Manual of Petroleum Measurement Standards Chapter 3.1A

Standard Practice for the Manual Gauging of Petroleum and Petroleum Products

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Introduction

Personnel involved with the gauging of petroleum and petroleum-related substances should be familiar with their physical and chemical characteristics, including potential for fire, explosion, and reactivity, and with the appropriate emergency procedures as well as potential toxicity and health hazards. Personnel should comply with the individual company safe operating practices and with local, state, and federal regulations, including the use of proper protective clothing and equipment.

API Publication 2217, API Publication 2026, API Recommended Practice 2003, and any applicable regulations should be consulted when gauging. Information regarding particular materials and conditions should be obtained from the employer, the manufacturer or supplier of that material, or the material safety datasheet.

Information on exposure limits can be found by consulting the most recent editions of the Occupational Safety and Health Standards, 29 *CFR* Section 1910.1000 and following and the ACGIH publication *Threshold Limit Values for Chemical Substances and Physical Agents in the Work Environment*.

Standard Practice for the Manual Gauging of Petroleum and Petroleum Products

1 Scope

This standard describes the following:

a) the procedures for manually gauging the liquid level of petroleum and petroleum products in nonpressure fixed-roof, floating-roof tanks and marine tank vessels;

b) procedures for manually gauging the level of free water that may be found with the petroleum or petroleum products;

c) methods used to verify the length of gauge tapes under field conditions and the influence of bob weights and temperature on the gauge tape length; and

d) influences that may affect the position of gauging reference point (either the datum plate or the reference gauge point).

Throughout this standard the term petroleum will be used to denote petroleum, petroleum products, or the liquids normally associated with the petroleum industry.

This standard is applicable for gauging quantities of liquids having Reid vapor pressures less than 103 kPa (15 psia).

The method used to determine the volume of tank contents from gauge readings is not covered in this standard.

The determination of temperature, density, API gravity, and suspended sediment and water of the tank contents are not within the scope of this standard; however, methods used for these determinations may be found in the API *Manual of Petroleum Measurement Standards* (*MPMS*).

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API *Manual of Petroleum Measurement Standards* (*MPMS*) Chapter 2, (all sections) *Tank Calibration*

API *MPMS* Chapter 12.1, *Calculation of Static Petroleum Quantities*

API *MPMS* Chapter 17, (all sections) *Marine Measurement*

API Recommended Practice 2003, *Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents*

3 Terms and Definitions

For the purposes of this document, the following definitions apply.

3.1
closing gauge
Is an innage or outage gauge taken after the transfer of material into or out of the tank.

3.2
critical zone
The distance between the point where a floating roof is resting on its normal supports and the point where the roof is floating freely is referred to on a tank capacity table as the "critical zone."

3.3
cut
The line of demarcation on the measuring scale made by the material being measured.

3.4
datum plate
A level metal plate located directly under the reference gauge point to provide a fixed contact surface from which liquid depth measurement can be made.

3.5
emulsion
An oil/water mixture that does not readily separate.

3.6
free water
Water that exists as a separate phase.

3.7
innage gauge (dip)
Is the level of liquid in a tank measured from the datum plate or tank bottom to the surface of the liquid.

3.8
list
The leaning or inclination of a vessel, expressed in degrees port or starboard away from the vertical.

3.9
master tape
A tape that is used for calibrating working tapes for tank measurement and is identified with a Report of Calibration at 68 degrees Fahrenheit (68 °F) [20 degrees Celsius (20 °C)] and at a specific tension designated by the National Institute of Standards and Technology (NIST) or an equivalent international standard organization.

3.10
observed gauge height
The distance actually measured from the tank bottom or datum plate to the reference gauge point at the time of gauging a tank.

3.11
opening gauge
Is an innage or outage gauge taken before the transfer of material into or out of the tank.

3.12
outage gauge (ullage)
The distance from the surface of the liquid in a tank to the reference gauge point of the tank.

3.13
reference gauge height
The vertical distance, noted on the tank capacity table, between the reference gauge point on the gauge hatch and the datum strike point on the tank floor or the gauge datum plate.

3.14
reference gauge point
The point from which all liquid level measurements shall be taken:

a) as determined at the time of the tank calibration and as reflected by the tank capacity table; or

b) as modified in keeping with guidelines in API *MPMS* Ch. 2 and API *MPMS* Ch. 3 and for which either adjustment calculations shall be made or a new tank capacity table issued reflecting the new location of the reference gauge point.

3.15
tank capacity table (tank gauge table)
Shows the capacities of, or volumes in a tank for, various liquid levels measured from the reference gauge point.

3.16
trim
The condition of a vessel with reference to its longitudinal position in the water. It is the difference between the forward and aft drafts and is expressed “by the head” or “by the stern.”

4 Gauging Equipment

4.1 General

This part of the standard refers to equipment presently in use. It is not intended that it should exclude new equipment not yet developed for commercial use, provided that the accuracy of such equipment is within the maximum permissible error tolerances specified herein and that the procedures for its use are capable of achieving equivalent levels of accuracy.

All gauging equipment shall be suitable for use in hazardous environments and grounded as appropriate—see API 2003, *Protection against Ignitions Arising out of Static, Lightning, and Stray Currents*.

4.2 Nonelectronic Gauge Tapes, Bobs, and Bars

4.2.1 General

Graduated tapes (see Figure 1) that conform to the following specifications are required for innage and outage/ullage gauging procedures.

a) *Material*: Steel (or corrosion-resistant material, if the tape is to be used for gauging the contents of tanks that contain corrosive liquids).

b) *Length*: One continuous tape of sufficient length for the height of the tank to be gauged.

c) *Width Thickness*: The cross-sectional area of the tape shall be such that the tape in a horizontal position on a flat surface will not stretch by more than a unit strain of 0.0075 %.

d) *Housing*: A durable reel and crank; the assembly mounted in a frame or case.

e) *Free End*: Fitted with a spring snap catch or other locking device to which the bob can be attached. A swivel-type snap catch will reduce tape breakage.

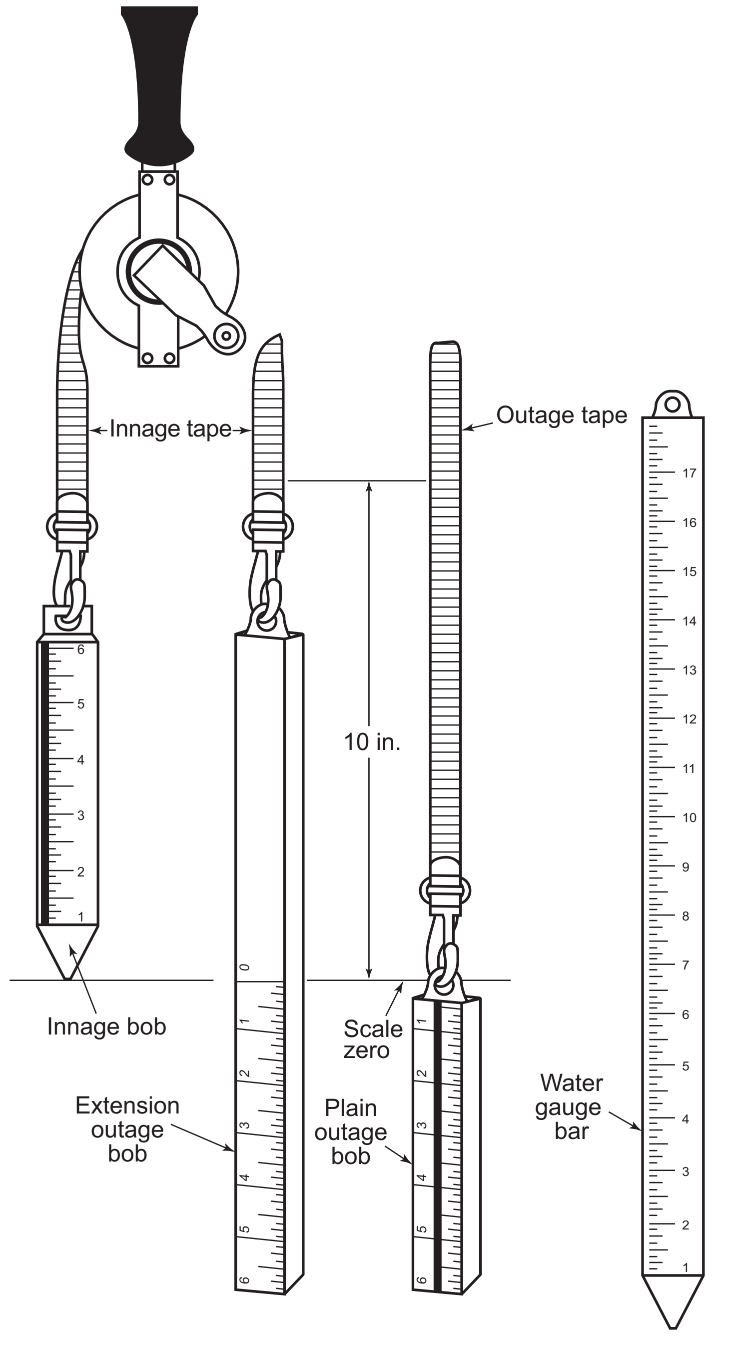
f) *Scale*:

   1) Innage Tape—Graduated in feet, inches, and fractions of an inch; in feet and hundredths of a foot; or in meters, centimeters, and millimeters. The tip of the bob will be the zero point of the scale.

   2) Outage/Ullage Tape—Graduated in feet, inches, and fractions of an inch; in feet and hundredths of a foot; or in meters, centimeters, and millimeters. The zero point of the scale is the point of contact between the snap catch and the eye of the bob.

NOTE 1 Tapes that have been kinked or spliced or that contain illegible markings shall not be used.

