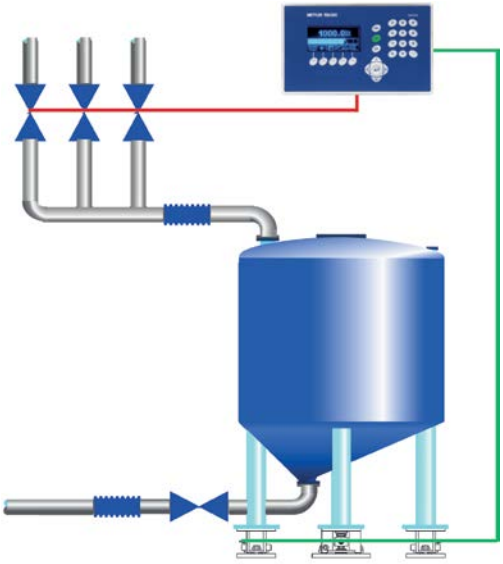


Figure 3: Weigh-In Tank Scale

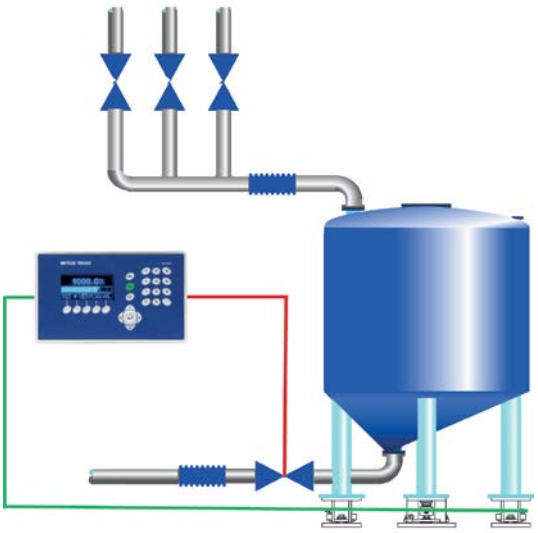


Figure 4: Weigh-Out Tank Scale

The terminal can also control both the input and discharge flows. In a typical application, the tank scale might be used in weigh-in mode to add various materials to create a batch. Then, after mixing it, it might be used in weigh-out mode to fill containers for shipment. Some terminals can control the filling and/or discharge of several tank scales simultaneously. However, for a single scale, only one material can be transferred (either fill or discharge) at a time. This is one of the limitations of weighing technology, making it best suited to batch processes.

Select a Suitable Batching Process

Introduction

Process manufacturing applications are often classified as continuous or batch. Continuous process manufacturing is characterized by a continuous flow of raw materials and transformation of the materials into a finished product while they are still moving. These are typically high-volume industries to justify a process dedicated to one product. Examples include cement production, oil refining, and electricity generation. Batch process manufacturing is characterized by raw material flow that is discontinuous, transformation of the raw material in batches, and a flow of finished product that is discontinuous. Batch process manufacturing is typically lower volume with a variety of raw materials combined to produce a wide variety of finished product. Line change-overs are frequent. Many industries manufacture in batches, including the food, pharmaceutical, and chemical industries. Weighing technology is suited to batch processes and is widely used in these industries.



Batching methods can be classified as simultaneous, sequential, and accumulative. Each one has its strengths and weaknesses and influences greatly the system accuracy that can be achieved, as discussed in the following sections.

Simultaneous Batching

Simultaneous batching (also referred to as horizontal batching) requires one scale per raw material, as shown in Figure 5. Each material is weighed independently and discharged to a mixing tank or down-line for further processing. Since each material has its own scale, its capacity can be optimized for that material, thus producing highly accurate results. It is also the fastest method as all materials can be weighed simultaneously. On the other hand it has the highest capital equipment costs. See the summary below for a complete list of advantages and disadvantages.

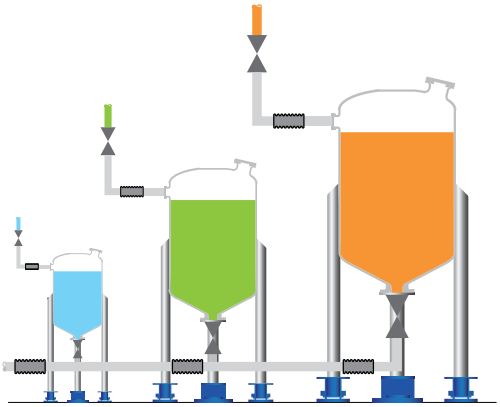


Figure 5: Simultaneous Batching

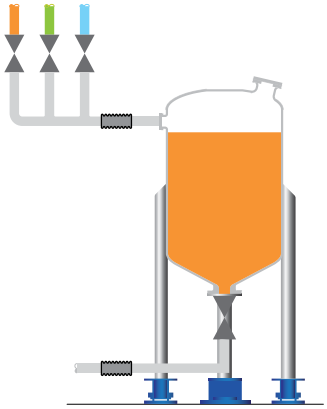


Figure 6: Sequential Batching

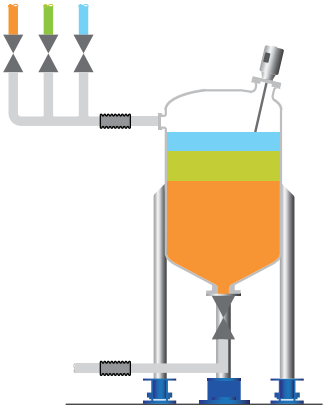


Figure 7: Accumulative Batching

Sequential Batching

In sequential batching (see Figure 6), a single tank scale is used to weigh and discharge each ingredient in sequence. The various materials may be accumulated in a separate mixing tank or sent downstream for further processing. The advantages are smallest physical size and lowest cost. The major drawback is that it is the slowest in operation.

Accumulative Batching

In accumulative batching (also referred to as vertical batching) the scale arrangement is identical to that used in sequential batching, but it must be large enough to accumulate the entire batch (see Figure 7). Each material is filled in turn and accumulated in the tank until the batch is complete. The major advantage is that all materials are present in the tank and further processes such as mixing and dissolving can be carried out without additional equipment. The disadvantage is that the scale capacity is the largest and least suited to weighing the minor ingredients, so it has the lowest accuracy.

Summary

The advantages and disadvantages of the three methods are summarized in the following table:

Comparison of Batching Methods

Parameter	Method		
	Simultaneous	**Sequential**	**Accumulative**
Scale capacity optimized per material[1]	+++	++	+
Accuracy[2]	+++	++	+
Speed of Operation	+++	+[3]	++
Lowest Scale Cost	+	+++	++
Lowest Control Complexity	+	+++	+++
Smallest Scale Size	+	+++	++
Lowest risk of cross-contamination[4]	+++	+	+
Further Processing possible in Scale	n/a	n/a	+++
No additional mixing tank Required	?[5]	?[5]	+++
Materials remain isolated until acceptance of batch[6]	+++	No	No
Scale(s) must be accurately calibrated[7]	Yes	No	No

Table 1

Notes:

1: Especially important to accuracy when the raw material proportions vary widely in a recipe.
2: Especially true when the raw material proportions vary widely in a recipe.
3: Speed is lowest in sequential batching because of multiple discharge cycles.
4: In a situation where all raw materials are not used in all recipes.
5: It depends on the down-stream process.
6: If something goes wrong during batching, it is more convenient to troubleshoot or rework the batch or to recycle the raw materials if they remain separated until final acceptance of the batch.
7: In simultaneous batching, all scales must be calibrated correctly to achieve correct proportioning across the scales. In sequential and accumulative batching, a poorly calibrated scale (that is otherwise functioning correctly, with good linearity, repeatability, etc.) will mean that the absolute weight of final product produced will be in error, but the proportion of each ingredient will be correct.

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Figure 8: Weighing hand-add materials off-line

In practice, combinations of these methods are often used to overcome the shortcomings of one particular method. For example, a system might have an accumulative tank for weighing the major ingredients while an independent sequential tank, discharging into the accumulative tank, might be used to weigh the minor ingredients.



K-Line Platform Scale with Magnetic Force Restoration Technology

The accuracy of all batching methods can be increased if minor ingredients such as flavors, essences, and dyes are weighed off-line on a suitable scale and added by hand. This is particularly attractive for solids as it avoids the need for a solids-feeding system on the tank. METTLER TOLEDO's highly accurate WMH or K-Line platform scales (discussed later) are often used in these critical weighing applications.

Understand Technology Basics

Magnetic Force Restoration

METTLER TOLEDO offers high performance Magnetic Force Restoration (MFR) technology with approximately ten times the accuracy of other weighing sensors which are described in the following sections. Figure 9 illustrates the parts of an MFR load cell, see Reference 4 for a description and comparison to strain gage sensors.

