# Manual of Petroleum Measurement Standards Chapter 3—Tank Gauging

## Section 1A—Standard Practice for the Manual Gauging of Petroleum and Petroleum Products

SECOND EDITION, AUGUST 2005

API
American Petroleum Institute

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**Measurement Coordination Department**

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# Chapter 3—Tank Gauging

## Section 1A—Standard Practice for the Manual Gauging of Petroleum and Petroleum Products

### 3.1A.1 Scope

This standard describes the following: (a) the procedures for manually gauging the liquid level of petroleum and petroleum products in non-pressure fixed-roof, floating-roof tanks and marine tank vessels, (b) procedures for manually gauging the level of free water which 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) the 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.

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

The determination of temperature, 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*).

### 3.1A.2 Referenced Publications

The following publications are cited in this standard:

API

*Manual of Petroleum Measurement Standards*

| | |
|---|---|
| Chapter 2, | "Tank Calibration" |
| Chapter 7, | "Temperature Determination" |
| Chapter 8, | "Sampling" |
| Chapter 9, | "Density Determination" |
| Chapter 10, | "Sediment and Water" |
| Chapter 12, | "Calculation of Petroleum Quantities" |
| Chapter 17, | "Marine Measurement" |
| RP 49 | *Recommended Practices for Safe Drilling of Wells* |
| RP 55 | *Recommended Practices for Conducting Oil and Gas Production Operations Involving Hydrogen Sulfide* |
| RP 2003 | *Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents* |
| RP 2026 | *Safe Descent Onto Floating Roofs of Tanks in Petroleum Service* |
| RP 2217 | *Guidelines for Confined Space Work in the Petroleum Industry* |

ACGIH[1]

Threshold Limit Values for Chemical Substances and Physical Agents in the Work Environment

ICOS[2], IAPH[3], OCIMF[4]

*Inert Flue Gas Safety Guide*

*International Safety Guide for Oil Tankers and Terminals*

OSHA[5]

29 *Code of Federal Regulations* Sections 1910.134 and 1910.1000 and following

### 3.1A.3 Significance and Use

Gauge readings of petroleum and free water are used with tank capacity tables to determine the total observed volume (TOV) of the petroleum contained in the tank. The total observed volume is used with various correction factors to calculate the gross standard volume (GSV), the net standard volume (NSV), and other volumes of interest. See "Calculation of Petroleum Quantities" in *MPMS* Chapter 12.

This standard is applicable for gauging quantities of liquids having Reid Vapor Pressures less than 103 kPa [15 pounds per square inch atmospheric (PSIA)].

### 3.1A.4 Outline of Method

There are two basic types of procedures used for obtaining a gauge reading—innage and outage (dip and ullage). For the innage method, the gauge reading shall be defined as the measure of the linear distance along a vertical path from the datum plate or tank bottom to the surface of the liquid being gauged. An innage gauge is a direct measurement of liquid level. For the outage method, the gauge reading shall be defined as the measure of the linear distance along a vertical path from the surface of the liquid being gauged to the tank reference gauge point. An outage gauge is an indirect mea-

[1]American Conference of Governmental Industrial Hygienists, 1330 Kemper Meadow Drive, Cincinniati, Ohio 45240, www.acgih.org.
[2]International Chamber of Shipping, Carthusian Court, 12 Carthusian Street, London, EC1M6EZ, England, www.marisec.org.
[3]International Association of Ports and Harbors, 5th Floor, North Tower New Pier Takeshiba, 1-11-1 Kaigan, Minato-ku, Tokyo, 105-0022, Japan, www.iaphworldports.org.
[4]Oil Companies International Marine Forum, 27 Queen Anne's Gate, London, SW1H9BU, England, www.ocimf.com.
[5]Occupational Safety and Health Administration, 200 Constitution Ave. N.W., Washington, D.C. 20210, www.osha.gov.

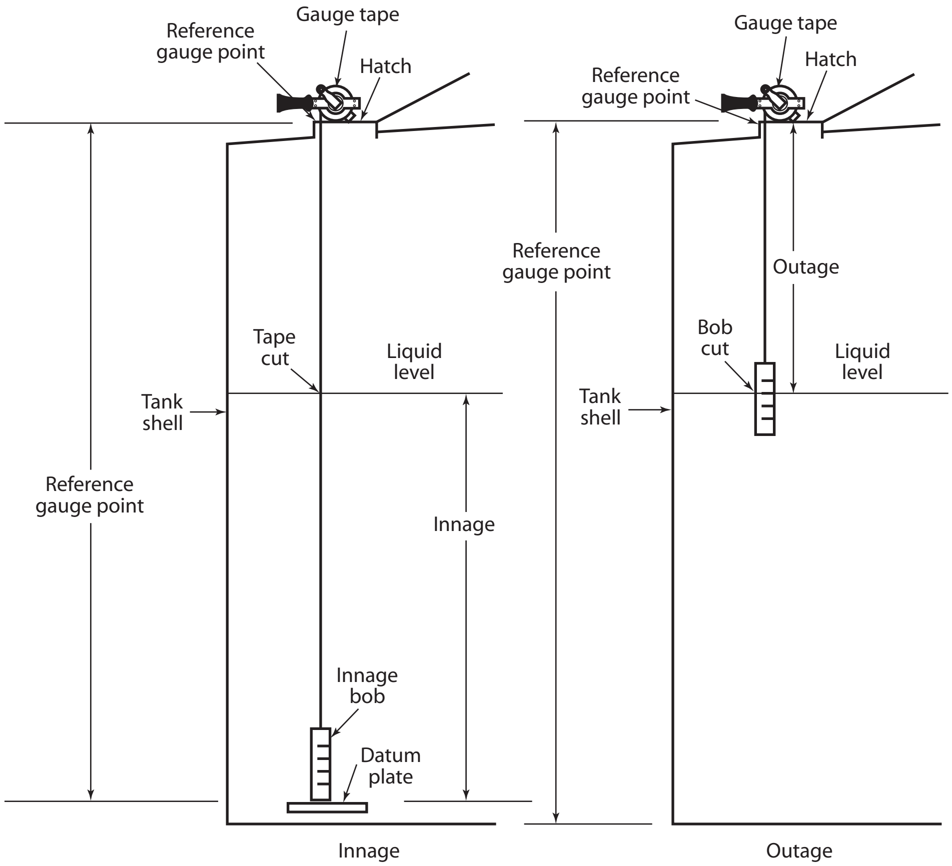



Figure 1—Gauging Diagram

surement of liquid level. Figure 1 illustrates the innage and the outage methods for obtaining a gauge reading.

Innage gauges are generally preferred, as these may reduce the effect of tank reference point movements.

However, there are circumstances where outages will be more applicable. When the outage method is used, every effort should be made to periodically verify the tank's reference gauge height for both opening and closing conditions to ensure it has not changed. If the reference gauge height has changed, use of innage gauges is recommended.

## 3.1A.5 Health and Safety Precautions

### 3.1A.5.1 GENERAL

These health and safety precautions represent good practice. This list is not necessarily complete or comprehensive. Refer also to the health and safety precautions described in API RP 2003, API RP 49, API RP 55, 29 *CFR* 1910.134 (Respirator Standard), or other applicable state/federal regulations, and described in Appendix B of this standard.

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.

### 3.1A.5.2 STATIC ELECTRICITY HAZARDS

To eliminate hazard from static electricity, ground your body by touching the steel stair rail, platform, or tank shall when approaching the top of the tank and before opening the gauge hatch.

Petroleum has static-accumulating characteristics. Ropes or cords used to suspend measuring instruments in a tank should be made of a material, such as cotton, which will not hold or transfer a static charge. Do not use ropes or cords made from synthetic fibers or personal items of clothing, such as coveralls, made from materials known to generate static electricity. Gauge tapes and bobs shall be grounded to the tank by maintaining contact between the gauge tape and the gauge hatch from the moment the gauge bob enters the hatch until at least such time as the bob enters the liquid. Never gauge a tank during an electrical storm.