NOTE 2 Innage tapes may be used to take both innages and outage/ullages; however, outage/ullage tapes should only be used to take outage/ullage gauges.



a) Typical Gauge Tapes and Bobs b) Typical Water Gauge Bar

Figure 1—Typical Gauge Tapes and Bobs and Typical Water Gauge Bar

Graduated cylindrical, square, or rectangular bobs, or water gauge bars (see Figure 1) that conform to the following specifications are required.

a) *Materials*: Spark and corrosion-resistant.

b) *Typical Length*: Bobs or bars, 15 cm (6 in.), 30 cm (12 in.), or 45 cm (18 in.).

c) *Weight*: Sufficient to extend the tape to meet accuracy requirements.

d) *Eye*: An integral part of the bob or bar, preferably reinforced with a hardened bushing to prevent wear.

e) *Tip*: Innage bobs and bars shall have a conical tip of sufficient hardness to prevent damage by contact with other metal.

f) *Scale*:

1) Innage Bobs and Bars—Graduated on one side in inches with at least $^1/_8$ in. subdivisions; in tenths of a foot with at least hundredths of a foot subdivisions; or in centimeters with at least 1 mm subdivisions. The zero point of the scale is at the tip of the bob.

2) Outage/Ullage Bobs—Graduated on one side in inches with at least $^1/_8$ in. subdivisions; in tenths of a foot with at least hundredths of a foot subdivisions; or in centimeters with 1 mm subdivisions. The zero point of the scale is at the inside of the eye, except for the extension outage/ullage bob (see Figure 1).

4.2.2 Accuracy Requirements of Nonelectronic Tape and Bob

4.2.2.1 Accuracy

New tapes shall be inspected throughout their entire length to determine that the numerals and increments between the numerals have been placed on the tape correctly. The accuracy of the working tape and bob attached shall be verified by comparison with a reference measurement device (e.g. master tape) that has been certified by or is traceable to NIST, or other national weights and measures standards authorities, using the procedure in Annex A. The accuracy of the working tape shall meet the requirements in A.3.

4.2.2.2 Frequency of Verification

The tape and bob assembly shall be inspected daily, or prior to use (whichever is less frequent), to ensure that wear in the tape snap catch, bob eye, or bob tip does not introduce error when the tape scale is being read. The tape shall also be inspected for kinks. Kinked, illegible, or spliced tapes shall not be used.

The working tape with bob attached shall be verified for accuracy when new and at least annually thereafter following the procedure in Annex A.

4.2.2.3 Marking

The graduated tape and bob of each gauge tape shall be marked with unique serial number(s) that can be annotated on the calibration certificate for the purpose of audit trail.

4.3 Portable Electronic Gauging Equipment

4.3.1 General

Portable electronic gauging devices (PEGDs) usually consist of an electronic sensing device suspended on a measuring tape, and a housing with readouts. These devices shall be capable of demonstrating the same measurement accuracy as the nonelectronic gauging tape and bob and shall be calibrated or verified against a reference measurement (see Annex A).

The device may be designed for open, restricted, or closed gauging applications. Closed and restricted gauging operations will generally require the portable electronic gauging tape to be used in conjunction with a compatible vapor lock valve.

4.3.2 Construction and Graduation

The material of construction and graduation of the main measuring tape should comply with the specification for gauge tapes given in 4.2.

4.3.3 Marking

The graduated tape, the sensor probe, and the body of the winding frame of each PEGD shall be marked with unique serial number(s) that can be annotated on the calibration certificate for the purpose of audit trail.

4.3.4 Zero Point

Due to the design of the probe used, the tip of the probe may not be the zero point of the gauge tape. In this case, an adjustment to the reading shall be made to convert the observed reference height to the corrected reference height. This adjustment should be found on the certificate of verification or in the manufacturer's instructions.

4.3.5 Accuracy Requirements of Portable Electronic Gauging Devices

4.3.5.1 Accuracy

New tapes shall be inspected throughout their entire length to determine that the numerals and increments between the numerals have been placed on the tape correctly. The accuracy of the PEGD, complete with working tape and sensor probe assembly attached, shall be verified by comparison with a reference measurement device, such as a master tape that has been certified by or is traceable to NIST, or equivalent national weights and measures authorities, using the procedure in Annex A. The accuracy of the working tape shall meet the requirements in A.3.

4.3.5.2 Frequency of Verification

Portable electronic gauging tape assembly shall be inspected daily or prior to use (whichever is less frequent) to ensure that wear in the tape/sensor does not introduce error when the tape scale is being read, and the sensor is functional. Kinked, illegible, or spliced tapes shall not be used.

PEGDs shall be verified when new and at least annually thereafter using the procedure in Annex A.

NOTE Refer to API *MPMS* Ch. 7 for temperature verification of portable electronic thermometers.

4.4 Other Gauging Equipment

4.4.1 Extension Outage/Ullage Bob

The extension bob (see Figure 1) is designed for taking outage/ullage gauges with an innage tape. The specifications for the graduated portion of the bob are the same as for the plain bob.

4.4.2 Water Indicating Paste

Water gauging pastes are used with gauge bars, bobs and tapes to indicate the petroleum and free water interface. The paste should not readily react with the petroleum or emulsions, but it should change color upon contact with free water.

NOTE Water pastes that indicate an emulsion by spotting are acceptable; however, water pastes that show emulsions as a complete color change, within the immersion times specified in Section 6, should not be used.

4.4.3 Product Indicating Paste

In very light petroleum, the level of the liquid cannot be read on the tape because the petroleum evaporates while the tape is being raised from the liquid. To overcome this problem, product paste is applied to the tape. When the paste comes in contact with the petroleum, it changes color or dissolves away thus giving a reading (cut).

4.4.4 Oil Thief

A trap type core thief (see 6.2) is a sampling device that may be used to approximately measure free water or emulsified oil, sediment, and water levels in tank bottoms. Reference API *MPMS* Ch. 8 for construction.

4.5 Water-finding Rules

4.5.1 General

Water-finding rules are used in conjunction with water-finding paste and are specifically designed for measuring the depth of any free water lying beneath opaque oils.

4.5.2 Construction

The IP water-finding rule shall be as specified in Figure 2. The outer framework and conducting spacer parts should be made of brass (to maintain earth continuity via the steel dip tape). The alternating transparent plastics parts should be sized so as not to present a potential electrostatic hazard, while still permitting the reaction of the water-finding paste to be observed through the rule. The surface area of each of the alternating plastics parts should be less than 2.8×10^{-3} m^2. The weight of the rule shall be sufficient to ensure that the dip tape is kept taut (when it is required to verify the tank reference height at the same time as gauging for free water).

The bottom face shall be the zero datum for the graduation of the rule, but not for the dip tape.

NOTE Because the rule is 200 mm longer than the standard bob, a 200 mm correction is applied to readings taken from the gauge tape used to suspend the water-finding rule (e.g. when the tank reference height is verified by using a gauge tape and waterfinding rule combination instead of a gauge tape with bob).

4.5.3 Marking

The full length of the face of the rule shall be graduated in 1 mm intervals. Each 5 mm and 10 mm graduation shall be of increased length to simplify reading. Each 50 mm graduation shall be figured to indicate its distance in centimeters from the bottom face. The water-finding rule shall be marked with the manufacturer's name and trade mark. The nominal mass of the rule should also be marked. The markings “water-finding rule” and “IP M14” are optional.

5 Gauging Procedure

5.1 Method Outline

There are two basic types of procedures used for obtaining a gauge reading—innage and outage (dip and ullage). An innage gauge is a direct measurement of liquid depth. An outage/ullage gauge is an indirect measurement of liquid depth. Outage/ullage gauging relies on having the same tank reference gauge height on opening and closing for accurate determination of transferred quantity. When performing outage/ullage gauging the reference gauge height shall be used at all times, except where the interested parties agree otherwise. Figure 3 illustrates the innage and the outage/ullage methods for obtaining a gauge reading.

For tanks or materials where the tank bottom (or datum plate) is clean of sediment or debris, either the innage or outage/ullage method may be used. For either chosen method, the observed gauge height shall be taken at opening and closing and recorded.