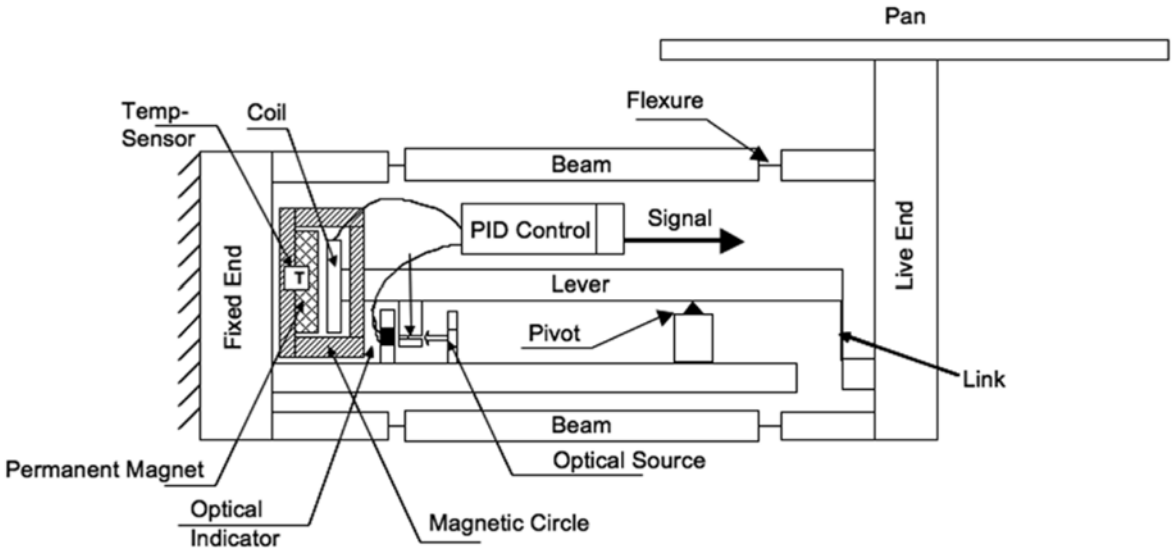


Figure 9: Sensor based on METTLER TOLEDO's MFR Technology



Magnetic Force Restoration (MFR) Load Cell with high resolution for best accuracy.



Magnetic force restoration load cell inside housing with IP66/67 protection.

Strain Gage

Load cells based on strain-gage technology are the most commonly used weighing sensor used in industrial scales. They are very versatile in that the same basic technology can be used with capacities ranging from 3 kg (7 lb) to 600 t or more. They also can be used individually or in multiples for bigger scales. METTLER TOLEDO provides weigh module hardware sets to make integration easier. These weigh modules are specifically designed to be accurate, safe, and robust considering today's installation and operating environments (see Reference 3). Metrology performance levels go up to OIML C6 and NTEP class IIIM 10,000 divisions.

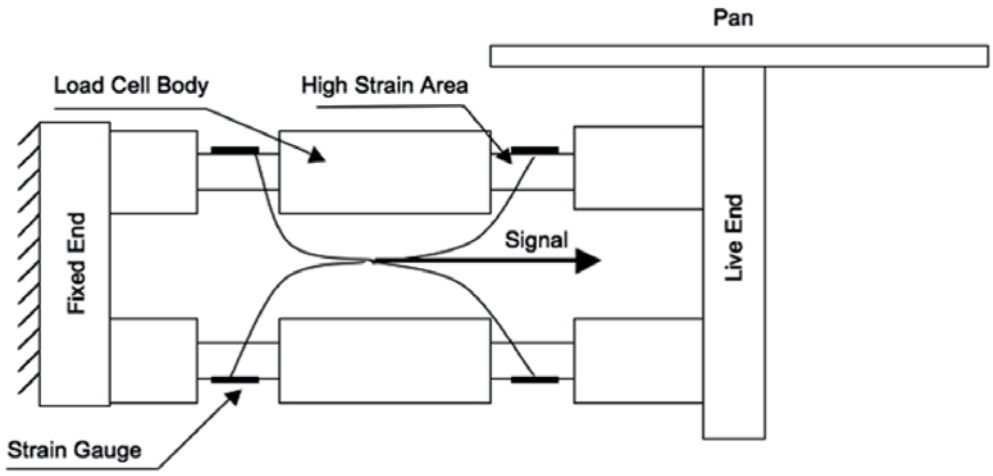


Figure 10: Sensor based on Strain Gages



Single Point load cell with strain gage technology. These load cells typically range from 3kg up to 2000kg (5lb to 4000lb).



Hermetically sealed beam load cell with strain gage technology. These load cells typically range from 5kg up to 5t (10lb to 10,000lb).



S-Type tension load cell with strain gage technology. These load cells typically range from 50kg up to 10t (100lb to 20,000lb)



Canister load cell for heavy capacity with strain gage technology. These load cells typically range from 7.5t up to 600t (15,000lb to 1,200,000lb).

PowerMount™

METTLER TOLEDO has manufactured digital load cells since the 1980's; these have become the gold standard in a number of industries. They are strain-gage load cells with an Analog/Digital (A/D) converter and microprocessor on board. They provide improved performance and functionality compared to conventional analog load cells. METTLER TOLEDO now offers this PowerCell technology in its PowerMount™ weigh modules. This has several benefits in process weighing:



PowerMount™ Weigh Module

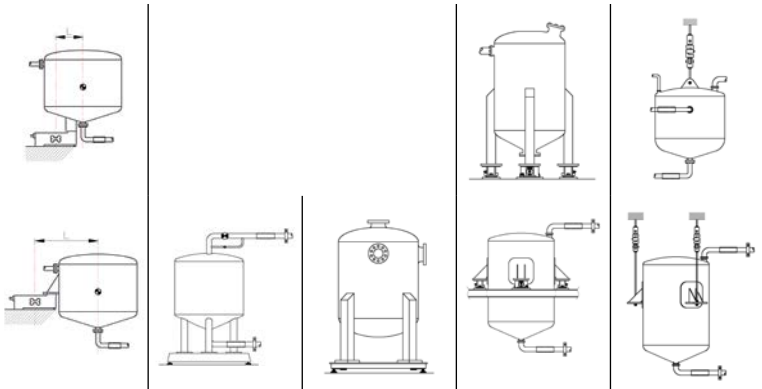
1. Predictive maintenance. The scale monitors each individual load cell and notifies the user if any part of the system is showing signs of impending problems.
2. No junction box and detachable cables. The PowerMount™ system works on a daisy-chained network cable running between the load cells. There is no junction box typical of analog systems, which often is the source of failures. Additionally, the load-cell cables are detachable, so they alone can be replaced if damaged.
3. Recalibration not required on component replacement. Digital load-cell outputs are matched very well, to the point where recalibration is not required if a load cell, cable, or terminal needs replacement.
4. Robust digital signal with high RFI/EMI immunity. Analog signal levels are very low. Each incremental step on the terminal display relies upon detecting a signal change of approximately 5 millionths of a volt (5 µV). PowerMount® uses CAN Bus for data transmission. It is a very robust +/- 5 V digital signal commonly used in the car industry.
5. Higher performance. With a microprocessor in each load cell, they are digitally compensated for higher performance up to OIML C10 and NTEP 10,000 III M levels.

See Reference 5 for a comparison between PowerMount and analog weigh modules.

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Select the correct Weighing Sensor/Scale

Tanks and vessels vary greatly in capacity and accuracy required, and there are several approaches to applying weighing technology to them. This is summarized in Table 2 and described in more detail in the sections that follow.



Column		1	2	3	4	5
Products based on MFR Load Cells		Single-Point Load Cell	Bench Scale	Floor Scale	Compression Load Cells or Weigh Modules	Tension Load Cells or Weigh Modules
Bench Scale, MFR	Max Scale Capacity: kg/lb	–	32 / 70	–	–	–
	Max Scale Size: cm/in	–	28x35 / 11x14	–	–	–
	Approval: OIML/NTEP	–	II 32, III 6.4 / II 32, III 10	–	–	–
Floor Scale, MFR	Max Scale Capacity: t/klb	–	–	3 / 6	–	–
	Max Scale Size: m/ft	–	–	1.5x1.5 / 5x5	–	–
	Approval: OIML/NTEP	–	–	III 6 / –	–	–
Products based on Strain-Gage Load Cells						
Single-Point Load Cell	No. of Load Cells/scale	1	–	–	–	–
	Max Scale Capacity: t/klb	1/2.2	–	–	–	–
	Max Scale Size: cm/in	See Below	–	–	–	–
	Approval: OIML/NTEP	C3/IIIS 5	–	–	–	–
Compression Load Cell or Weigh Module	No. of Load Cells/scale	–	–	–	3+	–
	Max Scale Capacity: t/klb	–	–	–	1000 / 2200	–
	Max Scale Size: cm/in	–	–	–	No Limit	–
	Approval: OIML/NTEP	–	–	–	C10 / IIIM 10	–
Tension Load Cell or Weigh Module	No. of Load Cells/scale	–	–	–	–	1+
	Max Scale Capacity: t/klb	–	–	–	–	25 / 55
	Max Scale Size: cm/in	–	–	–	–	No Limit
	Approval: OIML/NTEP	–	–	–	–	C3 / IIIM 5
Bench Scale	Max Scale Capacity: kg/lb.	–	600/1000	–	–	–
	Max Scale Size: cm/in	–	60x80/24x32	–	–	–
	Approval: OIML/NTEP	–	III 6/III 10	–	–	–
Floor Scale	Max Scale Capacity: t/klb	–	–	12 / 20	–	–
	Max Scale Size: m/ft	–	–	2x2 / 5x7	–	–
	Approval: OIML/NTEP	–	–	III 6 / III 5	–	–

Table 2

Single-Point Load Cells

Figures 11 and 12 show tanks mounted on single-point load cells. These load cells are designed to be used individually and to weigh within tolerance, despite lateral displacement of the tank's center of gravity. Single-point load cells are usually used in bench scales as shown in Figure 13 below; one load cell is centered under the weighing surface and their datasheets specify a "Max Platter Size" for this situation. When used as shown in Figures 11 and 12, it's best to place the tank's center of gravity along the load cell's longitudinal axis, and dimension L should not exceed half the maximum Platter size specification for the load cell.