#### 3.1A.5.3 HEALTH HAZARDS

Petroleum vapor dilutes oxygen in the air and may also be toxic, especially hydrogen sulfide vapors from "sour crude." Petroleum vapors with relatively low concentrations of hydrogen sulfide may cause unconsciousness or death. During and after the opening of the gauge hatch, position yourself so that gas will not be inhaled.

Harmful vapors or oxygen deficiency cannot always be detected by smell, visual inspection, or judgment. Appropriate precautions should be used for the protection against toxic vapors or oxygen deficiency. Procedures should be developed to provide for the following:

a. exposure monitoring,
b. need for personal protective equipment, and
c. emergency rescue precautions.

When necessary, suitable fresh air breathing equipment should be worn prior to entering the gauge site and during the gauging procedure.

#### 3.1A.5.4 ELECTRONIC GAUGING EQUIPMENT

Portable electronic gauging equipment are also known as portable electronic gauging devices, or portable electronic gauging tape. Portable electronic gauging equipment for detecting either the liquid level of petroleum and/or the interface of petroleum and free water must be certified by a suitable agency as safe for use in flammable atmospheres and for use with liquids that accumulate static charges.

Flashlights must be certified by a suitable agency as safe for use in flammable atmospheres.

#### 3.1A.5.5 MANUAL GAUGING ON INERTED MARINE TANK VESSELS

Manual gauging on inerted vessels requires observance of the safety procedures given in Chapter 9 of the *International Safety Guide for Oil Tankers and Terminals*; the *Inert Flue Gas Safety Guide*; and the relevant pamphlets issued by the International Chamber of Shipping, Oil Companies International Marine Forum; and other similar publications.

Personnel involved with the handling of 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. These persons should comply with individual company safe operating practices and local, state, and federal regulations, including use of proper protective clothing and equipment. Personnel should be alert to avoid potential sources of ignition and should keep containers of materials closed when not in use.

## 3.1A.6 Terminology

**3.1A.6.1 closing gauge:** An innage or outage gauge taken after the transfer of material into or out of the tank.

**3.1A.6.2 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."

**3.1A.6.3 cut:** The line of demarcation on the measuring scale made by the material being measured (see Figure 1).

**3.1A.6.4 datum plate (see Figure 1):** A level metal plate located directly under the reference gauge point to provide a fixed contact surface from which liquid level measurement can be made.

**3.1A.6.5 free water:** Water present in a tank which is not in suspension or dissolved in the petroleum. Free water should be gauged with the innage gauging procedure (see 3.1A.9.2). Free water may also be gauged with the outage gauging procedure (see 3.1A.9.3) if the reference gauge height has not changed from the opening to the closing condition. If the reference gauge height has changed, the innage gauging procedure should be used.

**3.1A.6.6 innage gauge (dip):** The level of liquid in a tank measured from the datum plate or tank bottom to the surface of the liquid (see Figure 1).

**3.1A.6.7 list:** The leaning or inclination of a vessel expressed in degrees port or starboard. 3.1A.6.3 observed gauge height: The existing distance from the datum plate (see Figure 1) or tank bottom, to the reference gauge point.

**3.1A.6.8 opening gauge:** An innage or outage gauge taken before the transfer of material into or out of the tank.

**3.1A.6.9 outage gauge (ullage):** The distance from the surface of the liquid in a tank to the reference gauge point of the tank (see Figure 1).

**3.1A.6.10 reference gauge height:** The standard distance from the datum plate (see Figure 1) or tank bottom to the reference gauge point. This distance should be clearly marked on the tank top near the gauge hatch.

**3.1A.6.11 reference gauge point:** A point marked on the gauge hatch of a tank (see Figure 1) to indicate the position at which gauging shall be carried out. Gauging from the reference gauge point is crucial to the achievement of repeatability among individual gauge readings. This point may be a stenciled mark, a small fixed plate inside the gauge hatch, a narrow groove cut horizontally on the inside of the hatch, or the edge of a fixed metal arm which projects a short distance above the gauge hatch but does not contact the hatch.

**3.1A.6.11 suspended sediment and water:** Sediment and water which is entrained or suspended in the petroleum. Suspended sediment and water cannot be determined with innage or outage gauging procedures. Refer to API *MPMS* Chapter 8, "Sampling" and to Chapter 10, "Sediment and Water."

Note: Sediment may settle to the tank bottom. Floating roofs may come to rest on the settled sediment resulting in a shift of the roof's critical zone.

**3.1A.6.12 tank capacity table (tank gauge table):** A table showing the capacities of, or volume in, a tank for various liquid levels measured from the datum plate (tank bottom) or reference gauge point. The volume shown on the table may be in gallons, barrels, cubic meters, liters, or cubic feet. The table may be prepared for use with innage gauges or outage gauges. Tank capacity tables should be developed per API *MPMS* Chapter 2, "Tank Calibration."

**3.1A.6.13 trim:** The condition of a vessel with reference to its longitudinal position in the water. Trim refers to the difference between forward and aft drafts and is expressed "by the head" or "by the stern."

## 3.1A.7 Gauging Equipment

### 3.1A.7.1 GAUGE TAPES

Graduated tapes (see Figure 2) which conform to the following specifications are required for innage and outage gauging procedures:

a. *Material*: Steel (or corrosion-resistant material, if the tape is to be used for gauging the contents of tanks which contain corrosive liquids). The steel of the tape should have a thermal expansion coefficient similar to the steel of the tank.

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% when pulled by a force of 44 N (10 lbf). Typically the cross-sectional area shall not be smaller than 2.5 $mm^2$ (0.004 $in.^2$).

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; feet and hundredths of a foot; or meters, centimeters, and millimeters. The tip of the bob will be the zero point of the scale.
2. Outage Tape—Graduated in feet, inches, and fractions of an inch; feet and hundredths of a foot; or 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: Tapes which have been kinked or spliced or which contain illegible markings shall not be used.

### 3.1A.7.2 GAUGE BOBS AND BARS

Graduated cylindrical, square, or rectangular bobs, or water gauge bars (see Figure 2) which conform to the following specifications are required:

a. *Materials*: Spark and Corrosion-resistant.

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

c. *Weight*: Minimum 20 oz; maximum 2 $^3/_8$ lb.

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; tenths of a foot with at least hundredths of a foot subdivisions; or centimeters with at 1 mm subdivisions and with the zero point of the scale at the tip of the bob.
2. Outage Bobs—Graduated on one side in inches with at least $^1/_8$ in. subdivisions, or in centimeters with 1 mm subdivisions and with the zero point of the scale being at the inside of the eye, except for the extension outage which is described below.

### 3.1A.7.3 OTHER GAUGING EQUIPMENT

#### 3.1A.7.3.1 Customary/Metric Tapes and Bobs

Customary/metric tapes and bobs are innage and outage tapes and bobs which have two measurement scales. On one side of the tape and bob, the scale is graduated in customary (feet & inches) units; on the opposite side of the tape and bob, the scale is graduate in metric units (SI).

#### 3.1A.7.3.2 Extension Outage Bob

The extension bob (see Figure 2) is designed for taking outage gauges with an innage tape. The specifications for the graduated portion of the bob are the same as for the plain bob. The eye of the bob is so located in the ungraduated portion that the zero point of the bob scale will also be the zero point of the tape scale.

#### 3.1A.7.3.3 Portable Electronic Gauging Equipment

##### 3.1A.7.3.3.1 General

Portable electronic gauging devices (PEGDs) usually consist of an electronic sensing device suspended on a measuring tape, and a housing with readouts. If used for custody transfer gauging, these devices shall be capable of demonstrating the same measurement accuracy as the non-electronic gauging tape and bob, and shall be calibrated or verified against a reference measurement (Refer to Appendix A).