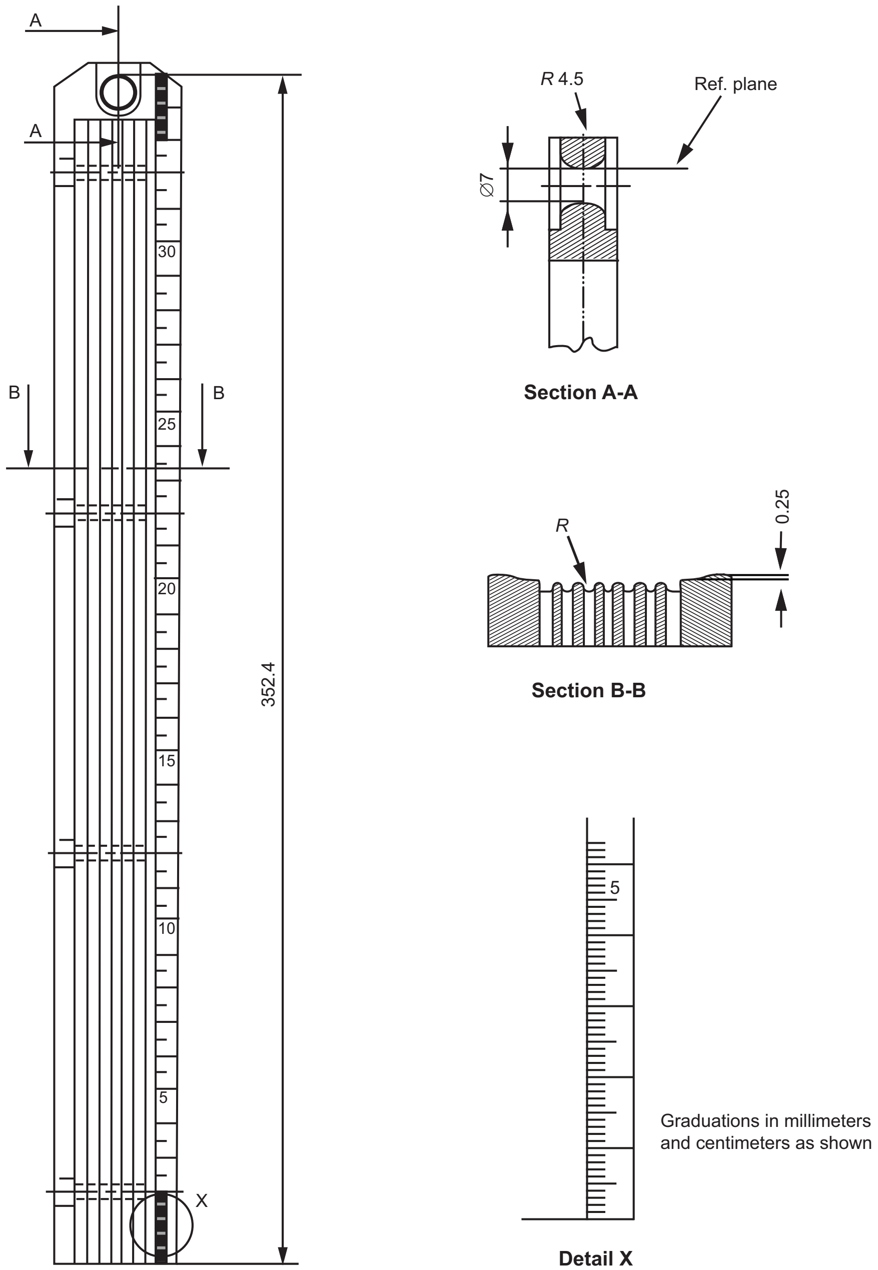


Figure 2—Water Finding Rule

NOTE A review of the collected reference height history may indicate if the tank bottom is subject to elastic diaphragming (bottom flexing). For more information, see the “bottom movement” discussion in informative Annex B.

There are some materials (e.g. asphalt, pitch, caustic soda, acids) where innage gauging would rarely, if ever, be used. Outage/ullage gauging of these materials minimizes the exposure of equipment and personnel. Under any of the above described circumstances, there is typically no expectation of manual tank reference height verification. Outage/ullage gauging is usually chosen and the reference gauge height is used for calculation of innage by outage/ullage.

Another common condition for many tanks or materials is a known layer of sediment, hardened material, or debris laden tank bottom that prevents manual verification of tank reference height while the tank is in service. Under these

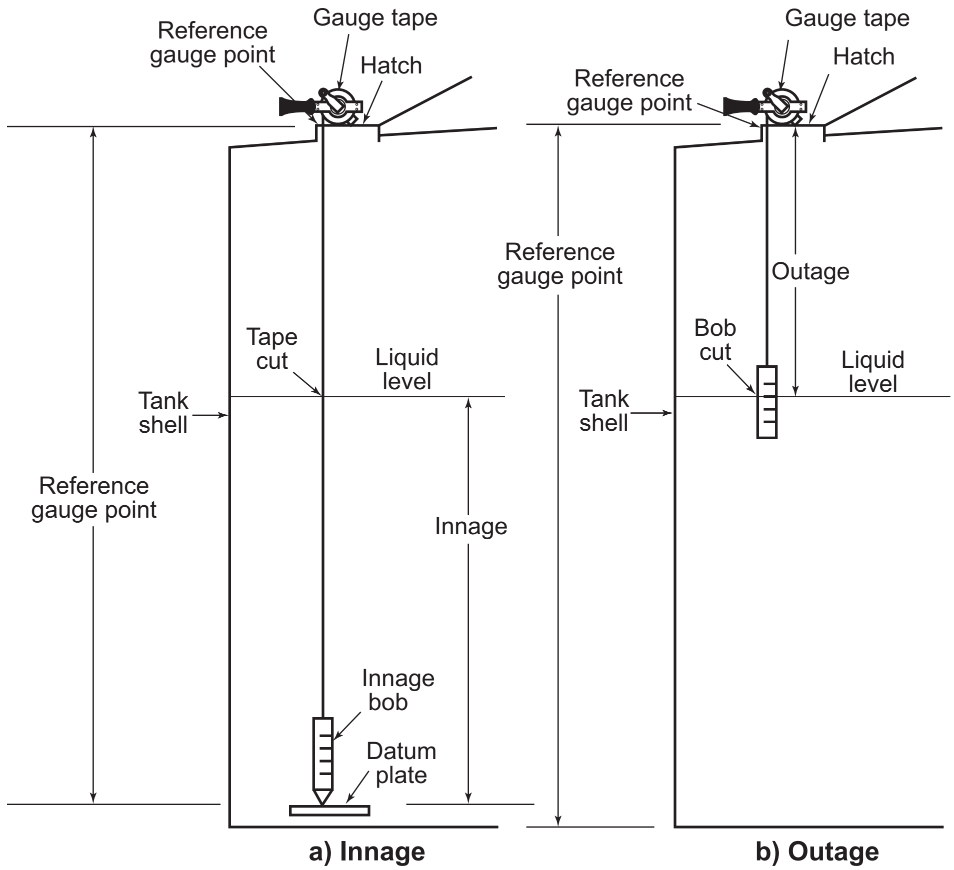


Figure 3—Gauging Diagram

circumstances, outage/ullage gauging is usually chosen and the reference gauge height is used for calculation of innage by outage/ullage.

If there are repeated variations between observed and certified reference height, the cause should be investigated by the tank owner to determine if the tank is suitable for future custody transfer use.

Tank gauging shall not be carried out from unperforated or unslotted still pipes (which are referred to as "guide poles" or "stand pipes"), since the liquid level measured inside the unperforated or unslotted still pipes is usually not the same the liquid level outside the still pipe. Tank gauging shall only be taken from still pipes that have perforations or slots that allow free flow of liquid into and out of the still pipe. In certain locations, still pipes without slots are used to comply with local air pollution regulations. These "solid" still pipes can lead to serious liquid height measurement, temperature determination, and sampling errors. (See Annex B.)

5.2 Reading and Reporting Gauges

The reported gauge shall be determined by the gauge readings from consecutive measurements as follows.

Manual gauging shall require obtaining either two consecutive gauge readings that are identical or three consecutive readings within an absolute range of 3 mm ($^1/_8$ in.). If the first two readings are identical, this reading shall be reported to the nearest 1 mm if metric tapes are used or to the nearest $^1/_8$ in. if customary tapes are used. When three readings are taken, all three readings shall be within the 3 mm ($^1/_8$ in.) range and readings averaged to the nearest 1 mm for metric tapes and $^1/_8$ in. for customary tapes.

For lighter materials, a suitable product-indicating paste should be used on the tape to facilitate reading the cut. The use of chalk or talcum powder is not permissible, as petroleum has a tendency to creep on chalk or powdered tapes.

5.3 Innage Gauging Procedure

For innage gauging, proceed as follows.

a) After safely grounding the tape and opening the gauge hatch, apply product paste as appropriate and slowly lower the bob and tape into the tank until the bob is within a short distance of the bottom as determined by the length of tape unwound from the reel in comparison to the reference gauge height of the tank.

b) Then, with the tape adjacent to the reference gauge point, lower the tape slowly until the tip of the bob just touches the datum plate (or tank bottom if no datum plate exists) (see Figure 3).

c) Record the tape reading at the reference gauge point and note any variance from the reference gauge height of the tank. The comparison of the observed gauge height tape reading to tank reference gauge height is an indication that the gauge bob is suspended in a vertical position while in contact with the datum plate or tank bottom. If the tape is lowered too far, causing the bob to tilt, or if the bob is resting on foreign material in the bottom of the tank, an inaccurate gauge reading will be obtained.

d) When obtaining innage gauges, be sure the tape is lowered at the same reference gauge point for both opening and closing gauges. It is recommended that the gauger allows sufficient time for the surface of the liquid to settle after the bob breaks the surface, before continuing to lower the bob.

e) Withdraw the tape from the tank until the liquid cut is observed.

f) Read the tape scale at the liquid cut and note this reading as the innage gauge.

g) Repeat the procedure as set forth in 5.2.

5.4 Outage/Ullage Gauging Procedure

For outage/ullage gauging, proceed as follows.

a) After safely grounding the tape and opening the gauge hatch, apply product paste as appropriate and slowly lower the tape and bob into the tank until the bob touches the surface of the liquid (see Figure 3).

b) After the bob has stopped swinging, lower the tape slowly until a small portion of the bob is in the liquid and an even inch, tenth of a foot, or centimeter graduation on the tape is at the reference gauge point.

c) Record the tape reading at the reference gauge point.

d) Withdraw the tape from the tank and read the outage/ullage bob scale at the liquid cut and record the reading. Care should be exercised during the withdrawal procedure to ensure that the tape and bob are not allowed to reenter the liquid. If the tape is allowed to reenter the material, the gauge is invalid and has to be repeated.

e) Repeat the procedure as set forth in 5.2.

5.5 Conversions Between Innage and Outage/Ullage Gauges

An outage/ullage gauge may be converted to an innage gauge by subtracting the outage/ullage gauge reading from the tank's reference gauge height.

EXAMPLE

	Feet	Inches	Meters
Reference Gauge Height	44	5 $^{7}/8$	13.560
Outage Gauge	10	8 $^{5}/8$	3.275
Innage Gauge (Ref – Out) =	33	9 $^{1}/4$	10.285

6 Free Water Gauging Procedure

6.1 Water-indicating Paste Procedure

6.1.1 General

This procedure is used to determine the height of free water found under petroleum where there is a distinct water/petroleum demarcation, (see Figure 4). When using a manual tape and bob, the recommended procedure for free water gauging is by the innage method.

The water cut may be read on the bob or the tape; however, if the water cut falls on the clasp, a longer bob should be used. A square bob or bar is not recommended because the corners on the bob may cause dips and slants to occur on the paste, thus giving false readings.

There are many brands of water indicating pastes available that change color on contact with free water. It has been found that, although all pastes react to free water, they may differ.

It is recommended to use two different pastes on the bar at the beginning of gauging. After it has been established which paste works best for the given product, the other may be discontinued. At certain origin locations where only one type of product is being handled, it is recommended that tests be made on several different pastes to choose the one that gives the best performance.