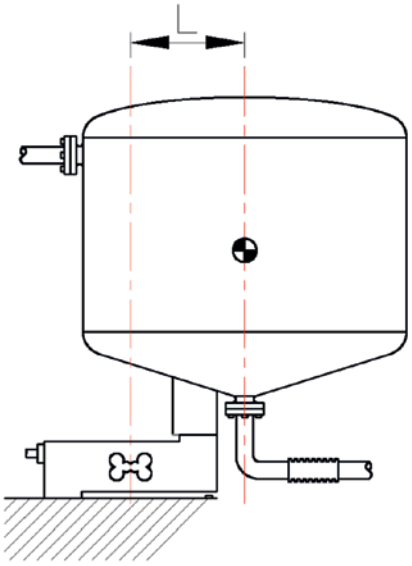


Figure 11: Small tank/vessel weighed on a single-point load cell

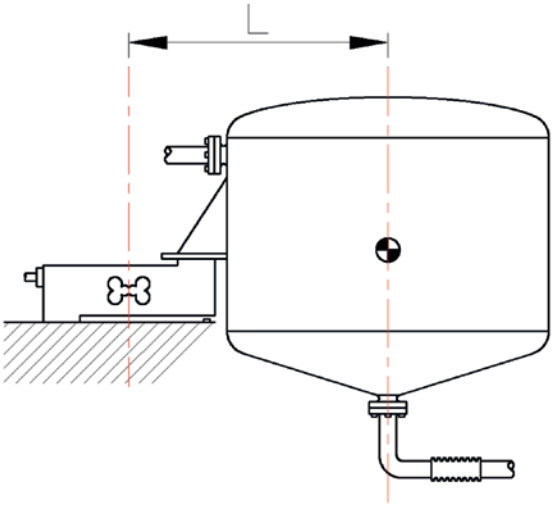


Figure 12: Small tank/vessel weighed on a single- point load cell offset to one side

For example, for load cell model MT1241, the Max Platter Size specification is 40x40 cm (16x16 in), which means that dimension L should be 20 cm (8 in) maximum for this cell. Be more conservative in selecting the load cell capacity as dimension L approaches this limit. The ideal situation would be where dimension L is zero, putting the tank's center of gravity right above the center of the load cell, but this is rarely achievable in practice. Use an overload stop to prevent damage to the load cell. With any scale mounted from a single point like this, provide a backup means to secure the scale if failure of the load cell or any hardware could cause damage or injury.

METTLER TOLEDO offers a complete range of single-point load cells with capacities from 3 kg (7 lb) to 2,000 kg (4,400 lb.) in various materials, protection levels, and with a full range of approvals.



Model MT1241 single-point load cell

Bench and Floor Scales

Figure 13 shows a small tank mounted on a typical bench scale while Figure 14 shows a larger tank mounted on a floor scale.

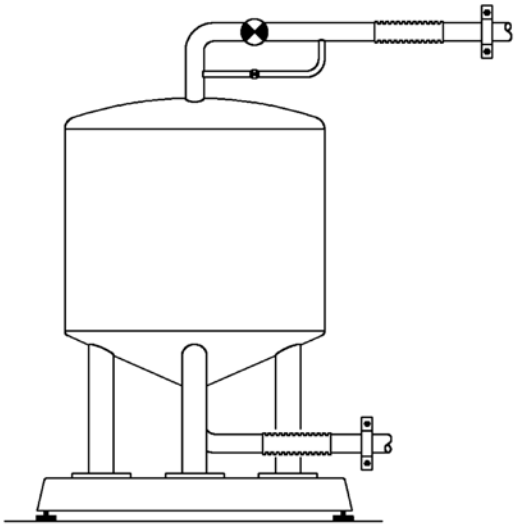


Figure 13: Small tank/vessel weighed on a bench scale.

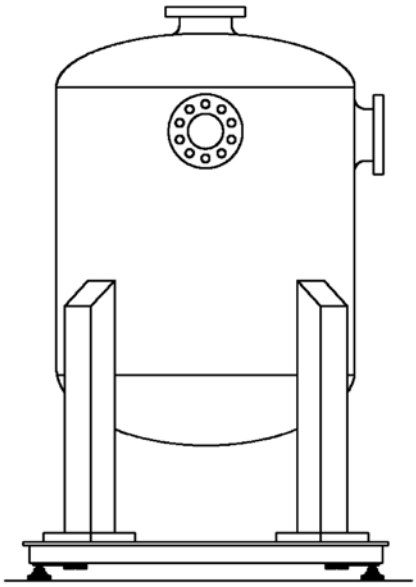


Figure 14: Tank/vessel weighed on a floor scale.

Floor scales can be mounted on the ground or in a pit, as shown in Figure 21. When bench or floor scales are used, the tank must be inherently stable against toppling as the scale cannot provide lift-off protection. Also, consult METTLER TOLEDO about where to best position the tank legs on the weighing surface.

Suitable products are models WMH or K-Line bases, which range in size from 20 cm (8 in) square and 3 kg (6 lb) capacity to 1.5 m (60 in) square and 3,000 kg (6,000 lb) capacity. With legal-for-trade approvals up to OIML and NTEP class II 32,000e, these products are approximately ten times more accurate than strain-gage based scales, and open up a new dimension in what can be achieved in tank weighing. They are available in hot-dipped galvanize or stainless steel, and have a built-in weight for routine calibration.



K-Line Bench Scale with superior MFR weighing technology



K-Line Floor Scale with superior MFR weighing technology

METTLER TOLEDO provides a complete range of standard industrial bench scales based on strain-gage technology with capacities up to 600 kg (1,000 lb) and floor scales with larger platform sizes and capacities up to 12 t (20 klb).



Bench Scale Model PBD655



Floor Scale Model 2256 VLC

Compression Load Cells and Weigh Modules

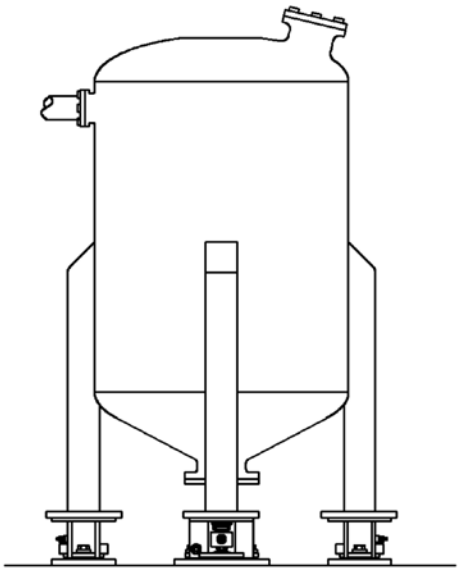


Figure 15: Tank weighed on Compression Weigh Modules

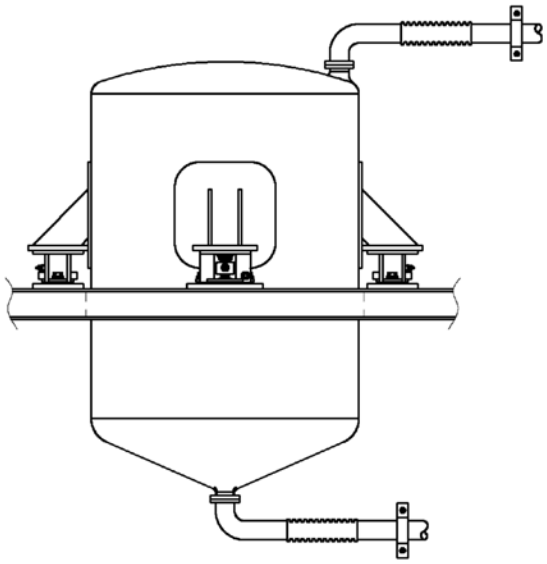


Figure 16: Tank weighed on Compression Weigh Modules, "through floor" method

Compression load cells and weigh modules provide the greatest versatility in applying weighing technology to tanks and vessels with the same basic concept applicable to tanks of capacity 10 kg (20 lb) to 1,000 t or more.

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MultiMount Compression Weigh Module with integrated traditional strain-gage load cell.



PowerMount Compression Weigh Module with integrated strain-gage load cell with on board micro processor.

At least three compression load cells or weigh modules must be used to stabilize a scale and typically four would be used on square or rectangular scales. They can be applied under tank legs (as shown in Figure 15), or in through-floor applications (as shown in Figure 16). Load cells can be used, but care must be taken to design the mounting and load introduction correctly to allow free thermal expansion and contraction. Mounting accessories are available to make the job easier, but all horizontal and vertical restraint must be provided externally. The easier approach is to use weigh modules where all such concerns have been addressed in the design of the module. In addition, PowerMount™ weigh modules can be used to take advantage of the many extra features available, such as predictive maintenance.