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

##### 3.1A.7.3.3.2 Construction and Graduation

The tape cross-sectional area shall be designed for the increase of tension due to the weight of the sensor probe assembly when the tape is vertically suspended in air. The material of construction and graduation of the main measuring tape should comply with the specification for gauge tapes given in 7.1.

##### 3.1A.7.3.3.3 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.

##### 3.1A.7.3.3.4 Zero Point

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 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 shall be verified and stated on the certificate of the said unit.

If the portable electronic gauging tape can be used to measure the reference height of a tank, then it will be necessary to add this distance (the zero point offset distance) to the observed tape reading to calculate the actual reference height value.

##### 3.1A.7.3.3.5 Reading Index Mark with Use of a Vapor Lock Valve

Portable electronic gauging tapes that are designed for use via a vapor lock valve should be provided with a reading index mark. The offset distance of the center of the reading index mark from the point of the portable electronic gauging tape which corresponds to the gauging reference point (or datum point of the vapor lock valve) should be pre-set. The offset distance should be specified by the manufacturer.

#### 3.1A.7.3.4 Water Indicating Paste

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

#### 3.1A.7.3.5 Gasoline 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, gasoline 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).

#### 3.1A.7.3.6 Oil Thief

A trap type core thief is a sampling device that may be used to approximately measure free water or emulsified oil, sediment, and water levels in tank bottoms. The oil thief may also be used to take spot samples of petroleum. Reference API *MPMS* Chapter 8 for construction.

## 3.1A.8 Gauging Accuracy

### 3.1A.8.1 EQUIPMENT ACCURACY

#### 3.1A.8.1.1 Accuracy Requirements of Non-electronic Steel Tape and Bob

a. 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 the National Institute of Standards and Technology (NIST), or other national weights and measures standards authorities, using the procedure in Appendix A. The accuracy of the working tape shall meet the requirements in Appendix A.1.2.

b. Frequency of Verification

1. The tape and bob assembly shall be inspected daily, or prior to each use 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

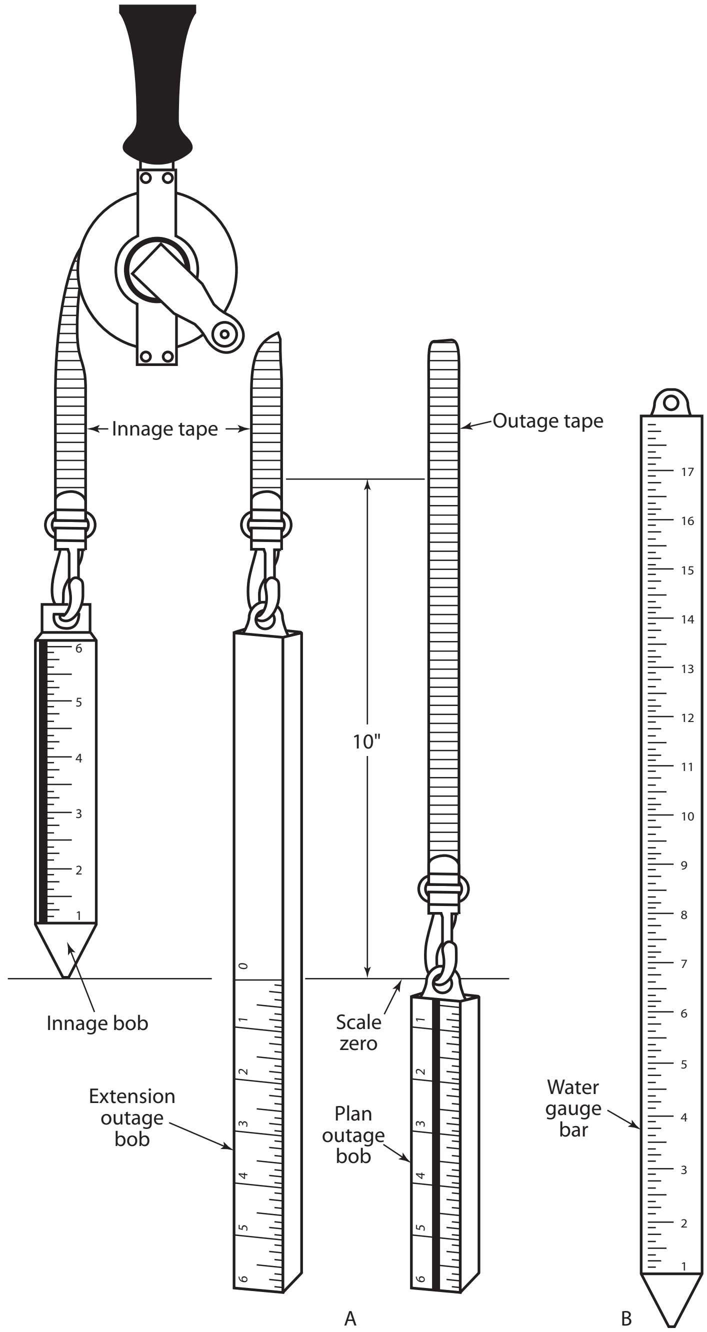



Figure 2—(A) Gauge Tapes and Bobs (B) Typical Water Gauge Bar

inspected for kinks. Kinked or spliced tapes shall not be used in custody transfer applications.

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

#### 3.1A.8.1.2 Accuracy Requirements of Portable Electronic Gauging Device

a. 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, the NIST, or national weights and measures authorities, using the procedure in Appendix A. The accuracy of the working tape shall meet the requirements in Appendix A.1.2.

b. Frequency of Verification

1. Portable electronic gauging tape assembly shall be inspected daily or prior to each use 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 or spliced tapes shall not be used in custody transfer applications.

2. Portable electronic gauging devices shall be verified when new and at least annually thereafter using the procedure in Appendix A. The sensor/probe shall be checked using a beaker of water for detection signal at least once every six months.

### 3.1A.8.2 UNCERTAINTIES OF TANK MEASUREMENTS

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.

#### 3.1A.8.2.1 Tank Capacity Table Accuracy

The API *MPMS* Chapter 2, "Tank Calibration," 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 over- or under-statement of quantity.

#### 3.1A.8.2.2 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 head 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* Chapter 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.

#### 3.1A.8.2.3 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). Generally, as the tank is filled, the bottom section adjacent to the tank shell moves upward because of the angular deflection of the tank shell. Further from the shell, the tank bottom is stationary. 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.

With elastic deformation (diaphragming), the tank bottom moves up or down in relation to the height of the liquid contained in the tank. Unless tank capacity tables have been adjusted for the effect of elastic diaphragming of the tank, or unless water bottoms are employed to negate this feature, elastic diaphragming of the tank bottom results in an understatement of quantity on every transfer.

#### 3.1A.8.2.4 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 shall 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.).

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

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

f. 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.

g. 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.

h. Tank gauging shall not be carried out from un-perforated or un-slotted still pipes (which are referred to as “guide poles” or “stand pipes”), since the liquid level measured inside the un-perforated or un-slotted 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 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.

### 3.1A.8.2.5 Changes in Reference Gauge Point Height

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 x 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.

### 3.1A.8.2.6 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 shall be an open space between the lower lip of the still pipe and the datum plate.

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

Notes:

1. Tank bottom movements described in 3.1A.8.2.3 may cause movement of datum plate.

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 – 60 cm (18 – 24 in.) from the tank shell.

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

### 3.1A.8.2.7 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.

### 3.1A.8.2.8 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* Chapter 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 upper reference gauge point is usually located). This movement may cause an error if liquid level (or dip) is determined from the ullage gauging.

### 3.1A.8.3 OPERATIONAL PRECAUTIONS

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.

#### 3.1A.8.3.1 Leaks

Tanks, connecting valves, and transfer lines that leak during a transfer of petroleum will cause an over- or under-statement of quantity. Report any leak promptly so that the condition can be corrected.