When applying the two pastes to the bar, cover a little less than one-half of the entire surface of the round bar with each paste. Make sure that the measurement scale remains free of paste. Apply a thin but adequate coat of the paste to the bar. Practice will determine how much paste should be applied to obtain a satisfactory water cut. It is recommended on discharges that one of the pastes used is the same as the one used at loading to record the free water and that the same paste be used for the receipt and delivery of the same product, if known and available.

Allow the bar to remain in the gauging position for a minimum of ten seconds for gasoline, kerosene, and similar light petroleum products. Allow the bar to remain in the gauging position from one to five minutes for heavy viscous petroleum. This amount of time is required to shed the petroleum that adheres to the paste. When measuring free water in tanks containing heavy viscous petroleum, apply an even film of light lubricating oil over the paste to facilitate the shedding of the petroleum from the paste.

When the bar is removed, do not blow or wipe the petroleum off the paste as this may distort the clarity of the water cut. If the water cut is obscured by the petroleum (black oils), it may be necessary to wash the surface of the paste with a suitable solvent. When this is required, the solvent should be poured or lightly sprayed on the bar well above the anticipated cut and allowed to rinse down over the cut area. Pouring directly on the paste may distort the clarity of the water cut.

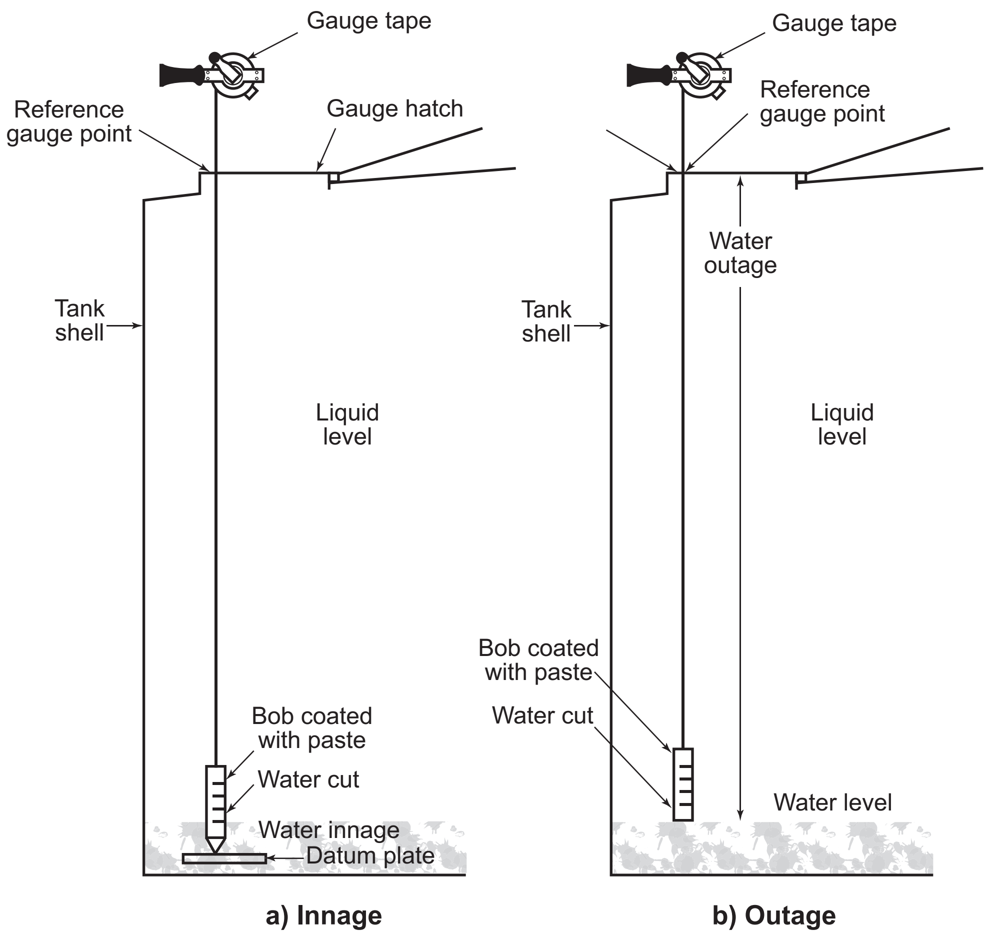


Figure 4—Free Water Gauging

Some pastes do not adhere well with layered applications. In those instances, the bar has to be wiped dry and cleaned with a solvent before reuse.

By coating the entire surface of the bar with two pastes, a clear line of demarcation will give evidence of the water cut. If one side is spotted or lower than the other, record the highest level reading for the measurement. Oil adhesion may cause low readings, but not high readings. The spotting may indicate a layer of emulsified oil and water, or more probably, it may indicate that the product did not completely shed off pastes. This phenomenon has been observed in light as well as heavy product and appears as either spotting, dips, or slants. Record, for reference, the level of the spotting.

NOTE When emulsions are found, sampling and subsequent laboratory testing is required. If it is believed that an emulsion layer is present, read and record both clear cut and spotting measurement. Some water pastes show emulsions as a complete color change and should not be used as the percentage of oil and water in emulsions cannot be accurately determined with water-finding pastes. A sample of this layer may be obtained by using procedures defined in API *MPMS* Ch. 8.1.

6.1.2 Selection of Paste

The selection of a suitable water-finding paste should be such that it:

— gives a clear and unambiguous color change when in contact with free water;

— has an acceptably rapid reaction time under operating conditions;

— does not exhibit “creep”;

— has a consistency suitable for use at ambient and operating liquid temperatures.

6.1.3 Problems in Use

Certain brands of water-finding paste indicate the presence of free water when actually immersed in high water-content emulsions or mixtures (e.g. ≥30 % water in oil). The reaction point of each type of water-finding paste should be determined and borne in mind during any subsequent stock calculations where emulsion layers may be present.

When suspended water droplets are present, the paste may exhibit a “speckled” reaction. Under these circumstances it may be more appropriate to quantify the water/emulsion layer(s) by manual tank-sampling techniques.

When water-finding paste is used in opaque oils, a solvent may be sprayed on to the measuring instrument to wash off the oil and render the discolored portion visible. This operation requires care as the use of solvent may affect the paste and result in false readings being recorded. In these circumstances, it may be preferable to use a water-finding rule, where the coating of opaque oil may be wiped away from the reverse side of the rule to enable the viewing of the water-finding paste through the transparent sections of the rule (without disturbing the reacted paste or affecting it with solvent).

NOTE Care is required to ensure that the layer of water-finding paste is not applied too thickly to a transparent water-finding rule. Since the entire thickness of the paste has to react for the color change to be visible from the reverse side of the rule, it is essential that the paste is only sparingly applied.

6.2 Thief Procedure

When oil and water emulsions are present or suspected, the thief procedure may be used to determine the height of the emulsified layer or to obtain a sample of the emulsified layer for testing. If the thief procedure is used, it should be approved by all parties concerned. A trap type core thief (see Figure 5) should be used for this procedure. Proceed as follows.

a) With the bottom valve or slide open and the top fully open, lower the thief slowly to the bottom of the tank. After allowing sufficient time for the free water and oil-water emulsion to reach the proper level, close the thief with the cord provided for that purpose. Some thiefs close automatically when an adjustable trip rod strikes the tank bottom.

b) Withdraw the thief and pour the contents of the thief back into the tank until water is detected. If desired, the contents may be poured in a small flat stream over a test glass.

c) As soon as water or emulsion shows, return the thief to a vertical position.

d) Using the thief’s graduated scale, measure the remaining contents of the thief. Record this measurement as the height of the free water and oil-water emulsion layer contained in the tank.

e) Holding the thief in a vertical position, slightly open the bottom valve or slide and drain the free water back into the tank.

f) Using the thief’s graduated scale, measure the remaining contents of the thief. Record this measurement as the thickness of the oil-water emulsion layer. By subtracting the thickness of the oil-water emulsion layer from the height of the free water and oil-water emulsion, the free water height may be approximated.

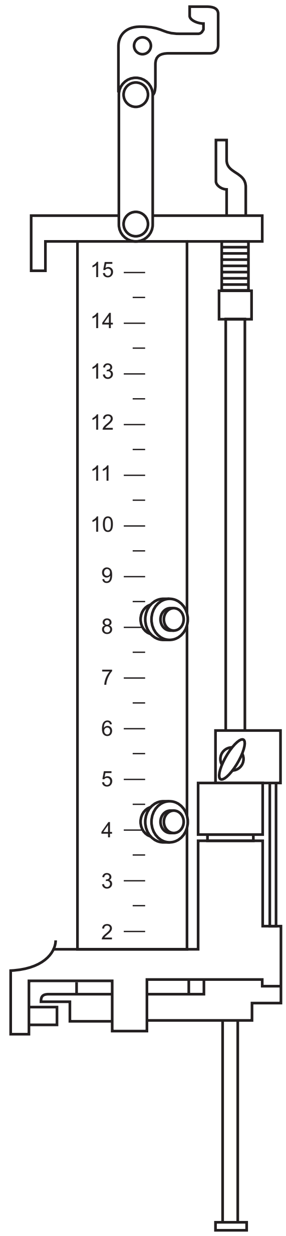


Figure 5—Core Thief, Trap Type

g) Petcocks installed on the side of the thief may be used to withdraw samples into centrifuge tubes or other containers to determine the height of the oil-water emulsion layers. Start with the highest petcock and withdraw lower samples until the layer is identified.

This procedure is commonly used for crude oil production tanks (lease tanks) with a nominal capacity of 1000 barrels or less; however, it is not appropriate for other custody transfer operations.

6.3 Electronic Interface

Reference HM 52/API *MPMS* Ch. 17.11 (May 2009).