SLB215 beam load cell with threaded load introduction



Mounting accessories for SLB215 load cell to facilitate correct installation



0745A beam load cell with a blind load-introduction hole



Accessories for 0745A load cell for optimal load introduction and performance

Tension Load Cells and Weigh Modules

Tanks can be suspended from a single tension load cell or weigh module as shown in Figure 17 and Figure 18 shows a more typical situation in which a tank is suspended from three weigh modules.

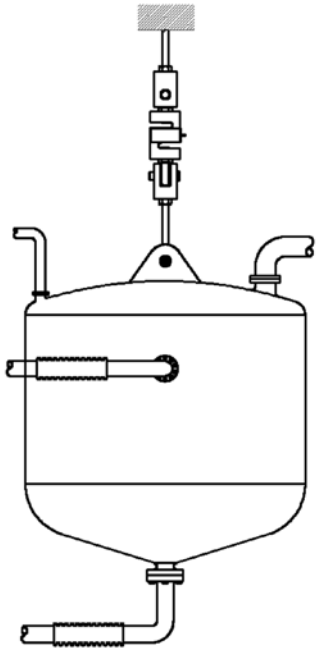


Figure 17: Small tank/vessel weighed on Tension Weigh Module

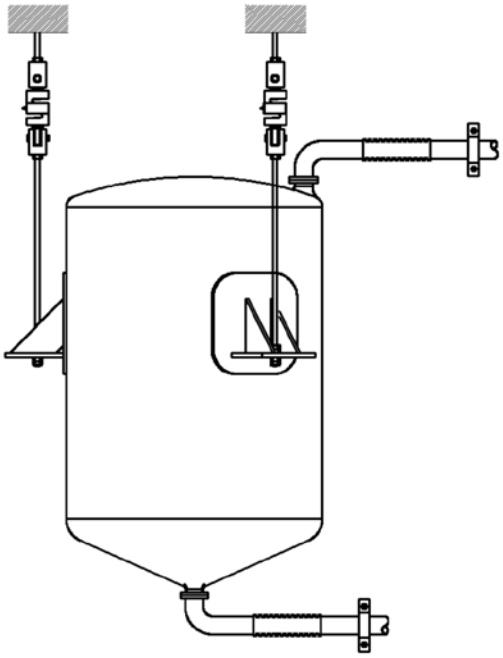


Figure 18: Tank/vessel weighed on Tension Weigh Modules

This mounting method can be convenient if an overhead structure already exists or the ground space under the scale must be kept clear. It is applicable for scale capacities from approximately 20 kg (45 lb) to 30 t.

Horizontal stabilizers are often required to prevent swinging. The accuracy is similar to that achievable with compression systems. Again, load cells can be used directly or weigh modules, such as SWS310, provide ideal load introduction conditions for greater convenience in integration.

Every suspended scale must have a safety backup such as chains, rods, etc. (not shown in Figures 17 and 18) to protect against any failure in the suspension system.



SWS310 Tension Weigh Module

Tips for Scale Design and Installation

Piping

Some tank scales do not have attached pipes and that is the perfect design where scale accuracy is concerned. Figure 19 shows such a scale where the tank is open-topped with four unattached inlet pipes; the outlet outlet pipe is also unattached and only connected as necessary. The accuracy of such a tank scale can approach the limits of the weighing technology used. Of course unattached pipes are not practical in many situations where, for example, the materials are hazardous, toxic, or the scale must be pressurized.



Tank with pipes unattached

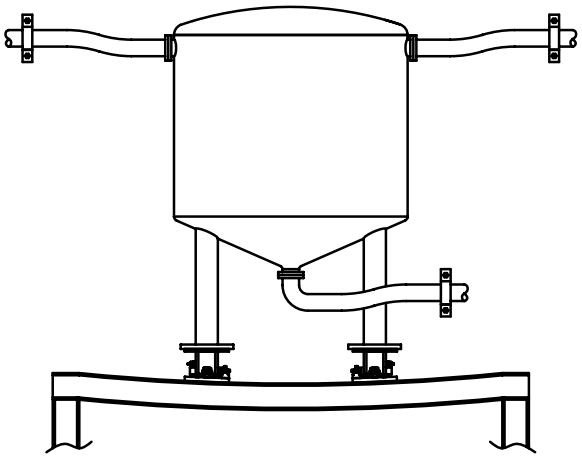


Figure 19: Deflection of a Loaded Tank with attached pipes

As soon as pipes are attached, you can expect weighing accuracy to be degraded. The reason is illustrated in Figure 19 which shows a loaded tank whose support structure has deflected downwards (greatly exaggerated), causing a corresponding deflection of the pipes. The pipes act like leaf springs applying a retarding force as the scale is loaded and deflects downwards. Depending on the stiffness of the pipes, the retarding force can be very large and can greatly diminish the weight registered on the scale. If the pipes were perfectly linear springs then it would be OK because the effect could be compensated by calibration. But pipes are far from ideal springs with slippage likely in the pipe clamps. So the result is a scale with poor linearity, hysteresis, repeatability and return to zero. Here are measures that can be taken to help:



Tanks with multiple attached pipes

1. Reduce scale deflection. Stiffen the support structure or, better still, mount the tank at floor level on a rigid concrete foundation. Note that load cells deflect by a small amount, typically 0.25 mm (0.010 in) at rated capacity, this is inherent to their design and cannot be avoided.
2. Reduce the stiffness of the pipes. Only connect horizontal pipes and use flexible hose sections or expansion joints.
3. Calibrate with weight. Calibrate the scale by one of the methods that applies load to the scale. This stretches the pipes so the scale terminal can "see" and compensate their attenuation effect on the weight signal.

In summary, first reduce the piping effects until they are in a reasonable range and linear, then calibrate with weight to eliminate the remaining effect. See Reference 1 for more details.

Structural Support

Structural support of tanks and vessels is an important consideration for both safety and accuracy reasons, and it becomes more of a concern as the capacity of the scale increases. Here are some of the reasons:

1. Vertical deflection of the scale with load exacerbates piping effects, as discussed above.
2. Variable stiffness of support points causes weight to be transferred between load cells and may cause inaccuracies and damage to the load cells.
3. Where several scales are mounted on the same structure, deflection can cause cross-talk between scales as they fill and empty.
4. The scale must be restrained so that the installation is safe under all conditions, routine and exceptional.

See Reference 1 for more information.

Weighing Portable Tanks

A portable tank can be weighed while standing on an in-pit floor scale (shown in Figure 20) and this is convenient where weighing needs to occur at just one work station. If a portable tank must have an on-board scale for use in multiple locations, then load cells or weigh modules can be incorporated into its frame (shown in Figure 21). Note that it's necessary to place a frame under the weigh module base plates as the casters will not be stable if attached directly to them (see Reference 1).

Piping and wiring connections to a portable tank must be done in a repeatable manner for good accuracy.

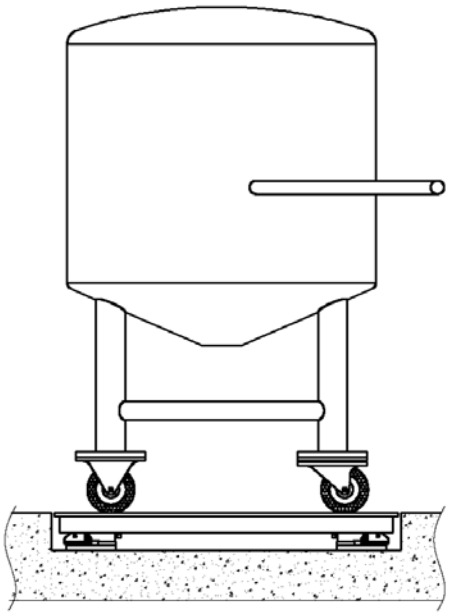


Figure 20: Portable Tank Weighed on Floor Scale

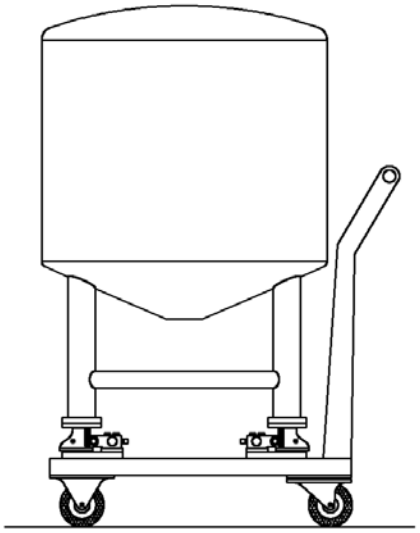


Figure 21: Portable Tank with on-board Scale

Sensor Capacity

It is important to pick the correct sensor capacity for the application. If it's too low, then the sensor may be damaged, too high and accuracy is sacrificed. The typical approach is to sum all loads applied to the sensor(s) including live load and dead loads (see also the section on Chemical Reactor Vessels), multiply this by a factor of safety (often 1.25) and divide by the number of load cells or weigh modules. Then pick a sensor with this or the nearest higher capacity. There are situations where you may need to be more conservative. These include situations where:

1. The loads (live or dead) are not certain.
2. A concentrated dead load (such as a mixer) is not evenly distributed.
3. Even load distribution is difficult to achieve, for example, with more than 3 points of support.
4. Wind or seismic forces can be expected.
5. The Load application point on the scale can vary.
6. The scale is subject to shock loading.