#### 3.1A.8.3.2 Line Displacement

Before taking an opening or closing gauge, verify the displacement of the transfer line. Make every effort to have the transfer line in the same condition of fill for both opening and closing gauges. Refer to API *MPMS* Chapter 17.6.

#### 3.1A.8.3.3 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.

#### 3.1A.8.3.4 Water Draw-Off

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

#### 3.1A.8.3.5 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.

#### 3.1A.8.3.6 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. The same gauging apparatus should be used for both opening and closing gauges.

#### 3.1A.8.3.7 Roof Displacement

A floating roof (see Figure 3) 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, temperature, and the density of the liquid must 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. For the closest approach to accuracy, the roof should be floating freely for both opening and closing gauges.

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.

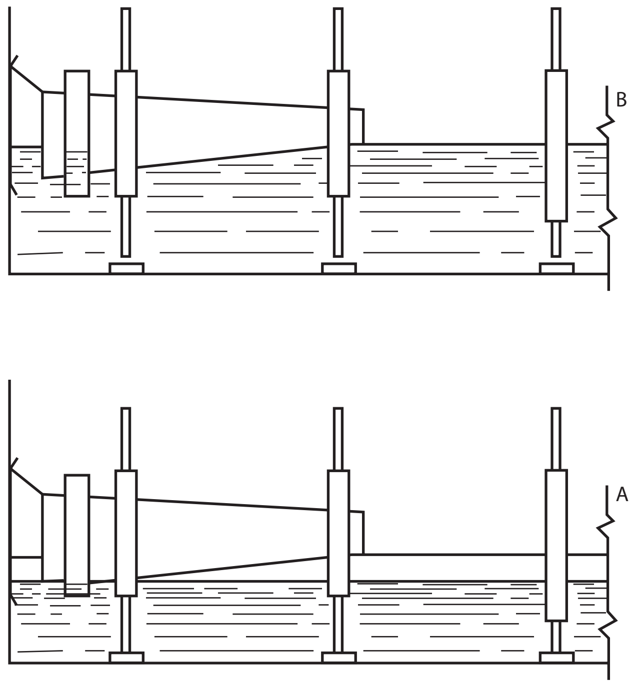
#### 3.1A.8.3.8 Tank Bottoms

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 must 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.

#### 3.1A.8.3.9 Temperature Determination and Sampling

As stated in 3.1A.1, this chapter 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 over- or understate-




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 3—Schematic Diagram Illustrating the Zone of Partial Displacement Common to all Floating Roofs

ment of quantity regardless of the accuracy obtained in gauging the liquid's level.

#### 3.1A.8.3.10 Solid Crust

This existence of a solidified crust of material on top of the product in a tank can adversely affect the accuracy in the gauging, and caution must 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, alternate methods of measurement should be reviewed.

## 3.1A.9 Gauging Procedure

### 3.1A.9.1 READING AND REPORTING GAUGES

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

**3.1A.9.1.1** Manual gauging shall require obtaining either two consecutive gauge readings to be identical, or three consecutive readings within a 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 crude oil lease tanks of 1,000 bbl nominal capacity or less, the range may be increased to 5 mm (or $^1/_4$ in.), and should be reported to the nearest 5 mm (or $^1/_4$ in.).

**3.1A.9.1.2** A suitable product-indicating paste may 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.

**3.1A.9.1.3** For maximum accuracy, the same tape and bob should be used for both opening and closing gauges.

### 3.1A.9.2 INNAGE GAUGING PROCEDURE

For innage gauging, procede as follows:

a. After safely grounding the tape as set forth in 3.1A.5.2 and opening the gauge hatch, 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 1).

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 reference gauge point 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 allow 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 3.1A.9.1.

h. Use the tank capacity table to convert the innage gauge to the corresponding tank observed volume.

### 3.1A.9.3 OUTAGE GAUGING PROCEDURE

Outage gauges are reliable for determining volume in a tank only if the reference gauge height is the same as the observed gauge height at the time of tank measurement. This height equality should be established at the opening and closing conditions. Alternatively, records may be kept which indicate that the reference gauge height and the observed gauge height are checked routinely and are consistently the same. If the observed and reference gauge heights are different, but the observed gauge height is the same for both opening and closing gauges, then the transferred volume may be considered correct. For outage gauging, procede as follows:

a. After safely grounding tape (see 3.1A.5.2) and opening the gauge hatch, slowly lower the tape and bob into the tank until the bob touches the surface of the liquid, (see Figure 1).

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 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 re-enter the liquid thereby giving a false reading.

e. If a deep-grooved bob is used, read the bob scale at the uppermost groove in which liquid is retained.

f. The sum of the tape reading at the reference gauge point and the outage bob reading at the liquid cut is the outage gauge. The following is an example:

| | Feet | Inches | Meters |
|---|---|---|---|
| Tape reading at reference gauge point | 10 | 6 | 3.200 |
| Outage bob reading at cut | 0 | $2^{15}/16$ | 0.075 |
| Sum | 10 | $8^{15}/16$ | 3.275 |

g. Repeat the procedure as set forth in paragraph 3.1A.9.1.

h. Use the tank capacity table to convert the outage gauge to the corresponding tank observed volume.

### 3.1A.9.4 CONVERSIONS BETWEEN INNAGE AND OUTAGE GAUGES

**3.1A.9.4.1** An outage gauge may be converted to an innage gauge by subtracting the outage gauge reading from the tank's reference gauge height, for example:

| | Feet | Inches | Meters |
|---|---|---|---|
| Reference Gauge Height | 44 | $5\text{-}^{7}/8$ | 13.560 |
| Outage Gauge | –10 | $8^{15}/16$ | –3.275 |
| Innage Gauge (Ref-Out)= | 33 | $8^{15}/16$ | 10.285 |

**3.1A.9.4.2** An innage tape and bob may be used to take an outage gauge. The procedure is the same as that described in 3.1A.9.3 except that the bob reading is subtracted from the tape reading, for example:

| | Feet | Inches | Meters |
|---|---|---|---|
| Innage tape reading at gauge point | 10 | 6 | 3.200 |
| Innage bob reading | –0 | $2\text{-}^{15}/16$ | –0.075 |
| Difference (Outage gauge) | 10 | $3\text{-}^{1}/16$ | 3.125 |

## 3.1A.10 Free Water Gauging Procedure

### 3.1A.10.1 WATER-INDICATING PASTE PROCEDURE

**3.1A.10.1.1** This procedure is used principally to determine the height of free water found under petroleum where there is a distinct water/petroleum demarcation, (see Figure

4). The recommended procedure for free water gauging is by the innage method (see 3.1A.9.2).

**3.1A.10.1.2** The recommended water gauge bar is the 30- or 45-cm (12- or 18-in.) round bar. If 30- or 45-cm (12- or 18-in.) round bars are not readily available, then a 15-cm (6-in.) bob may be used. The use of these bars is recommended because it is very convenient for the application of water-finding pastes. Also, the length reduces incidents of water cuts on clasps and areas not scaled between the tape and bar.

Note: If circumstances dictate the use of a 15-cm (6-in.) bob and a water cut falls on the clasp, then the reference gauge height should be noted and every effort made to use an alternate means such as a 30- or 45-cm (12- or 18-in.) bar.

**3.1A.10.1.3** When the height of water exceeds the height of the bar, the free water can be gauged by coating the tape with water paste.

**3.1A.10.1.4** 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.

**3.1A.10.1.5** 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. This difference is caused by the adhesion of the oil to the paste, which causes some pastes to give low or spotted readings.

#### 3.1A.10.1.6

The following qualities should be known before using water pastes, since there are differences between brands:

a. Clarity of color change.
b. Ability to "shed" oil in which the paste is used.
c. Shelf life (some tend to harden shortly after opening).
d. Ease of application to the bar and ability to "grip" the bar.
e. Dense enough not to scrub off during the trip through oil.
f. Effectiveness equally in slightly alkaline, salt, fresh, or acidic water.