7 Gauging Procedure for Marine Vessels

7.1 Outline and Selection of Method

The procedures and guidance from 5.1 generally apply to marine vessels; however, the fifth paragraph that deals with differences between opening and closing observed gauge heights and the differences between the observed gauge height and the reference gauge height does not apply to marine vessels because they experience conditions of trim and list (i.e. the measured gauge height will change due to the deflection of the tape away from the vertical). This change will vary with the amount of trim and list and the height of the tank. This issue is addressed in API *MPMS* Ch. 17, which should be referenced for guidance.

7.2 Reading and Recording Gauges

7.2.1 General

The recorded gauge shall be determined from the average of three consecutive tank gauges, within a range of 3 mm (or $^1/8$ in.).

NOTE If the first two gauge readings are identical, that reading may be recorded without taking additional gauges.

7.2.2 Rolling Gauges

In the event that three gauges cannot be taken within a range of 3 mm (or $^1/8$ in.) because the cargo is moving, at least five readings shall be obtained in minimal time, recorded, and then averaged. The ullage/outage gauges are to be taken as quickly as is practical and the immersion time of the bob/tape should be as brief as possible. Adverse conditions such as these shall be recorded.

NOTE In the event of extreme weather conditions the use of the vessel's automatic gauges may be preferable. Any decision to utilize automatic gauges shall also be recorded and retained with the gauging records.

For additional information on gauging procedures for marine vessels refer to the appropriate section of API *MPMS* Ch. 17.

8 Operational Precautions

8.1 General

The overall accuracy of tank gauging may be influenced by the following operational procedures used in the transfer of petroleum into or out of the tank.

8.2 System Integrity and Line Fullness

Tanks, connecting valves, and transfer lines that leak during a transfer of petroleum will cause an overstatement or understatement of quantity. Any suspected system integrity issues should be promptly investigated.

8.3 Checks Before Measuring

Before measurements are commenced the following conditions shall be observed.

— *Datum Plate*: When gauging shore tanks with a datum plate, the liquid level should be at or above the datum plate when used for custody transfer.

Precautions shall be taken to ensure that oil or water does not flow into or out of the tank during measurement and, in the case of ship's tanks, that the vessel trim and list remain constant.

— *Settling:* After oil has been pumped into or from a tank, gauging shall not be commenced until time has been allowed for the cessation of any movement of the oil surface and for relaxation of any static charge that may have accumulated on the liquid surface, whichever is longer. In the case of viscous oils, time shall be allowed for any entrained air to be liberated from the oil. When foam is present on the surface of the oil, it shall be allowed to subside or be cleared from the surface beneath the gauge hatch before the oil depth is measured.

8.4 Tank Mixers

If the tank is equipped with a mixer, it should be turned off prior to gauging. The period of time between turning off the mixer and gauging should be long enough to allow the liquid to come to rest and for the dissipation of static electricity.

8.5 Water Draw-off

Water draw-off lines shall be kept closed for the period between the opening and closing gauges.

8.6 Entrained Air and Foam

Sufficient time should be allowed before gauging a tank to permit the liquid to free itself of entrained air or vapors. Custody transfer gauges should not be taken until the foam has subsided from the liquid surface beneath the gauge hatch and until the surface of the liquid is at rest.

8.7 Gauge Hatch

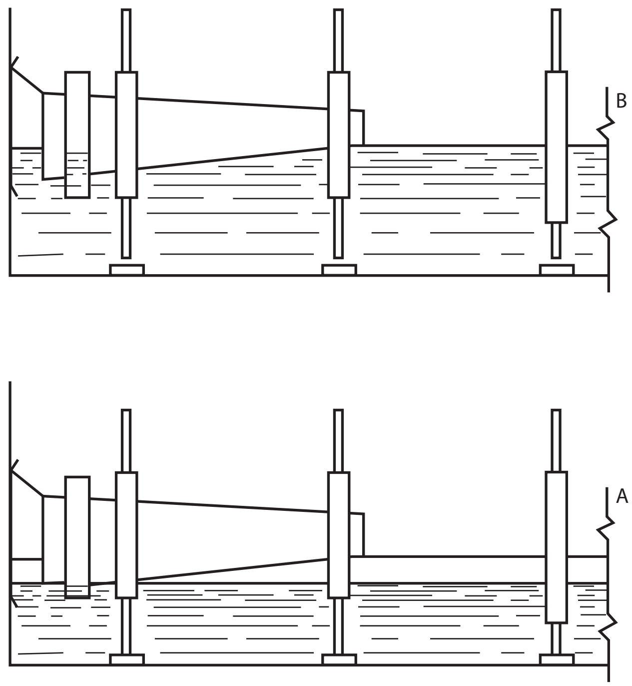
Tanks occasionally have more than one hatch through which it is possible to take measurements. Only one hatch should be used for gauging, specifically, the hatch on which the reference gauge point has been established. This hatch should be the one used for calibration. This is important because the reference gauge height may vary from one hatch to another and because the roof may not be level. Regardless of the number of hatches, it is important to obtain opening and closing gauges through the same hatch.

8.8 Roof Displacement

A floating roof (see Figure 6) will displace a certain volume of liquid when it is in the free-floating position. The weight of the liquid displaced will be equal to the weight of the roof and attached deadwood. Therefore, the roof weight, liquid temperature, and observed density have to be considered when calculating the roof displacement. The roof displacement is used to correct the tank capacity table volumes when the liquid height in the tank is at, or above the point or elevation where the roof floats freely. When the floating roof is resting on any of its supports, the correction for roof displacement does not apply. The liquid is partially displaced by the roof between the point or elevation where the liquid just touches the lowest section of the roof and the point or elevation where the roof floats freely.

This partial displacement area is referred to as the “critical zone.” The tank volume in this partial displacement area may be computed. However, the only accurate way to obtain volumetric data for a tank capacity table in the critical zone is by a liquid calibration procedure. Computing the tank volume in the critical zone is subject to considerable error. It is essential, therefore, that the opening and closing gauges be taken with the roof floating freely or with the roof resting on its normal supports and with the liquid height below the lowest section of the roof. If operationally practical, the roof should be floating freely for both opening and closing gauges.

The position of the critical zone is dependent upon the length of leg (low or high) in use. Also, caution should be exercised if there is sludge and/or sediment in the tank as this can raise the level of the critical zone as indicated on the tank’s capacity table.



Zone in which floating roof displaces part of its weight. Zone limits should be clearly marked on the gauge table. If accuracy in liquid measurements is desired, gauges in this zone should be avoided. For critical measurements, the zone may be callibrated with liquid, using a calibrated tank or meters of known accuracy. For operating control, the zone may be calibrated by field determination of the geometric shapes between positions A and B, or by geometric shapes determined from builder's drawings. Incremental displacements throughout the zone of partial displacement should be continued up to the total displacement, which is equivalent to the weight of the roof and appurtenances.

Figure 6—Schematic Diagram Illustrating the Zone of Partial Displacement Common to All Floating Roofs

Should the displacement of the floating roof be increased due to accumulations of water, snow, or ice, it will be necessary to remove or estimate the additional weight in order to compute the roof displacement. During custody transfer operations involving tank gauges, if water, snow, or ice cannot be removed from a floating roof, it is best to keep the same conditions for both opening and closing gauges if possible.

The calculation of roof displacement is also applicable to fixed-roof tanks containing internal floating roofs.

8.9 Tank Bottoms

Some tanks are equipped with inverted cone bottoms or bottom sumps to facilitate free water removal. With this type of tank bottom, the free water height may not be sufficient to reach the datum plate. In this situation, free water gauges have to be taken through a gauge hatch located over the lowest point in the tank. This is only applicable if the tank's capacity table lists the incremental volumes contained below the datum plate from the gauge point to be used for the determination of free water volumes.

8.10 Temperature Determination and Sampling

As stated in Section 1, this standard outlines procedures for gauging the level of liquid in a tank. Temperature determination and sampling necessary for density and sediment and water determinations should be conducted at time of gauging.

An error in the determination of temperature, density, or sediment and water may result in either overstatement or understatement of quantity regardless of the accuracy obtained in gauging the liquid's level.

8.11 Solid Crust

The existence of a solidified crust of material on top of the product in a tank can adversely affect the accuracy of the gauging, and caution has to be exercised when this condition presents itself. If the gauge bob cannot readily penetrate the surface of the product during an attempt to obtain a gauge for custody transfer, alternate methods of measurement should be reviewed.

Annex A
(normative)

Tape Comparison Against a Traceable Reference Standard

A.1 General

If a certificate of calibration is required for any of the equipment outline in this annex, it shall be traceable to national or international standards.

A.2 Verification of Working Tapes by Comparison with Reference Measurement

Working tapes and bobs shall be checked for accuracy when new, when repaired, and at least annually from the in-service date thereafter by comparison with a reference (e.g. a master tape). The tape and bob comparison, which is considered as verification, may be conducted either horizontally (see A.5) or vertically (see A.6) where a master tape is used. Requirements for PEGDs are described in A.7.

A.3 Accuracy Requirements of Working Tapes/Bobs

When comparing equipment to be used as a working tape/bob, the difference between the inscribed reference point of the working tape and the true length of the working tape/bob at that point shall not exceed ±2 mm for any distance from 0 to 35 m (0 to 125 ft). The comparison shall be verified at regular intervals throughout the working length of the tape/bob weight combination, with such intervals not to exceed 5 m (or 15 ft).

A.4 Requirements of Reference Standard

The uncertainty of the reference standard (e.g. a master tape) shall not exceed ±0.3 mm (or ±0.01 in.) for any distance between 0 and 30 m (0 to 100 ft). A master tape shall be recalibrated at least every five years. Certification shall be provided with the master tape.

NOTE Master gauge tapes are currently certified with a tension applied to the tape in a horizontal position. The tension is normally 44 N (10 lb) for tapes up to 100 ft or 88 N (20 lb) for tapes greater than 100 ft. For metric tapes, the tension applied is normally 50 N (12 lb) for tapes up to 30 m and 100 N (24 lb) for tapes greater than 30 m.