See Reference 1 for more information.

Calibration

There are various calibration methods available with a trade-off between accuracy on the one hand, and difficulty and cost on the other. Here is a description of the most important methods available, listed from most to least accurate.

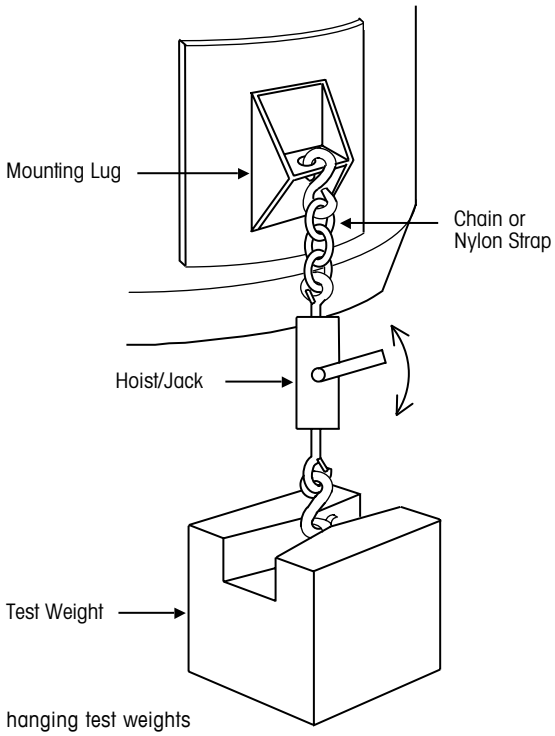


Figure 22: Tank calibration with hanging test weights

1. **Test weights.** Using test weight is the most accurate method and is required for calibration of commercial (legal-for-trade) scales. Calibration with weight is quite easy to do with small scales, but it becomes increasingly difficult and impractical as scale capacity increases. Tanks and vessels do not have a flat surface upon which to load the weights, so the loading method must be planned in advance; for example, provide lugs on the side of the tanks from which to hang weights, as shown in Figure 22.

2. **Material Substitution.** With this method, a small amount of test weight (5% to 10% of scale capacity) is required. The weights are applied to the scale and the scale reading noted. The weights are removed and material is "substituted" (added to the scale) until the scale reads the same value. The weights are added once more and the new reading, approximately double, is noted. The weights are removed and material is substituted once again until the noted value is again displayed. This process continues until enough material is present on the scale for calibration. This method is less accurate compared to using test weights and is quite laborious.

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3. **Material Transfer.** With this method, material (such as water) is weighed on a separate reference scale and is transferred to the tank/vessel in question for calibration. This method is dependent on the accuracy of the reference scale and the care taken to avoid material losses in the transfer. It can be highly accurate if the reference scale is a METTLER TOLEDO precision scale based on MFR technology and piping effects are minimized, as shown in Figure 23.

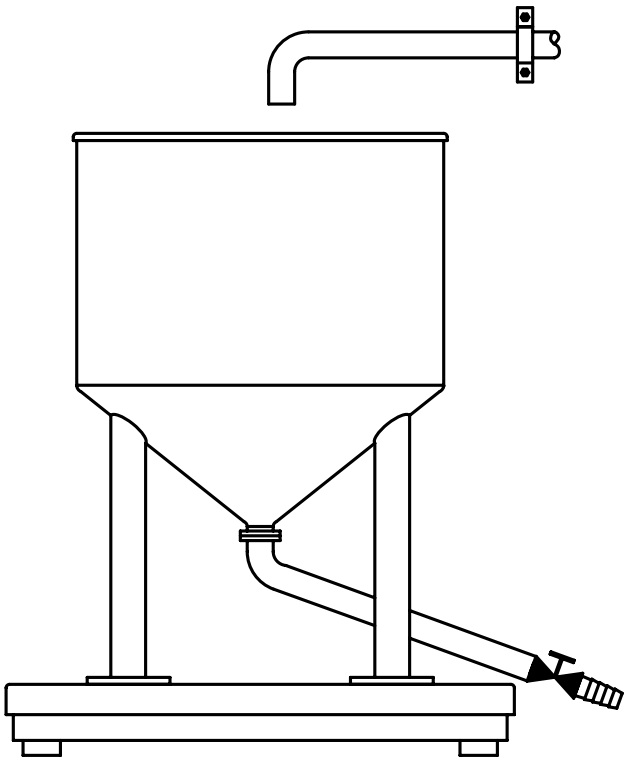


Figure 23: Reference Tank Scale

4. **CalFree™.** This is a theoretical calibration method available with some METTLER TOLEDO terminals. The load cell output values (provided with analog load cells) are averaged and entered into the terminal which automatically performs the calibration. This method can be done simply and very quickly but it has limitations. It cannot compensate for mechanical effects such as piping, or any attenuation of the load-cell signal due to cables, junction boxes, or intrinsically safe barriers in the circuit. Hence, the typical accuracy limit for CalFree is 0.2%.

In conjunction with digital PowerCell technology used in PowerMounts, CalFree™ Plus provides the maximum possible accuracy with theoretical calibration. The terminal reads the output values directly from the load cells and automatically performs the calibration. Junction boxes have been eliminated from the circuit and cables have no effect on the digital signals. Also, local variations in g, the acceleration due to gravity, are accounted for in the calculations. With a simple push of a button, the system is calibrated to the best possible accuracy for this method. The accuracy can be bettter than 0.1 percent if there are no mechanical effects such as piping.

See Reference 1 for more information.

Influence of Material and Feeder on Accuracy

Materials

Process weighing with tanks and vessels involves liquid materials primarily, but sometimes gases and solids are added to liquids. In those cases the final product is usually still a flowing paste or slurry. In trying to achieve higher accuracy, here are some material issues to consider:

1. The flow of material from bulk storage to the feeder device should be consistent and without interruption. That means that there should be sufficient buffer stock where production output can be intermittent.
2. Batching by weight is not strongly influenced by material properties when compared to other technologies; however, for the highest accuracy systems, minimize changes in material properties such as viscosity, density, and granularity. Regulate the temperature and moisture content of materials where flow characteristics are greatly affected by these.
3. Regulate the pressure of liquids upstream of filling valves. This is difficult to do by mechanical means; it is easier to maintain a static pressure head in a storage tank.
4. Maintain a consistent head of solid materials above feeders such as slide and clamshell gates.
5. Stop the batching process when material flow is sporadic. Restart only when a sufficient buffer has been re-established.

Feeders

The term feeder is used here in the broadest sense to mean devices that move and regulate material flow, e.g., a rotary gear pump driven by a stepper motor, and those that simply regulate the flow, e.g., valves. The manner in which these devices operate can greatly influence batch consistency and accuracy. Ideally, they would react and shut off material flow instantly, but at a minimum, their reaction and operating times should be constant and independent of material properties such as viscosity and particle size and hardness. Some feeders are inherently more accurate than others, but the choice may be limited as material characteristics often dictate the type of feeder. In trying to achieve higher accuracy, here are some feeder issues to consider:

1. Motor-driven devices tend to coast to a standstill, and this can be influenced by variation in material properties and equipment condition. It is best to use a motor with a brake for more consistent stops.
2. Air supplies to air-actuated devices should be conditioned and pressure-regulated to ensure consistent reaction and operation times.
3. Where two-speed filling is to be employed, it's usually more convenient if the feeder can do this by modulating the flow. Otherwise feeders of different capacities must be run in parallel and be selectively activated.
4. Where a jog function is to be employed, the feeder must be suitable for repeated momentary activation without damage.

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Speed versus Accuracy

Filling is a dynamic operation and, unfortunately, there is an inverse relationship between speed and accuracy, as illustrated in Figure 24. If fill speed is fast, then accuracy is low, and vice versa. The exact shape and scale of this graph will vary for each set of circumstances, depending on the weighing and feeding equipment used, the overall design, the material, and the environment. Note that as the filling speed reduces towards zero, the weighing accuracy approaches the expected static weighing performance of the scale equipment.