Note: Items a, c, d, and e above also apply to product-indicating paste.

**3.1A.10.1.7** There is some tendency for water pastes to separate into liquid phase and heavy paste phase. This separation may increase under heat but does not appear to affect the accuracy of the paste. However, overall performance is best when the pastes are mixed completely. This is most easily done when paste is supplied in jars rather than in tubes. Water pastes may have a limited shelf life, especially after opening.

It is recommended that at all locations the gauger apply two different pastes on the bar for each innage gauge at the beginning of gauging. After it has been established which paste works best for the given product, the other can 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.

**3.1A.10.1.8** 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.

**3.1A.10.1.9** 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.

**3.1A.10.1.10** 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.

**3.1A.10.1.11** Some pastes do not adhere well with layered applications. In those instances, the bar must be wiped dry and cleaned with a solvent before reuse.

**3.1A.10.1.12** 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, 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.

**3.1A.10.1.13** Record, for reference, the level of the spotting.

Note: *Emulsions*. If it is believed that an emulsion layer is present, read and record both clear cut and spotting measurement. The percentage of oil and water in emulsions cannot be accurately determined with water-finding pastes. When this condition is found, sampling and subsequent laboratory testing are required. A sample of this layer may be obtained by using the thief procedure.

### 3.1A.10.2 THIEF PROCEDURE

When oil and water emulsions are present or suspected, the thief procedure may be used to approximate the height of the

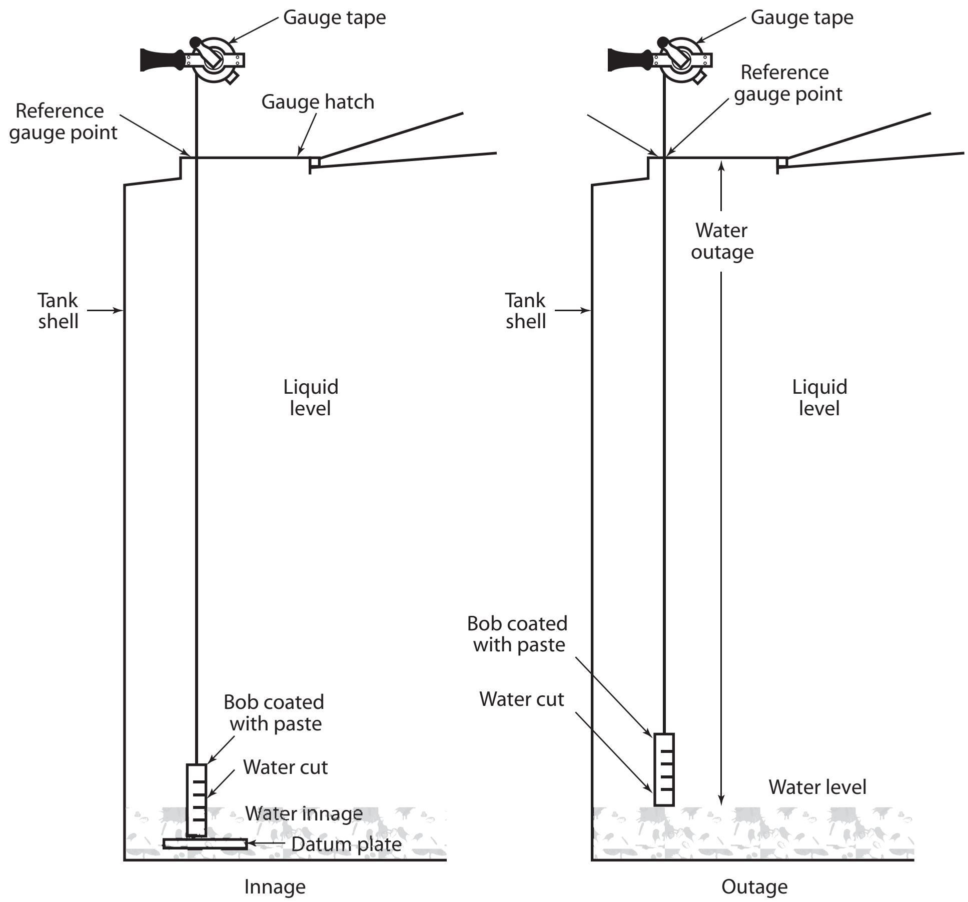



Figure 4—Free Water Gauging

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. This procedure is commonly used for crude oil production tanks (lease tanks).

g. Petcocks installed on the side of the thief can be used to withdraw samples into centrifuge 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.

### 3.1A.10.3 OTHER METHODS

Other methods of determining free water height, such as electronic interface detectors, a galvanic tape, etc., may be used if approved by all parties concerned.

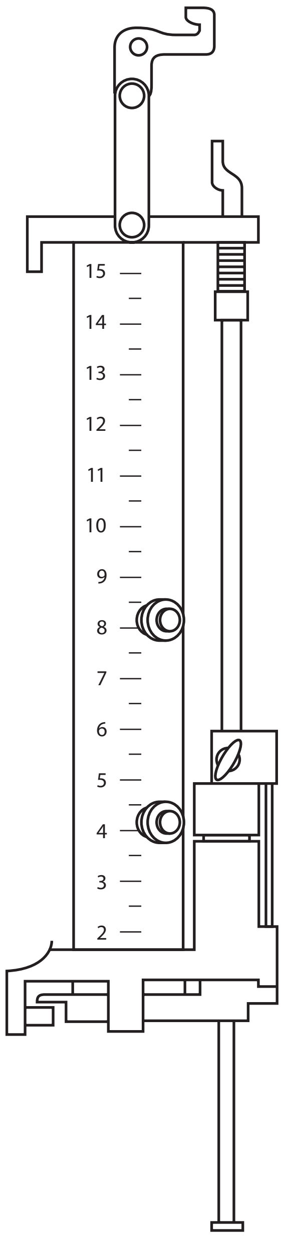



Figure 5—Core Thief, Trap Type

## 3.1A.11 Gauging Procedure for Marine Vessels

For maximum accuracy, the vessel should be on an even keel and upright and free of hog and sag.

### 3.1A.11.1 READING AND RECORDING GAUGES

Where entrained air and/or foam are present on the surface of the product, gauging should be suspended until it subsides or until it has been satisfactorily cleared. Settlement time varies depending on the conditions of the product. The recorded gauge shall be determined by use of a range from one set of three consecutive tank gaugings within which the three readings of the tank shall fall. For tanks larger than 150 $m^3$ (or 1,000 US bbls), a range of 3 mm (or $^1/_8$ in.) will be used. For tanks smaller than 150 $m^3$ (or 1000 US bbls) the range will be increased to 5 mm (or $^1/_4$ in.) and should be recorded to the nearest 5 mm (or $^1/_4$ in.).

Note: If the first two gauge readings are identical, that reading may be recorded without taking additional gauges. For statistical purposes, more than three readings may be taken and averaged overall if preferred and mutually agreeable.

#### 3.1A.11.1.1 Rolling Gauges

During lightering or offshore operations, or when the vessel is at an exposed berth, cargo may be moving during gauging. In such cases, at least five readings shall be obtained in minimal time, recorded, and then averaged. The 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. It has been found useful to immerse the bob in the petroleum liquid and to take readings from the tape. Adverse conditions such as these must be recorded.

#### 3.1A.11.1.2 Closed Manual Systems

Closed Manual Systems refers to gauging equipment similar in array and construction to hand-held electronic gauging equipment, but not fitted with electronic sensing devices, which can be deployed in tanks with a closed or inert atmosphere.