The tension applied to the master tape during certification in NIST is provided on the certificate. NIST uses a laser interferometer as the reference standard to achieve the required uncertainty. The graduations on the master tape are premarked by the tape manufacture, often under a tension of 44 N or 88 N (10 lb or 20 lb).

A.5 Horizontal Tape Verification

To conduct a horizontal tape comparison, set up a test arrangement similar to that shown in Figure A.1 and Figure A.2 and do the following.

a) Inspect the master tape and check the certificate against the tape serial number.

b) Inspect the working tape for kinks, worn snap catch, worn bob eye, worn bob tip, and illegible numbers.

c) Check the calibration of the spring balances for proper reading with a known weight of 5 kg (10 lb) ±0.10 kg (±0.25 lb) as verified on a certified scale or balance that is traceable to NIST or an equivalent national standard. The known weight shall be verified at least once every five years. If the weight is dropped or damaged, it shall be reverified prior to the next use (see Figure A.1). The spring balance has to be capable of indicating a load of 5 kg (10 lb) with an accuracy of ±0.10 kg (±0.25 lb).

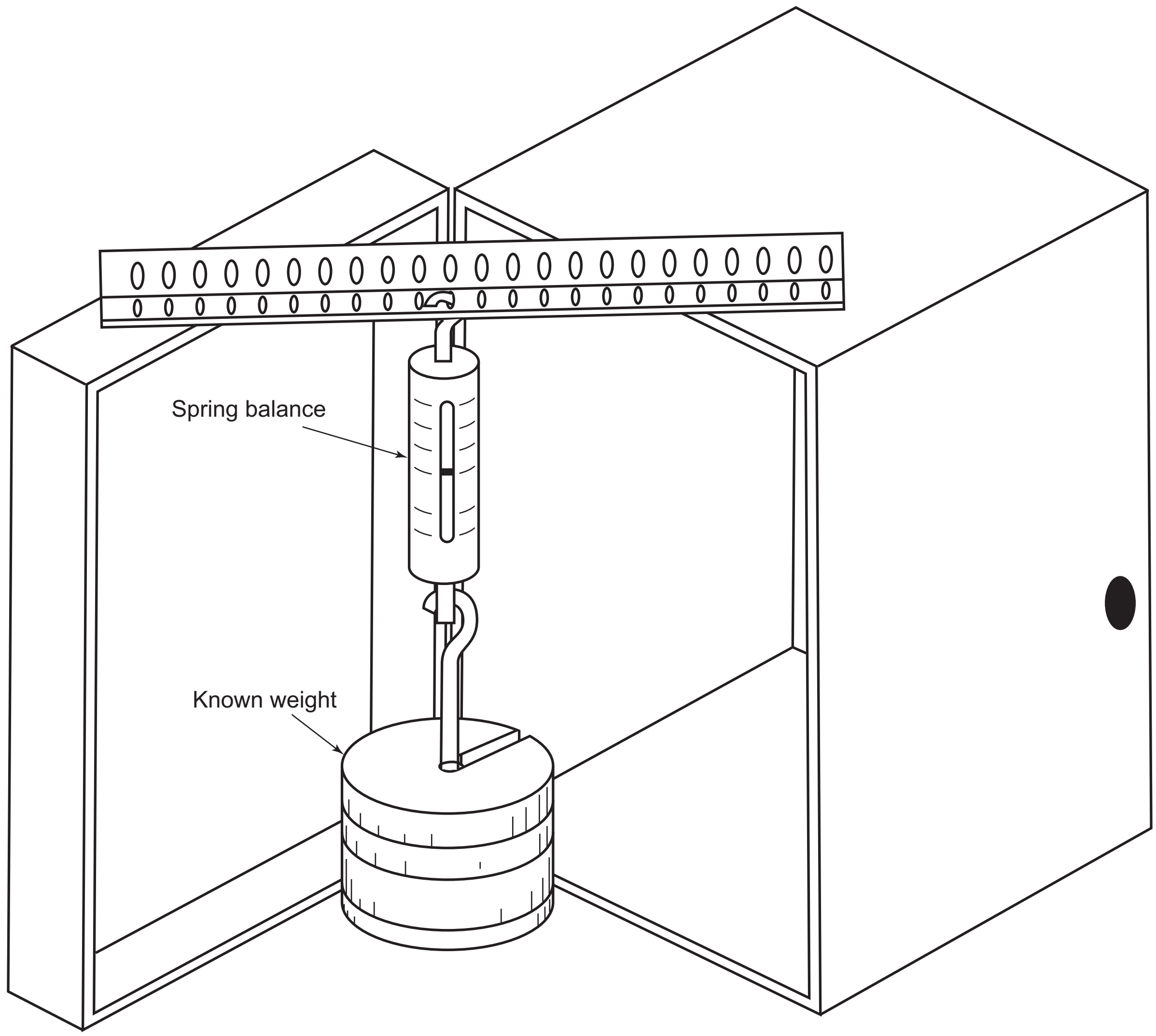


Figure A.1—Calibration of Spring Balance

d) The tape and bob pad (see Figure A.2) allows comparison of two tapes with bobs or a tape with bob and a tape without bob (tank strapping tape). Tapes should be removed from their frames and laid out as shown in Figure A.2. Tapes and bobs should be placed with the bob tip firmly against the bulkhead on the tape and bob pad. Tapes without bobs (if used) should be placed through the slot in the bulkhead so that the center of the tape's zero mark is even with the bulkhead's front face. During setup, care should be taken to avoid kinking the tapes.

NOTE It is not recommended to use a tape with a bob as a master tape because the continuous application of 5 kg (10 lb) of tension will likely cause the clasp to stretch over time.

e) Stretch the working tape and the master tape parallel to each other on a reasonably flat surface such as the corridor of a building or the surface of a parking lot. The evenness of the surface is less important than the parallelism of the tapes. The two tapes should be separated by a constant distance of about 1 cm to 3 cm ($^3/_8$ in. to 1 $^1/_8$ in.). The zero points (usually the bob tips) of the tapes should be even, as shown in Figure A.2.

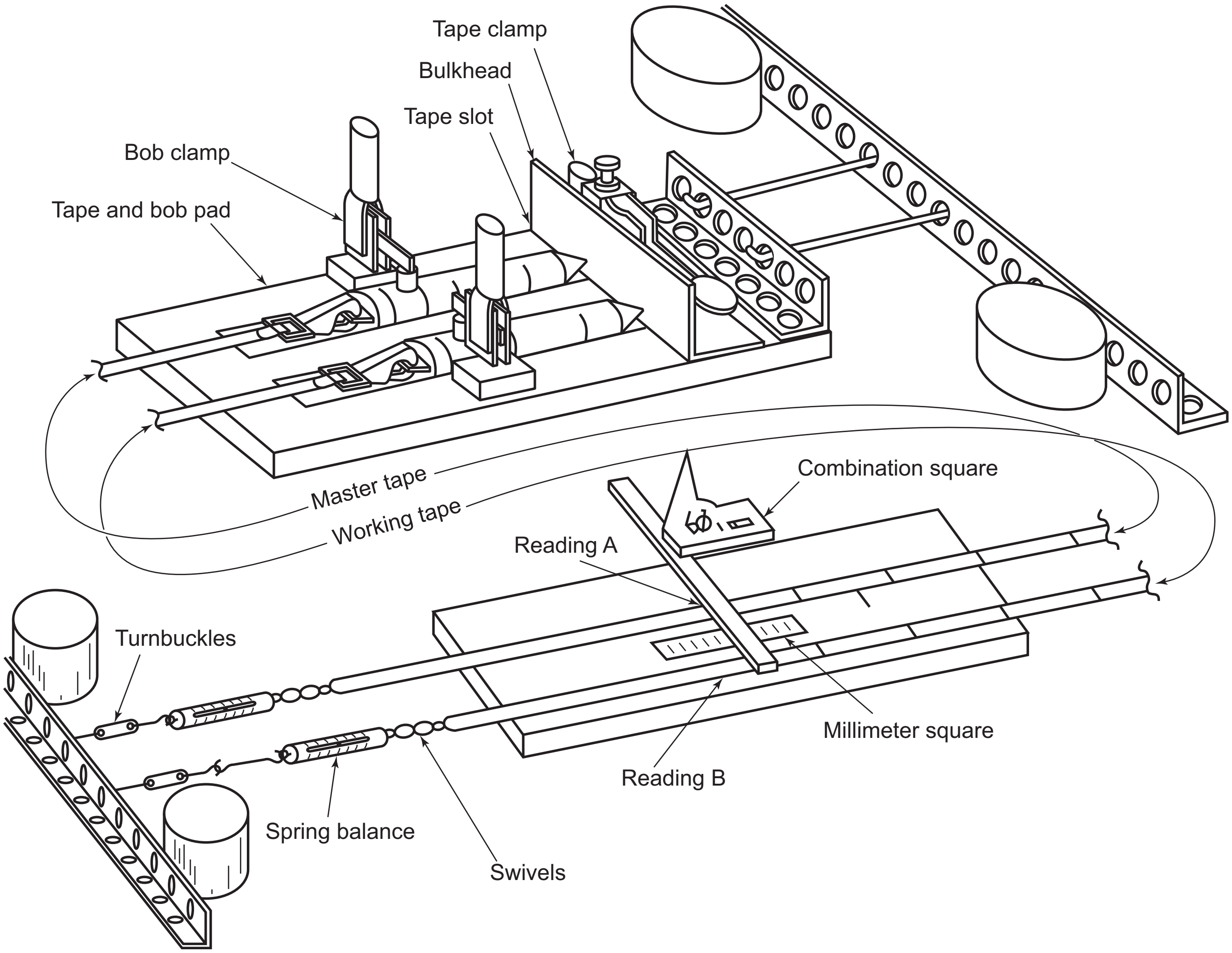


Figure A.2—Tape and Bob Comparison

f) Use the turnbuckles (see Figure A.2) to apply loads as indicated by the spring balances (note the use of swivels to prevent twisting of the tapes). The tension used (by NIST) to certify the master tape shall be applied to the master tape. The tension applied to the working tape should be either:

1) 44 N (10 lb), which is the same tension by NIST for master tapes < 30 m (100 ft) length, or

2) corresponding to the tape/bob combination in operation, provided that the tension applied is sufficient to keep the working tape taut and with no slacks in the verification.