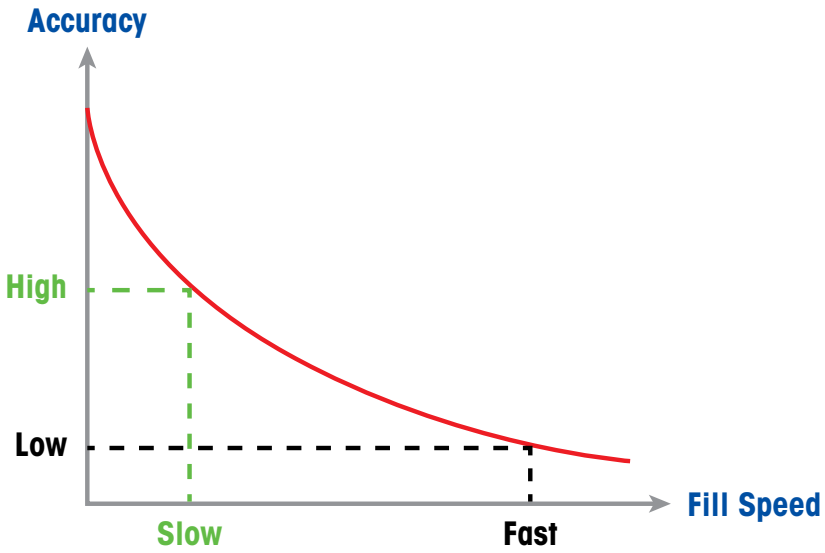


Figure 24: Fill Speed versus Accuracy

Once this characteristic is known, then a trade-off can be made in selecting the operating point that best balances the need for higher accuracy on the one hand, and higher fill speed on the other. Suggestions are made throughout this document on how to improve accuracy, here is a summary of the main points in achieving fast and accurate batches:

1. Choose carefully the batching method to be employed, especially when there is a large variation between the lightest and heaviest ingredients in the recipe. Look at hybrid systems and consider hand-add for critical ingredients. See the section entitled Select a Suitable Batching Process.
2. Choose a terminal with a high quality A/D converter and high internal update rate. You need highly accurate weight information and you need it very quickly if you are going to react in time at critical points in the filling cycle. High update rates sending just raw data is not as good as slower update rates with processed weight data with filter algorithms, the TraxDSP from METTLER TOLEDO, adapted to the process equipment and environment. Generally, filter algorithms developed by weighing equipment manufacturers are superior to those available for PLCs or other controllers.
3. Choose a terminal with a high Input/Output (I/O) bus update rate and feeders that react and operate quickly and are repeatable over time.
4. Control the environment (mechanical and electrical noise) and choose a terminal with sophisticated filtering that can be fine-tuned to the particular conditions.

5. Figure 25 suggests one way to improve the speed/accuracy conundrum. We can fill the majority of the tank at fast speed/low accuracy and then switch to slow speed/high accuracy towards the end. In other words, use two-speed filling, as discussed in more detail below. There is no penalty for having filled the majority of the tank at low accuracy, as long as we apply the brakes in time to finish at high accuracy. This has been the conventional approach to achieving an acceptable balance of speed versus accuracy in filling, and it is widely used today.
6. You can use a controller with advanced control algorithms that builds a real-time mathematical model for each fill and learns and compensates automatically. With these very sophisticated controllers it is possible to improve speed and accuracy while utilizing a simpler single-speed filling process. See the section IND780 Q.iMPACT Controller below.

Control Your Process

Filling Process

Figure 25 is a graph of fill weight versus time for a conventional two-speed filling operation. Some or all of these elements may be incorporated into a typical filling operation, depending on the accuracy required. At the top is shown a target fill weight with a ± tolerance band. The filling cycle can be broken down into several phases as illustrated. When the feeder device is first activated, the material flow takes some time to ramp-up to a steady flow in the fast-feed phase, which accounts for the majority of the fill time and weight. Beyond that are additional phases which refine the fill weight to ensure it is within tolerance. The various terms are explained in detail below.

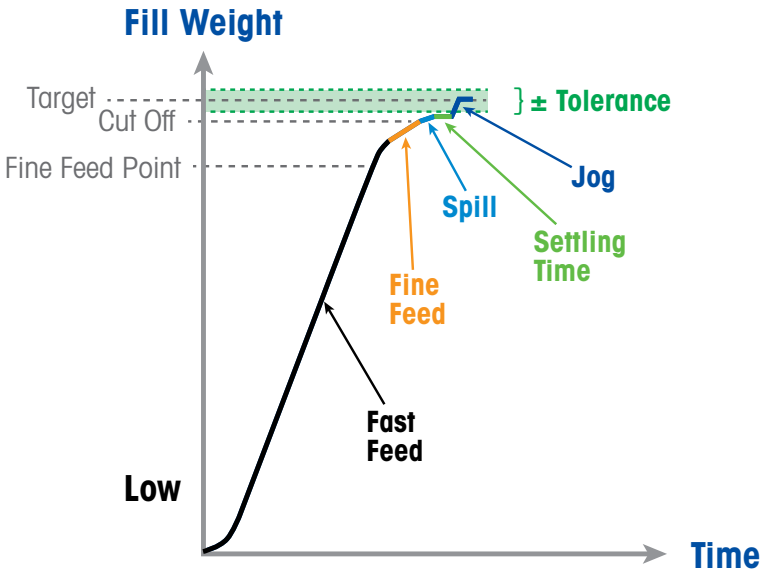


Figure 25: Two-Speed Filling Operation

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Fast & Fine Feed

The combination of fast and fine feed is referred to as two-speed filling, and can be used to improve filling speed and accuracy at the same time. With this, the majority of the material is fed very quickly during the fast-feed period, after which the feeder is slowed to the fine feed for better control in the final stages. For example, 97% of the target fill weight could be filled during fast feed, and then the feeder might be adjusted to feed at 1/10th the rate (the fine feed) to fill the last 3%.

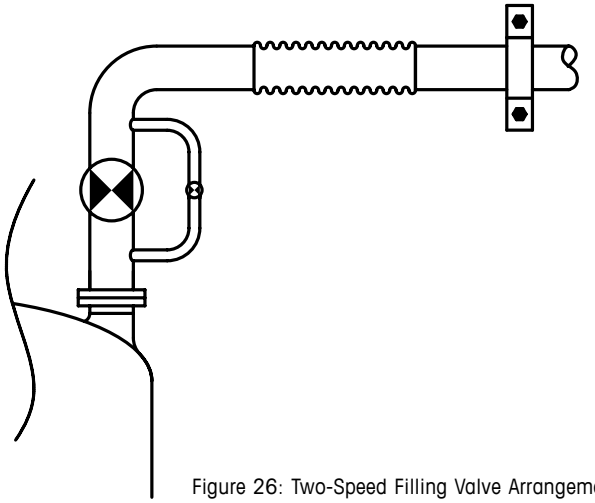


Figure 26: Two-Speed Filling Valve Arrangement

For example, two-speed filling can be accomplished by varying motor speed on screw or rotary vane feeders. For liquids, it may be more effective to place two simple on/off valves in parallel (shown in Figure 26). One branch might have 10 times the flowrate of the other. In operation, both valves are open during fast-feed, then the fast-feed valve closes to provide fine-feed.

Spill

When any feeding device shuts off the flow, there's a certain amount of material in motion that has left the feeder but has not yet registered on the scale. This is referred to variously as spill, preact, and in-flight material. The amount of spill, obviously, depends on the height of the feeder above the surface of the filled material and the feedrate at the time. Some terminals will have spill compensation whereby the feeder is stopped early, but spill is a source of variability and error and should be minimized. Here are some suggestions for minimizing spill and improving accuracy:

1. Minimize the distance from the valves or feeders to the tank.
2. Use two-speed fill to minimize the flowrate at cut-off.

Note that in weigh-out operations you need to consider the amount of material that will escape from the scale before the feeder has fully closed, but spill is not a consideration in this form of weighing.

Jog

The Jog function momentarily activates the feeder to provide a small quantity of additional material to an under-filled tank. In operation, filling would proceed as normal to cut-off, and then the tank would be allowed to settle before comparing the fill weight to target. If under the desired weight, the jog function would be used to rectify this. It is effective only in the case of underfills.

Control

In manual filling operations, the scale displays the tank weight for an operator who controls the feeder, adjusts the final fill weight if necessary, and decides when the fill is within acceptable limits. He or she will do this for each ingredient and then decide when the overall batch is acceptable. The terminal does not require any I/O for such an operation. However, it may communicate the ingredient and batch weights to another system for inventory control and traceability. Just about any simple METTLER TOLEDO terminal could be used.



Figure 27: Manual Filling Operation

More typically, the scale will control the feeders with varying levels of automation possible up to fully automatic systems. In that case the scale performs a tolerance check for each ingredient and decides when the batch is acceptable. Figure 27 shows a tank scale built using analog weigh modules. Here, the load cells are wired to a Junction Box for summing and it's wired to a terminal. Here are three possibilities for controlling the filling:

1. For a standalone system, terminals such as METTLER TOLEDO models IND560, IND690, or IND780 could control a batching system of low to medium complexity where a PLC or Programmable Automation Controller (PAC) is not otherwise required. These terminals have optional application software designed specifically for filling applications and can handle all of the features discussed in the previous sections.



IND560Fill Terminal for Filling

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2. A simple terminal, such as model IND131, could be used to provide weight only to a PLC/PAC, which could perform all control functions.



IND131 Din-Rail Terminal

3. A hybrid system is shown Figure 28. Here, the filling control is performed by a terminal such as the IND560, IND690, or IND780, while the PLC/PAC controls the overall process. The PLC/PAC can dictate when to fill and the batching parameters such as target weight and tolerance for each ingredient. However, this information is downloaded to the terminal which has autonomy to execute the batching process. After batching is complete, the terminal can report to the PLC/PAC for record-keeping, inventory control, etc.

   This approach has several advantages. The terminal is dedicated to reading the weight and controlling the feeders, which are the processes at the heart of any batching operation. Feeder shutoff at the critical time is key and this can be done fastest and without distraction. Also, terminals are available with software packages that have been designed specifically for sophisticated control of filling and batching operations. In Approach 2 above, there are more devices in the loop with the possibility of delay especially at the PLC/PAC if it happens to be engaged in another activity just as shutoff needs to be triggered.