### 3.1A.11.2 GAUGING VESSELS OUT OF TRIM/LIST

#### 3.1A.11.2.1 Gauging Procedure

Gauging procedures are not altered for vessels which are out of trim. In situations where both trim and list exist, every effort should be made to eliminate one or both conditions. On vessels where the reference gauge point is located at the center of the tank, trim will not significantly affect the gauge readings or the reference heights. Where the reference gauge points are located toward the after or forward ends of the tanks, trim correction must be applied to obtain the correct volumes. Apply the trim correction by using the trim corrections tables or instructions listed in the vessel's official Capacity Tables. If the necessary information is not listed in the Capacity Tables, refer to Appendix C.

Note: *Origin of Capacity Tables*. The origin of the capacity tables should be identified and recorded. It should be verified that the capacity tables refer to the actual ullage locations. For further information on calibration procedures, please refer to *MPMS* Chapter 2.8B, Standard Practices for Calibration of Tanks on Ships and Ocean Going Barges.

Note: *Missing Capacity Table.* All parties involved, including the vessel's owners, should be notified immediately when the Capacity Tables cannot be located. A letter of Protest should be issued immediately. Copies of the tables should be obtained at the earliest possible opportunity. In such situations, measurement data must be obtained as usual and retained until the tables become available and calculations can be performed.

#### 3.1A.11.2.2 Gauging for Free Water on Out of Trim Vessels

Gauging for free water on out of trim vessels presents special problems because free water may not be measurable at the usual gauging points. If, for example, the vessel is trimmed by the stern, and the gauge points are located at the forward end of each tank, free water will have moved in the general direction of the trim and thus may not be detected. If free water is detected, the gauge reading will need to be corrected for trim. This can be done in the usual manner by reference to the Trim Correction Tables. However, great care should be exercised when correcting free water gauges from trim. If the trim correction is greater than the innage at the reference gauge point, the wedge formula should be used to calculate the free water volume. Where a vessel is out of trim and listed, more extensive methods may need to be used to obtain a gauge of free water. This could involve, but is not limited to, gauging from locations other than the reference gauge point.

#### 3.1A.11.2.3 Reference Gauge Heights

**3.1A.11.2.3.1** In some cases, the reference gauge point is situated on a hinged manway, an expansion trunk, or a tank hatch. If these are not properly secured or if the gasket has been overly compressed, the observed gauge height might be affected, resulting in erroneous gauges. A variance in reference gauge height can also be caused by a buildup of rust, scale, and/or other solid residue underneath the reference gauge point or hatch covers.

**3.1A.11.2.3.2** Tank reference gauge heights as well as observed reference gauge heights before and after transferring cargo should be reported. When the observed reference gauge height does not match the published reference gauge height, the discrepancy should be resolved by one of the following means:

a. The use of innages in the following instances:

1. The published reference gauge height is reached or exceeded.
2. The observed reference gauge height is less than the published height, but there is confidence that the tank bottom has been reached. When innages are used for OBQ/ROB measurements, it will be necessary to convert these readings to ullages if the calibrations table is presented in an ullage format. To make this conversion, the innage reading is to be subtracted from the reference gauge height for the tank.

b. The use of ullages, when the observed reference gauge height is less than the reference gauge height due to buildup of residue on tank bottom or due to structural members, curvature of tank walls, etc. (Alternate gauging locations should be checked to confirm presence of material throughout tank.)

**3.1A.11.2.3.3** If no reference gauge height is indicated, it should be determined as follows:

a. When sounding depths are shown as well as ullages, use the ullage reading corresponding to a zero sounding as the reference gauge height (see Table 1, rows A1 and A2).
b. When sounding depths are shown to indicate the reference gauge height, the maximum ullage for which capacity is shown is considered to be the reference gauge height (see Table 1, rows A3 and A4).

**3.1A.11.2.3.4** In those cases where zero innage is measured and the reference gauge height is reached, the reported volume will be zero. Where significant volumes are shown below the reference gauge height, confirm readings if possible by measuring from another location capable of reaching deeper into the tank. When an innage is obtained, convert it to an ullage.

**3.1A.11.2.3.5** It is suggested that in case 5 (see Table 1, row A5), extrapolate linearly down to the observed gauge height, using the barrels/centimeter of the pervious two tabulated values, in order to obtain a new volume, and then interpolate normally. Thus, if the table bottom is zero, ignore the discrepancy but report it in the documentation.

### 3.1A.11.3 OBQ/ROB MEASUREMENT

#### 3.1A.11.3.1 Application

OBQ and ROB volumes can be determined by using either the innage or ullage method of gauging. While the techniques involved are similar to those applied when obtaining a ullage or innage on partially full tanks, there are some significant differences when gauging ROB/OBQ.

#### 3.1A.11.3.2 Preliminary Steps

#### 3.1A.11.3.2.1 Reference Gauge Heights

Reference Gauge Heights should be recorded from the Capacity Tables before gauging.

#### 3.1A.11.3.2.2 Reference and Alternative Gauging Points

The vessel's General Arrangement Plan should be consulted to determine the position of the Reference Gauge Points. In addition, alternate gauge points throughout a tank or tanks should be identified by name and by location. On some vessels that have been built to comply with Marine Pollution Requirements (MARPOL), alternative gauge points are provided throughout the length of tanks. This provision enables the gauger to obtain several innages throughout a tank in order to establish the nature and form of the retained material.

Note: When multiple gauging points are available, manual gauges from these positions in each compartment should be taken and recorded, in accordance with API *MPMS* Chapter 17, Sections 1, 2, and 4.

Table 1—Examples of Alternative Methods for Determining Reference Gauge Height

| Case | Ullage | Barrels | Sounding Depth |
|---|---|---|---|
| A1 | 20.52 m | 96 | 0.035 m |
| | 20.53 m | 68 | 0.025 m |
| | 20.54 m | 41 | 0.015 m |
| | 20.55 m | 14 | 0.005 m |
| | 20.555 m | 0 | 0.000 m |
| Reference Gauge Height 20.555 m volume @ 2 cm 55 Barrels | | | |
| A2 | 15.23 m | 50 | 0.034 m |
| | 15.24 m | 47 | 0.024 m |
| | 15.25 m | 44 | 0.014 m |
| | 15.26 m | 41 | 0.004 m |
| | 15.264 m | 40 | 0.0 m |
| Reference Gauge Height 15.264 m Volume @ 2 cm 46 Barrels | | | |
| A3 | 20.27 m | 150.2 | |
| | 20.28 m | 115.2 | |
| | 20.29 m | 80.3 | |
| | 20.30 m | 45.4 | |
| | 20.31 m | 10.5 | |
| Reference Gauge Height 10.31 m Volume @ 2 cm 80.3 Barrels | | | |
| A4 | 24.11 m | 166 | |
| | 24.12 m | 147 | |
| | 24.13 m | 129 | |
| | 24.14 m | 110 | |
| | 24.149 m | 93 | |
| Reference Gauge Height 24.149 m Volume @ 2 cm 131 Barrels | | | |
| A5 | 24.11 m | 166 | |
| | 24.12 m | 147 | |
| | 24.13 m | 129 | |
| | 24.14 m | 110 | |
| | 24.149 m | 93 | |
| | 24.15 m | 92 | |
| | 24.16 m | 74 | |
| | 24.17 m | 56 | |
| Reference Gauge Height 24.149 m Volume @ 2 cm 131 Barrels | | | |
| Observed Gauge Height 21.17 m Volume @ 2 cm 92 Barrels | | | |

### 3.1A.11.3.3 Gauging for OBQ/ROB

#### 3.1A.11.3.3.1 Innage Tape and Bob

Follow this procedure:

a. Lower the tape and bob into the tank until the tip of the bob is a short distance from the tank bottom. This can be judged by comparing the reading on the tape against the Reference Gauge Height quoted for the compartment.

b. Wait until the tape has completely stopped swinging. Then lower the tape slowly until the tip of the bob just touches the tank bottom.

c. Note and record the Observed Gauge Height. It should be noted that the Observed Gauge Height may be different than the Reference Gauge Height quoted in the Capacity Tables due to the effects of trim, causing a deflection of the tape. However, if the Observed Gauge Height exceeds the Reference Gauge Height by more than 5 cm (2 in.) it should be ascertained as to why this is so (see 3.1A.11.2.3 of this standard).

d. Withdraw the tape from the tank and read the cut on the bob. This cut represents the sounding or innage of the OBQ or ROB in that compartment. This sounding can be converted to a volume by reference to the Capacity Tables. See Table 1 of this standard for examples.