In either case, the tension applied to the master tape and the working tape in the verification shall be documented in the tape verification report.

g) The tension applied to the master tape during certification in NIST is provided on the certificate. NIST uses laser interferometer as the reference standard. The graduations on the master tape are marked by the tape manufacture, often under a tension of 44 N or 88 N (10 lb or 20 lb).

h) Place a steel scale graduated in millimeters at the test point as shown in Figure A.2. Adjust the tapes, the scale, and the support board so that all are precisely parallel. Note the amount of separation between the tapes near the zero point and maintain this distance at the test points. In this way, parallelism of the two tapes is easily verified.

i) Make final tension adjustments on the tapes and recheck for parallelism at all test points before taking readings. Do not disturb the tapes or scale during the measurement sequence.

j) A combination square (see Figure A.2) is used to aid reading the scale. At each test point, center the blade of the square on the master tape's graduation mark and read the millimeter scale where it is intersected by the blade of the square. [See reading A example in Step p).] Without disturbing the tapes or the millimeter scale, center the blade of the square on the working tape's graduation mark and read the millimeter scale where it is intersected by the blade of the square. [See reading B example in Step p).] When reading the scale, estimate the reading to the nearest 0.5 mm.

k) Record the readings on an observation sheet as First Trial.

l) Release the tension on the tapes and reapply it.

m) Displace the scale several millimeters. Then readjust the tape tensions, check for parallelism, and record a second set of readings as Second Trial.

n) Readjust as in Steps l) and m). Then record a third set of readings as Third Trial.

o) Calculate the true length of the working tape at the test point according to the following equation:

$$L = S + K \times [(\Sigma B - \Sigma A)/3]$$

$$L = S + (K/3) \times (\Sigma B - \Sigma A)$$

where

L is the true length of working tape at the test point;

S is the certified length of master at the test point;

K is the conversion factor, tape unties/scale units (i.e. K = 0.00328084 ft/mm);

$K/3$ is 0.0010936 (this is for three readings);

ΣA is the sum of scale readings for master tape;

ΣB is the sum of scale readings for working tape.

p) Calculate and record $B - A$ for each trial. Then record R, the range of values (highest to lowest).

EXAMPLE Certified length of master tape (S) = 100.001 ft.

	Reading A	**Reading B**	**($B - A$)**	**Range (R) [a]**
First Trial	25.5 mm	28.0 mm	2.5 mm	
Second Trial	27.0 mm	29.0 mm	2.0 mm	1 mm
Third Trial	29.0 mm	32.0 mm	3.0 mm	

ΣA=81.5 mm.

ΣB =89.0 mm.

$L = S + 0.0010936\ [\Sigma B - \Sigma A]$ = 100.0092 ft.

[a] The range of values ($B - A$) represented by (R), in the absence of gross errors, would normally differ no more than 3 mm for a 30-m (100-ft) tape, or 0.01 %.

In the preceding comparison procedure (see A.5), the cross-sectional area of the two tapes should be equal. If this comparison procedure is used with tapes of different cross-sectional areas, the length difference found may be a combination of differences in tape lengths and differences in the unit strain between the two tapes.

No temperature correction is required, provided the working tape and the master tape are the same temperature and are made of materials with a similar coefficient of thermal expansion. Tapes of the same color will attain the same temperature, even in sunlight. However, black and white tapes have shown temperature differences of as much as 8 °C when exposed to direct sunlight. In such cases, the temperature difference, even if measured, would be uncertain due to variability of exposure along the length of each tape. Accordingly, calibrations in the laboratory or at least in shade are preferred when possible.

The comparison between the working tape/bob and the master tape may be conducted in the horizontal position. The comparison shall be verified at regular intervals throughout the working length of the tape/bob weight combination, with such intervals typically not exceeding 5 m (15 ft), as well as the full length. When used for custody transfer, the working tape/master tape comparison shall meet the accuracy requirements in A.3.

While the horizontal tape comparison is a practical comparison of tape lengths, it subjects the working tape to a higher tension (unit strain) than is found under normal operating conditions. Therefore, the length of the tape while being used to gauge level may not be the same as the tape length found during the tape comparison test.

A.6 Vertical Tape Verification

The comparison between the working tape/bob and the master tape may be conducted in a vertical position, which will subject both tapes to conditions similar to that found in normal gauging operations. The comparison shall be verified at regular intervals throughout the working length of the tap/bob weight combination, with such intervals not exceeding 5 m (or 15 ft), as well as the full length. When used for custody transfer, the working tape/master tape comparison shall meet the accuracy requirements in A.3.

Master tapes used to compare a working tape in a vertical position shall be certified with a tension corresponding to the tension of working tape/bob in operations. The certifying body has to specifically be requested to certify master tapes for this application with a tension that will more accurately reproduce the effect of the weight of working unit's bob on a vertical tape.

A.7 Verification of Portable Electronic Gauging Devices

The following steps should verify the accuracy of portable electronic gauge tapes.

a) The zero point of the level measured by a portable electronic gauging tape shall be the reaction point at which the sensor detects a liquid surface when operating in the ullage/outage mode. Because the electronic sensor(s) usually need to be protected from mechanical damage, the zero point of the tape/probe combination is generally not the bottom surface of the sensor probe. Thus the zero point will not be directly verifiable without vertical suspension into a liquid surface. In these circumstances, the zero point is at a fixed distance from the bottom surface of the probe. The zero offset distance (recommended by the manufacturer) shall be verified and stated on the certificate of the said unit.

b) Verify the zero point distance against a calibration reference when the sensor probe is suspended vertically into a liquid surface. If the sensor is also intended for measuring oil/water interface, the sensor zero point shall also be verified with the probe suspended vertically into a water surface.

c) Verify the graduated tape in accordance with A.1 and A.5 or A.6, following the same procedure and tolerance for mechanical steel gauging tapes. The tension applied should not damage the electrical and signal wiring connecting with the sensor(s) embedded in the tape. The accuracy of the working tape (and sensor/probe) shall be verified by comparison with a master tape that has been certified by or is directly traceable to NIST, or an equivalent national standard, following the procedure in this annex.

Annex B
(informative)

Gauging Uncertainties of Tank Measurements

B.1 General

Gauge readings and tank capacity tables are used to determine the total observed volume (TOV) of petroleum contained in the tank. The accuracy of the TOV is limited by the inherent accuracy of the tank, regardless of the gauging equipment used.

NOTE While the scope of this standard is limited to the determination of liquid level, a conversion of level to volume will at some point be necessary. The following section is placed here to aid the user in identifying possible inaccuracies associated with tank measurement. It should be further noted that in most cases it is not possible to quantify the effect, if any, of these uncertainties and caution should be exercised if choosing an alternate measurement process as a result of these uncertainties if the precision or uncertainty of the alternate process is equally unknown or unquantifiable.

B.2 Tank Capacity Table Accuracy

API *MPMS* Ch. 2 describes the methods and procedures used to calibrate a tank as well as the calculation procedures used to develop a set of tank capacity tables from the tank calibration data. Tank capacity tables produced from these procedures include inherent inaccuracies due to:

a) strapping tape calibration,

b) strapping tape thermal expansion,

c) tension of the strapping tape,

d) correction for shell expansion due to liquid head (static head),

e) measurement of shell plate thickness,

f) calculation of deadwood, and

g) other factors.

The errors due to these inaccuracies can result in either an overstatement or understatement of quantity.

B.3 Shell Expansion Due to Liquid Head

As a tank is filled, the tank shell will expand due to the weight of the tank's contents (liquid head). The liquid head correction may be applied in volume calculations, or alternatively, the liquid head correction should be incorporated into the tank capacity table. Calculation procedures used to correct the tank capacity table for shell expansion due to liquid head are found in API *MPMS* Ch. 2.

An angular deflection of the tank shell near the bottom of the tank is the result of the bottom of the tank counteracting the shell expansion caused by an increasing liquid head when the tank is filled. This angular deflection of the tank shell (barreling) may result in movement of the tank bottom and the cone roof. A correction for these two movements is not contained in the tank capacity table.

B.4 Bottom Movement

Tank bottoms may deform into the supporting soil under the weight of the tank contents. This deformation can be either permanent (settlement) or elastic (diaphragming).

Sometimes, as the tank is filled, the bottom section adjacent to the tank shell moves upward because of the angular deflection of the tank shell outward. Further from the shell, the tank bottom may be stationary, while the center of the tank bottom moves downward. The amount of movement depends on the soil's compressive strength and on the shape of the tank bottom. If the gauging location is close to the tank shell, the reference height may grow shorter as the tank fills. Under this scenario (see Situation 1 in Figure B.2), outage/ullage gauging is recommended rather than innage gauging; otherwise, an understatement of liquid volume in the tank (at the time of measurement) is likely.

If the gauging location is further from the tank shell, the reference height may grow longer as the tank fills. Under this scenario (see Situation 2 in Figure B.3), innage gauging is recommended; otherwise, an understatement of liquid volume in the tank (at the time of measurement) is likely.

In order to determine whether either condition exists, and to reduce the effect of elastic diaphragming on measurement accuracy, a recording and analysis of the observed gauge height history for each tank is recommended.