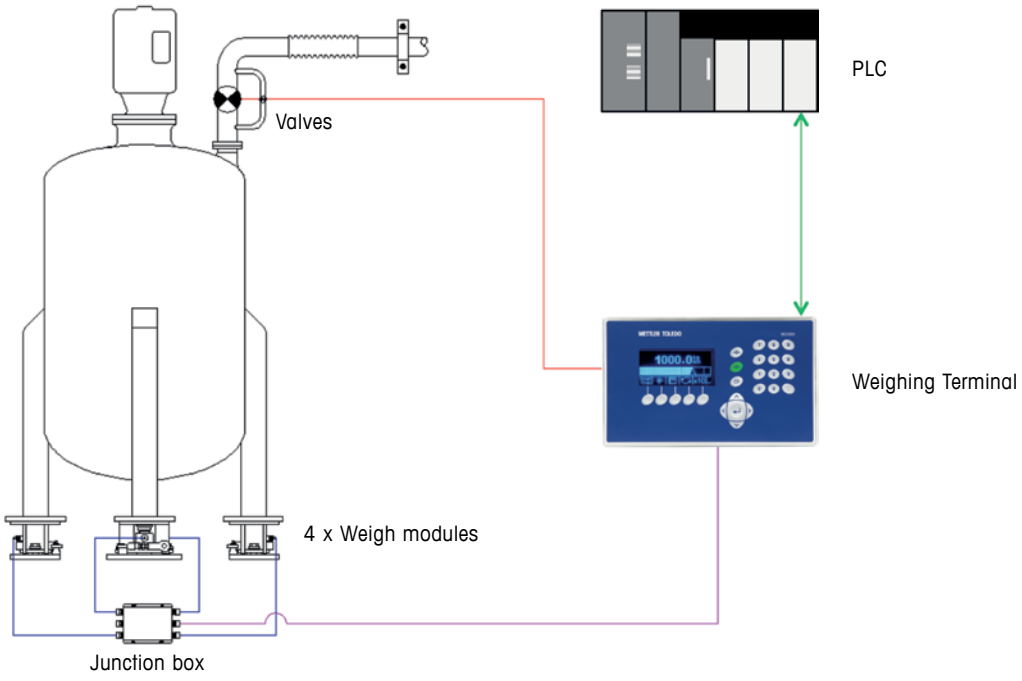


Figure 28: Hybrid Batch Control System with PLC and weighing terminal.

Terminals

The terminal is the key component in any scale system. It provides the excitation voltage to analog load cells and receives their analog output signal. It performs an A/D conversion, filtering, and processing to produce a calibrated weight value which may be displayed, used directly to control the process, or transmitted to other devices.



IND560
Terminal

A/D Conversion and Filtering

The A/D converter is the heart of the operation and conversion must be done quickly in a filling operation to track the progress of the fill and to trigger shut-off at the correct instant. Unfortunately, the analog signal is contaminated with electrical noise from nearby electrical equipment, and mechanical noise from other machinery such as mixers, pumps, compactors, and even the act of filling itself.

METTLER TOLEDO's proprietary TraxDSP™ system combines ultra-fast A/D technology with conversion rates of up to 366 Hertz, tunable multi-stage digital filters, and patented compensation algorithms to constantly and rapidly track the true weight portion of the load cell signal. The mechanical and electrical noise will vary from one installation to another (for example, in frequency and amplitude). So TraxDSP™ can be tuned to the particular conditions to optimize speed, stability, and accuracy resulting in an ultra-fast internal target comparison rate of 50 Hertz, ensuring best-in-class filling and batching accuracy. TraxDSP™ is supplied as standard on process terminals such as IND131, IND560, and IND780.



ARM100 External I/O Module

Digital I/O

More sophisticated terminals will have a range of internal and external digital I/O capabilities. The internal I/O will be limited but is often sufficient for simple filling and batching operations. Many terminals can also utilize external I/O modules, such as the ARM100 from METTLER TOLEDO, for more complex systems.

Connectivity

Connectivity is a key consideration in today's world and terminals can provide a range of standard and optional serial interfaces such as RS232/422/485 and Ethernet TCP/IP, and PLC interfaces as summarized in Table 3.

PLC Interfaces
• 4-20mA Analog
• AB RIO
• ControlNet
• DeviceNet
• EtherNet/IP
• Modbus RTU
• Modbus TCP
• Profibus DP
• Profinet
• CC-Link

Table 3:

IND780batch

METTLER TOLEDO's terminal IND780batch combines multiple control options with easy configuration in applications using up to four scales. Its features and benefits include:

- ISA S88-compliance, providing a consistent protocol for batch operations
- Up to 40 inputs and 56 outputs allow maximum flexibility in control setup
- Storage for up to 1,000 recipes with as many as 99 steps per recipe with the ability to control 42 automatic material feeds
- Configurable on-the-fly recipe rescaling and recipe-looping capability
- Manual, semi-automatic and automatic modes, with user-defined messages and simplified data collection for operators
- BatchTool 780 PC-based configuration utility simplifies recipe and order creation, track and trace logging, security setup, usage reporting, and configuration back-up and restore
- Equipment view screens show system status for advanced diagnostic capabilities



IND780 Terminal

The packaged IND780batch supports single scale operation and has the following additional features and benefits:

- Self-contained, stand-alone controller for batch applications
- Logic for 10 automatic materials, one dump-to-empty and one auxiliary control
- Start/Resume and Pause/Abort buttons
- Status-annunciator light



Packaged IND780batch terminal

IND780 Q.iMPACT Controller

The IND780 terminal with Q.iMPACT advanced material transfer software represents the state-of-the-art in filling and batching controllers. The patented Predictive Adaptive Control algorithms build a real-time mathematical model for each fill, learning and compensating automatically for natural process variations during each feed. The system utilizes simple single-speed on-off control, which greatly reduces system complexity and capital and maintenance costs. Utilizing a simple single-speed filling process, the filling is faster and much more accurate compared to conventional arrangements. A company can achieve higher throughput with lower overall capital costs while improving product quality and consistency. A dedicated PC-based configuration tool eases setup and configuration.



IND780 Q.iMPACT terminal

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Chemical Reactor Vessels

Chemical reactor vessels present a number of challenges from a weighing perspective and these are discussed in the following sections. Some of these conditions apply to tank weighing as well, but usually to a lesser extent.



Figure 29: Weighing Vessel

Reactor Types and Applicability of Weighing Technology

A batch reactor is a vessel as shown in Figure 29, and is operated by having all feedstocks (reactants, catalyst, and reagents) added to the reactor prior to initiation of the reaction by, for example in the case of an endothermic reaction, raising the temperature of the reactive mixture. There are no additions or discharges during the reaction. The product and effluent are removed only when the reaction is complete.

A semi-batch reactor is similar to the batch reactor in that all feedstocks except one reactant, are batched-in at the outset. Then the remaining reactant is dosed-in to control the rate of reaction. In another mode, the semi-batch reactor starts out with all feedstocks present just like the batch reactor, however, the product is removed at a controlled rate as the reaction progresses. It is not very common, but a semi-batch reactor may be used to do both—to dose a reactant and remove product or effluent during the reaction.

One possibility for control by weight is to proportion the feedstocks in tank scale(s) using the simultaneous or sequential batching methods described previously, the output from the scale(s) being discharged directly into the reactor.

Another possibility would be to fit a scale to the reactor itself and to use the accumulative batching method to batch-in the feedstocks. For semi-batch reactors the scale could also be used to control the dosing of additional reactants or the discharge of product. The only difficulty would arise if dosing and discharge had to occur simultaneously and could not alternate between those tasks.

A continuous-flow stirred-tank reactor (CFSTR) is physically identical to the batch and semi-batch reactors but by definition the feedstocks are added and the product and effluent are removed continuously. Weighing technology cannot be applied to this or any of the other reactor types that utilize a truly continuous flow process.

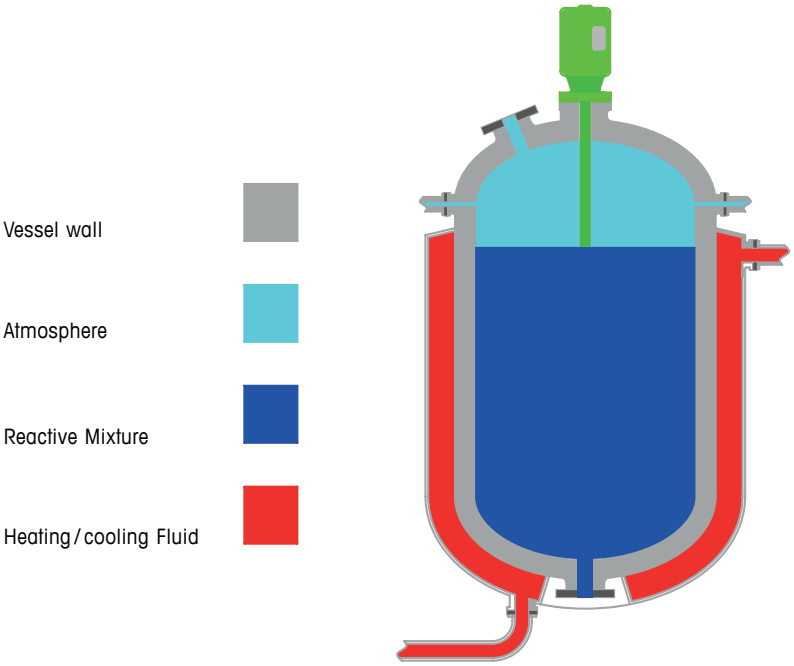


Figure 30: Cross-section through a typical batch reactor

Dead Load

Refer to Figure 30 which is a cross-section through a typical batch reactor. There are a number of factors that contribute to the dead load of a reactor, something that is undesirable from an accuracy perspective. Here is a brief description of those factors.