#### 3.1A.11.3.3.2 Out of Trim Vessels

When a vessel is out of trim, it may not be possible to gauge OBQ/ROB from the reference gauge point. In such circumstances, it may be necessary to gauge from other points in the tank or tanks (see 3.1A.11.3.3.3). When alternative gauging points are used, the innage method should be employed, preferably from the location towards the direction of trim [usually the aftermost International Maritime Organization (IMO) opening. An IMO opening is the name given to certain permanent through-deck apertures, through which innages may be taken at various points in a marine vessel's tank for use in monitoring oily residues, in accordance with the recommendations of IMO.]

#### 3.1A.11.3.3.3 Non-Liquid OBQ/ROB

**3.1A.11.3.3.3.1** Where the nature of the retain is non-liquid or solid, it is necessary to utilize the ullage method of gauging as follows:

a. Using an innage tape and bob, lower the tape into the tank until the tip of the bob is just above the retained product.

b. Wait until the tape has stopped swinging completely and then lower the bob until the tip of the bob just rests in the product. Great care must be exercised to ensure that the bob does not tilt over as this will result in an erroneous reading.

c. Read the tape graduations at the Reference Gauge Point and record the reading.

d. Remove the tape from the tank and read the cut on the bob. The difference between the tape reading at the Reference Gauge Point and the cut on the bob represents the ullage. For example:

| Metric | |
|---|---|
| Tape reading at Reference Gauge Point | 12.365 m |
| Bob Reading at Liquid Line | 0.015 m |
| Difference (Ullage/Outage Gauge) | 12.350 m |

| Customary | |
|---|---|
| Tape Reading at Reference Gauge Point | 40’6 7/8” |
| Bob Reading at Liquid Line | 0’0 1/2” |
| Difference (Ullage/Outage Gauge) | 40’6 3/8” |

Note: When multiple gauging points are available, manual gauges from these positions in each compartment should be taken and recorded in accordance with API *MPMS* Chapters 17, Sections 1, 2, and 4.

**3.1A.11.3.3.3.2** This ullage can now be converted to a volume by reference to the Capacity Tables when adjusted from trim, if applicable. In some cases, the cut may be difficult to read on the bob. Where this occurs, several readings should be obtained in order to determine as representative a gauge as possible.

### 3.1A.11.3.3.4 Wedge Correction

Where a vessel is out of trim and the liquid retain does not touch all four bulkheads in a give compartment, wedge tables or the wedge formula should be used. When the nature of the retain is non-liquid, it is then necessary to establish if the material lies in a wedge formation or if it is lying uniformly across the bottom of the compartments. This determination will involve taking gauges at more than one point in a tank. However, this may not always be possible because of operating conditions and the physical constraints of the tank. For further details refer to API *MPMS* Chapter 17, Section 4 “Method for Qualification of Small Volumes on Marine Vessels (OBQ/ROB)”.

### 3.1A.11.3.3.5 Water Indicating Paste

In some cases, part or all of the OBQ/ROB may be water or wet sediments. Where the presence of water or wet sediments is known or suspected, water-indicating paste should be used when gauging, and samples should be obtained where possible.

# APPENDIX A—TAPE COMPARISON AGAINST A TRACEABLE REFERENCE STANDARD

## A.1 General

### A.1.1 VERIFICATION OF WORKING TAPES BY COMPARISON WITH REFERENCE MEASUREMENT

Working tapes and bobs shall be checked for accuracy when new, and at least annually 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 (Refer to A.2) or vertically (Refer to A.3), where a master tape is used. Requirements for PEGDs are described in Appendix A.4.

### A.1.2 ACCURACY REQUIREMENTS OF WORKING TAPES/BOBS

When comparing a used working tape/bob for custody transfer application, the difference between the reference measurement (e.g., a master tape) and the working tape/bob shall not exceed ± 2 mm (or ± $^{1}/_{16}$ in.) for any distance from 0 to 30 m (0 to 100 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.1.3 ACCURACY 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 re-calibrated at least every five years. More frequent re-calibration shall be considered if the master tape is in regular use where there is a risk of it being mechanically damaged through repeated handling. 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 pre-marked by the tape manufacture, often under a tension of 44 or 88 N (10 or 20 lb).

If heavier bobs are routinely used, the master tape shall be certified at a corresponding tension force. While the tension applied to a horizontal tape does not address the effect of uneven vertical force exerted over the entire length of a vertical tape, both tapes will be similarly affected.

## A.2 Horizontal Tape Verification

**A.2.1** To conduct a horizontal tape comparison, set up a test arrangement similar to that shown in Figures A-1 and 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, worm 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) (see Figure A-1). The spring balances must be capable of indicating a load of 5 kg (10 lb) with an accuracy of ± 0.05 kg (± 0.1 lb).

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.

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 to 3 centimeters($^{3}/_{8}$ to 1-$^{1}/_{8}$ inches). The zero points (usually the bob tips) of the tapes should be even, as shown in Figure A-2.

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 < 30m (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.

Note: 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 mater tape are marked by the tape manufacture, often under a tension of 44 to 88 N(10 or 20 lb).