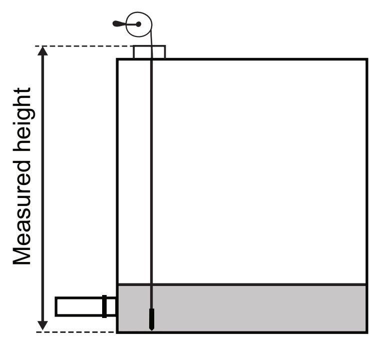


Figure B.1—Tank Without Deformation

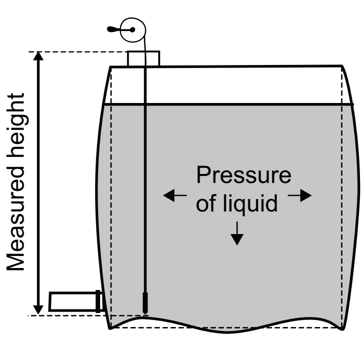


Figure B.2—Situation 1

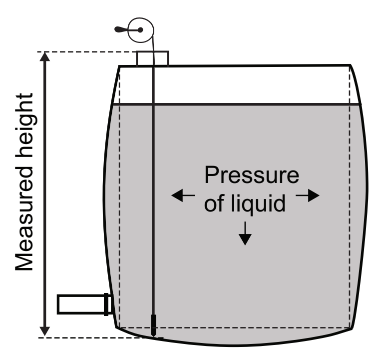


Figure B.3—Situation 2

B.5 Still Pipe (Stilling Well, Gauge Well) Tanks

Tanks, particularly floating-roof tanks, are frequently fitted with still pipes. The upper lip of the still pipe is a good location for the reference gauge point. The lower end of the still pipe serves as a good location from which to support the datum plate. However, a vertical movement of the still pipe will cause the attached reference gauge point and datum plate to move vertically. This movement causes liquid height measurement errors. The following describes a properly installed still pipe.

a) The recommended minimum diameter of a perforated or slotted still pipe is 20 cm (or 8 in.). Smaller diameter still pipes may be used provided that sufficient space is available for taking manual tank samples with a sample bottle or thief. If smaller diameter still pipes are used, the design and construction of the still pipe should be checked for mechanical rigidity and strength.

b) The still pipe should be guided at the top of the tank and not rigidly attached.

c) The lower lip of the still pipe should extend to within 30 cm (12 in.) of the tank bottom.

d) The still pipe should have two rows of slots or two rows of holes (i.e. perforations) located on the opposite sides of the pipe, which start at the lower end of the pipe and continue to above the maximum liquid level. Typical sizes of the slots are 2.5 cm (1 in.) in width and 25 cm (10 in.) in length. Typical diameter of the perforation is 5 cm (2 in.).

e) In the event a smaller diameter still pipe is retrofitted inside a larger still pipe, the slots or perforations should be designed to allow free flow of liquid to ensure accuracy of the tank measurement (level, sample, and temperature).

f) The maximum spacing between perforations or slots if not overlapping should be 30 cm (12 in.).

g) The still pipe may be supported from the tank bottom if the tank bottom does not move vertically in relation to the bottom corner of the tank where the shell plate is welded to the bottom plate.

h) If an alternate means of supporting the still pipe is used, the support should be designed to prevent vertical movement of the point of attachment.

NOTE If vertical movement of the still pipe cannot be prevented, alternative measurement systems should be explored.

i) Tank gauging shall not be carried out from unperforated or unslotted still pipes (which are referred to as “guide poles” or “stand pipes”), since the liquid level measured inside the unperforated or unslotted still pipes is usually not the same the liquid level outside the still pipe. Tank gauging shall only be taken from still pipes that have perforations or slots that allow free flow of liquid into and out of the still pipe. In certain locations, still pipes without slots are used to comply with local air pollution regulations. These “solid” still pipes can lead to serious liquid height measurement, temperature determination, and sampling errors.

B.6 Changes in the Height of the Reference Gauge Point

The angular deflection of the tank shell may cause the datum plate and/or the reference gauge point to move upward when either is rigidly connected to the bottom course of the tank shell. As the liquid head on the tank shell is increased, the top of the shell plates moves downward as a result of steel contraction perpendicular to the shell expansion. This downward movement is related to the shell expansion by the Poisson ratio of steel (i.e. 0.3). For example, if the shell expansion is 0.2 %, the top of the shell moves downward $0.3 \times 0.2\ \% = 0.06\ \%$ of the tank with a full tank and proportionally lower with the degree of fill. Reference gauge points connected to the top of the shell will also move downward when the tank is being filled. Other forces acting on the tank, like loads on the roof of a cone tank, may cause the reference gauge point to move in the vertical direction with respect to the top of the shell when supported by the roof.

B.7 Datum Plate

If a tank is equipped with a datum plate, the datum plate may be:

a) secured to the tank bottom,

b) secured to the corner where the tank shell and bottom meets,

c) directly attached to the lower end of the still pipe.

If the tank is equipped with a datum plate, it should be located directly under the reference gauge point. There should be an open space between the lower lip of the still pipe and the datum plate.

The datum plate centerline should be located between 45 cm (18 in.) and 80 cm (30 in.) from the tank shell, located vertically below the gauging point.

NOTE 1 Tank bottom movements may cause movement of datum plate.

NOTE 2 Datum plates, which are rigidly attached to the tank shell and cantilevered outward, will move up when the tank is filled, due to angular deflection of the tank shell. In most cases, angular deflection of the tank shell ceases to cause tank bottom movement at approximately 45 cm to 60 cm (18 in. to 24 in.) from the tank shell.

NOTE 3 Datum plate mounted at the end of still pipe will move in conjunction with any still pipe movement.

B.8 Incrustation

A tank may accumulate deposits such as rust, wax, paraffin, tar, water, and sulfur on the inside of the shell and roof supports. Such incrustation decreases the capacity of the tank, resulting in an over statement of quantity. A thorough cleaning of a tank in this condition is necessary before accuracy may be obtained. Refer to API 2556.

B.9 Thermal Expansion of Tank Shell and Still Pipe

Tank capacity tables are prepared with an assumed reference shell temperature. As a result, a correction factor is applied to the volume obtained from the tank capacity table to account for the actual tank shell temperature. See API *MPMS* Ch. 12.1 for details.

The upper reference gauge point may move up vertically due to thermal expansion of the tank shell (and still pipe where the reference gauge point is usually located). This movement may cause an error if liquid level (or dip) is determined from the ullage gauging.

B.10 Alternative Gauging Access Points

Gauging access points should normally be located between 0.5 m and 1.0 m radially inwards from the tank shell as this region is best able to provide stable datum levels. It also coincides with the region recommended for temperature measurement (in order to avoid errors due to direct solar radiation affecting the temperature within 0.5 m of the shell). If the tank bottom is coned downwards and water is likely to be present in the tank, or if bottom movement is likely due to settlement of the tank foundations, it is recommended that an additional hatch should be provided at or near the center of the tank.

Annex C
(informative)

Tank Mixers and Tank Mixing for Custody Transfers

C.1 Introduction

The custody volume determination in vertical cylindrical storage tanks is based on measurements taken at the stilling well. Such measurements include level, temperature, free water, and sampling. Stilling well is the certified location for all tank measurements. In doing so it is assumed that the product in the stilling well truly represents the total volume contained within the tank. In other words, it is assumed that the contents of the tank are fully mixed or homogenized.

C.2 Background

Both custody and inventory tanks receive products of different grades, different gravity, temperature, viscosity, and water content (especially in crude). While there is inherent mixing energy available from the flow conditions and pipeline configurations, the residual mixing energy is barely sufficient to provide adequate mixing of the tank contents.

In the absence of tank mixers (power mixers) and tank mixing, one cannot expect total homogenization of the tank contents, and thus the assumption that the stilling well location represents the entire tank may not be totally valid in all cases. Lack of mixing of tank contents could result in horizontal and vertical temperature stratification, could result in SW stratification, and also result in accumulation of sludge.

C.3 Mixers and Mixing Duration

All tanks in custody service would need power mixers and tanks should be adequately mixed prior to custody transfer measurements at the stilling well. The number of mixers and the duration of mixing will vary from tank to tank depending on tank size and the product's characteristics (viscosity, density, and temperature). The number of mixers may vary from one to three while the capacity each of mixer would depend on tank diameter and product quality parameters. As far as the duration of mixing, optimum mixing time should be determined by actual field tests. A minimum mixing time of 30 minutes may be considered in the absence of any other criteria.

Power mixers should be an integral part of any new tank construction for custody service. For tanks already in custody service, installation of power mixers should be considered when the tank is scheduled for internal inspection and maintenance work.

C.4 Application of Power Mixers

Application of power mixers for tank mixing will promote overall integrity of custody measurements in stilling wells. It will minimize density stratification, minimize accumulation of tank sludge, and facilitate easier reference height verification and free water determination as well as minimize SW stratification. Overall, tank mixing will enhance custody transfer measurements.

Annex D
(informative)

Caverns

In some countries, crude oil, petroleum products, or LPG are stored in underground caverns.

Caverns for petroleum storage may be naturally formed, but they are usually man-made and constructed by excavation or by leaching out salt deposits with water. There are two main types of cavern according to their method of operation, namely:

— caverns that are kept full at all times, where inward and outward movements of product are balanced by outward or inward movements of water;

— caverns that contain a vapor phase or ullage space, similar to a fixed-roof tank.

Some caverns are calibrated to enable volume measurement of the contents to be determined. For such caverns, level measurement techniques are similar to those employed in measurement of oil levels in storage tanks, with gauging being carried out using extra long dip tapes.

Due to the depths involved (and the possibility of debris accumulating on the cavern bottom), it is normal practice to carry out measurement of oil and water level by ullaging, with ullage being converted to equivalent dip by using a reference height.

Some caverns contain a water bottom. This may not be static due to water ingress from the subsoil, rainwater, and/or sea/rivers. Therefore, some form of water management technique is normally necessary.

Such techniques may include:

— a simple estimation of water ingress from historical data,

— sophisticated automatic level management methods involving weirs with pumps controlled by a computer containing data on water ingress when oil volumes are static.

When caverns are used for custody transfer measurement, it is necessary to measure water levels both before and after the movement and adjust the volume difference for any water ingress that may have occurred during the period between the measurements.

NOTE The control of cavern inventory may be based on measurements by flow meter. In such cases it is recommended that periodic checks should be carried out using manual or automatic gauging to verify the control data. It should also be noted that the precision of cavern calibration tables is likely to be significantly inferior to those of vertical cylindrical tanks calibrated by standard techniques such as the manual measurement and optical reference line methods.

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