1. Because they often operate at high pressure, the wall thickness of reactor vessels can be very great by comparison with typical tanks. They can also be made of steel lined with glass or ceramics, adding further to the dead load.
2. Usually they have mixers mounted directly to the vessel. This along with flanges, valves and other ancillary equipment can be a significant contributor to dead load.
3. Most reactors will have a heating/cooling coil or jacket (as illustrated in Figure 30). Its weight and sometimes more significantly, the weight of fluid it contains, contributes to dead load. Such a reactor will usually have insulation protected by an outer shell of stainless steel, again contributing to dead load.

The vessel dead weight can sometimes be much more than the total batch weight, not to mention that of the minor reagents. METTLER TOLEDO can provide load cells and weigh modules with capacities of up to 600 t or more, so the weight is not an issue per se, it is the fact that the weighing accuracy is reduced, especially for the minor reagents.

In estimating the capacity of the scale, load cell(s), or weigh module(s) required, do not forget to include all the factors above in the calculation of dead load.

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Multiple Fluid Systems

In weighing a reactor it is the weight of the reactive mixture that is of interest, for example, when batching-in the feedstocks initially. However, the scale is also weighing some other fluid systems and if their mass changes during the weighing process, then errors will result.

Heating/cooling Fluids

Any change in the weight of heating/cooling fluid on board the scale during weighing will have a direct impact on weighing accuracy. This can be considerable considering the temperature changes that can be experienced by reactors. You need to consider the change in internal volume of the coil or jacket, as well as the change in fluid density resulting from the temperature change. In steam-heating systems, make sure that any condensate accumulation is constant during the weighing operation.

Atmosphere

In reactors, the pressure is often elevated to speed-up the rate of reaction. You need to consider the change in weight of the atmosphere above the reactive mixture if it occurs during the weighing process. Taking air at a constant 21 °C (70 °F) as an example, its density is 1.2 kg/m3 (0.075 lb/ft3) at a gage pressure of 0 Pa (0 psi), but is 83 kg/m3 (5.18 lb/ft3) at 6895 kPa (1,000 psi). Of course the density of a gas varies with temperature also. In addition, a pressurized system presents some unique difficulties in relation to attached pipes. As discussed earlier, it is desirable to use flexible hose or expansion joints in making connections to tanks and vessels. However, these can act as "pneumatic cylinders" when subjected to pressure changes, imparting undesirable forces to the scale. This is especially bad if the flexible hose or expansion joint is in a pipe run connected vertically to the scale. See Reference 1 for more details.



The reactor's upper section extending through the next floor with adequate space for movement



Lower section of the reactor mounted on flexible compression weigh modules

Some reactions will cause the evolution of a gas and if this is vented, the scale weight will decrease accordingly.

Consider also the effect on semi-batch processes where a gaseous reactant is bubbled into the reactive mixture during the chemical reaction. Typically excess gas is supplied and the excess is vented continuously. Obviously the gain in weight of the reactive mixture is equal to the weight of gas added minus the amount vented.

Temperature

Load cells are sensitive to temperature changes with both their zero output and sensitivity affected. They are compensated for this in production and load cells with commercial (legal-for-trade) approvals are adjusted to the tightest tolerances. However, a sensitivity remains and it makes sense from an accuracy perspective, to limit the temperature change of the load cell in any application. In addition, load cells have an "Operating Temperature Range" specification outside of which their performance may be degraded or they may be damaged. So again it makes sense to limit the temperature extremes experienced by the load cells.

This is an important consideration with reactors that often operate at temperatures far removed from room temperature. Figure 31 shows the least desirable mounting arrangement due to the short heat-conduction path to the load cell, while Figures 32 and 33 show more desirable situations with longer conduction paths.

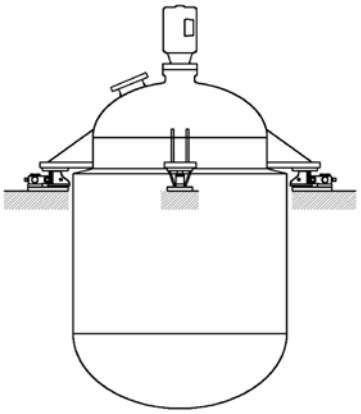


Figure 31: Reactor mounted in compression, "through floor" arrangement

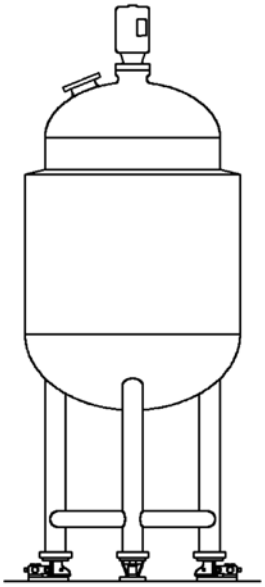


Figure 32: Reactor mounted in compression, with reinforced legs

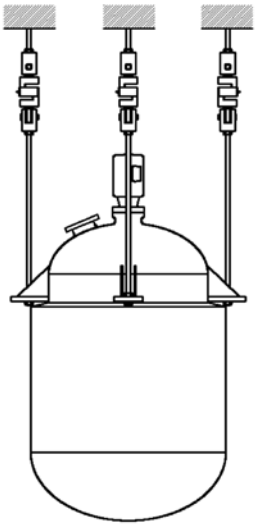


Figure 33: Reactor mounted in tension with tension weigh modules

If a mounting arrangement such as that shown in Figure 31 cannot be avoided, METTLER TOLEDO provides thermal isolation pads for its weigh modules. These are mounted between the weigh module top plate and vessel to reduce conduction. Also, keep the load cells as far as possible away from the heating/cooling fluid inlet as this tends to be the hottest/coldest spot on the vessel.

In general, if a load cell is subjected to radiant heating, it can be protected by simply inserting metallic shields between it and the source.

Vibration

As shown in figure 34, reactors will invariably be fitted with mixers and sometimes these can be very large relative to the capacity of the vessel. This can cause the scale to oscillate and vibrate and introduce noise into the electrical signal affecting accuracy. There are a number of things that can be done to mitigate these issues:

1. If possible, do not run the mixer during the weighing operation.
2. If the weigh module is of the self-aligning suspension type, use horizontal stabilizers to steady the scale. Optional stabilizers are available for some METTLER TOLEDO weigh modules.
3. Use shock/vibration pads, available from METTLER TOLEDO for most weigh modules, between the top plate of the weigh module and the scale to dampen vibrations.
4. Use a METTLER TOLEDO terminal with TraxDSP, as discussed earlier.

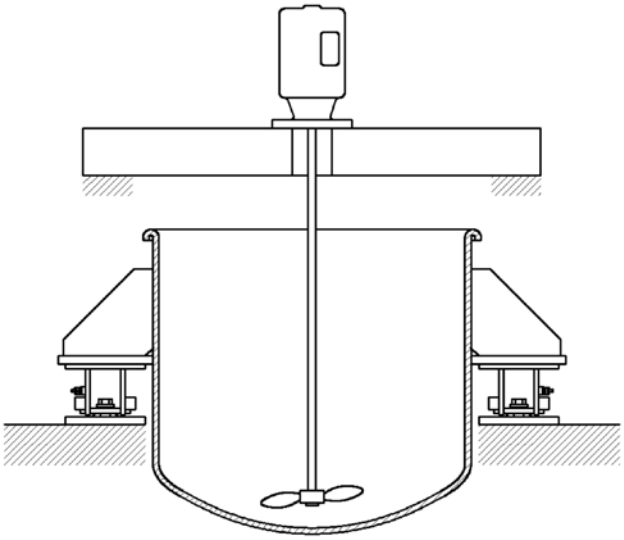


Figure 34: Tank with externally mounted mixer

When a tank (typically not a reactor vessel) has a mixer that is mounted independently as shown in Figure 34, large rotational torques can be transmitted to the tank, greatly affecting accuracy. It is important to stabilize the scale by application of tangential stabilizers.

See Reference 1 for more information on dealing with vibrations, mixers, etc.

Certification Requirements

The immediate vicinity around batching systems is often classified as hazardous due to vapors or dusts resulting from the batching process. METTLER TOLEDO has a complete product range that complies with the various global requirements for electrical equipment used in hazardous areas. These approvals are offered as standard on many METTLER TOLEDO load cells (see Reference 6). In addition, many weigh modules and load-cell accessories comply as standard with the EN requirement for non-electrical equipment used in hazardous areas (see Reference 10). METTLER TOLEDO also offers a number of resources to help you select equipment for hazardous areas (see References 9, 11, 12 and 13). Go to www.mt.com/webinar or www.mt.com/hazardous for webinar access.

There are various situations in which the performance of scale equipment must comply with national and international regulations, especially when used for custody transfer. METTLER TOLEDO provides a complete portfolio of products approved globally for use in commercial (legal-for-trade) applications. These approvals are offered as standard on load cells (see Reference 6 or: www.mt.com/ind-weighing-component-catalog).

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