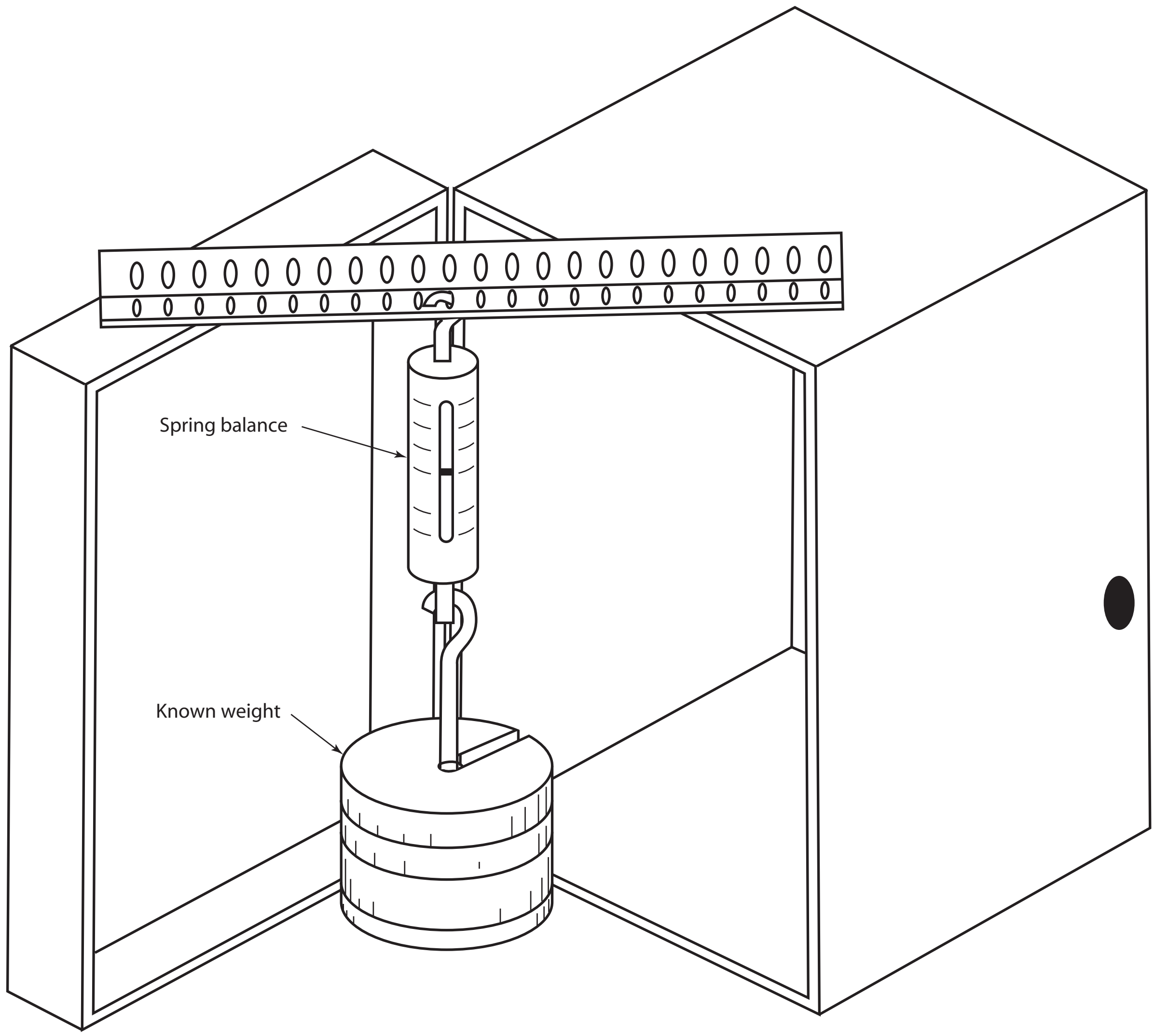



Figure A-1—Calibration of Spring Balance

g. 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.

h. 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.

i. 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", see example in step o.) 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" in step o.) When reading the scale, estimate the reading to the nearest 0.5 mm.

j. Record the readings on an observation sheet as First Trial.

k. Release the tension on the tapes and reapply it.

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

m. Re-adjust as in steps k and i. Then record a third set of readings as Third Trial.

n. Calculate the true length of the working tape at the test point according to the following equation:

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

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

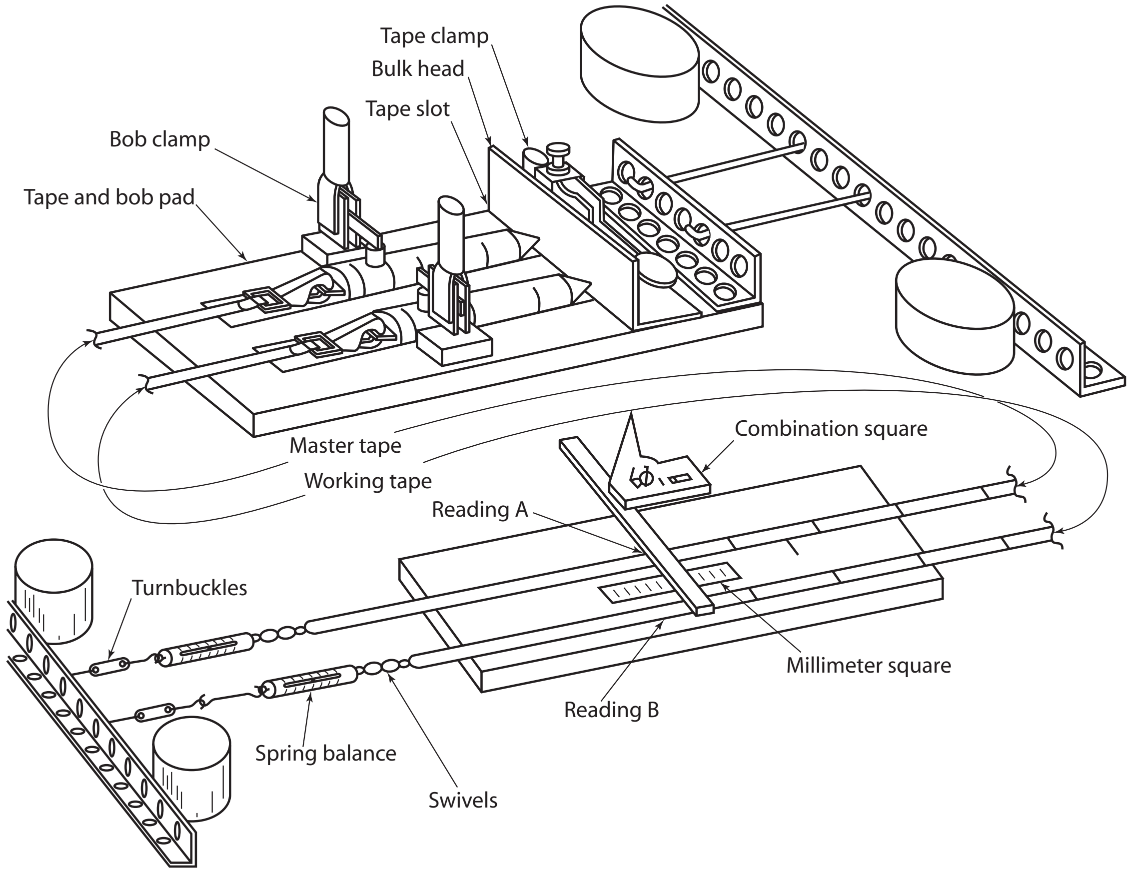



Figure A-2—Tape and Bob Comparison

where

$L$ = True length of working tape at the test point,

$S$ = certified length of master at the test point,

$K$ = conversion factor, tape unties/scale units; i.e.,

$K$ = 0.00328084 ft/mm.

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

$\Sigma A$ = sum of scale readings for master tape,

$\Sigma B$ = sum of scale readings for working tape,

o. Calculate and record $B - A$ for each trial. Then record $R$, the range of values (highest to lowest), for 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=85.1 mm | | | |
| | ΣB=89.0 mm | | | |

L=S+.0010936 [ΣB-ΣA]=100.0092ft.

**A.2.2** In the preceding comparison procedure (see A.2.1), 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.

**A.2.3** 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 8ºC 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.

**A.2.4** The comparison between the working tape and 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, and such intervals typically not exceeding 5 m (15 ft).

When used for custody transfer, the working tape/master tape comparison shall meet the accuracy requirements in Appendix A.1.2.

**A.2.5** 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.3 Vertical Tape Verification

The comparison between the working tape and 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). When used for custody transfer, the working tape/master tape comparison shall meet the accuracy requirements in Appendix A.1.2.

Master tapes used to compare a working tape in a vertical position shall be certified (by NIST) with a tension corresponding to the tension of working tape/bob in operations. NIST must specifically be requested to certify master tapes for this application with a tension to more accurately reproduce the effect of a 21-oz, or 6-in. bob on a vertical tape.

## A.4 Verification of Portable Electronic Gauging Devices

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

a. Verify the zero point distance against a calibration reference (e.g., a traveling vernier microscope) 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 be verified with the probe suspended vertically into a water surface.

b. Verify the graduated tape in accordance with Section A.1 and Section A.2 or A.3, 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 the NIST, following the procedure in Appendix A.

c. If the bottom of the PEGD sensor probe is also intended to serve as a datum to determine tank reference heights, the distance from the sensor bottom to the chosen tape graduation mark shall be verified according to manufacturers' recommendations.

# APPENDIX B—PRECAUTIONARY INFORMATION

## B.1 Physical Characteristics and Fire Considerations

**B.1.1** Personnel involved with the handling of petroleum-related substances (and other chemical materials) should be familiar with the physical and chemical characteristics of these substances, including potential for fire, explosion and reactivity, and appropriate emergency procedures. These personnel should comply with individual company safe operating practices and local, state, and federal regulations, including use of proper protective clothing and equipment. Personnel should be alert to avoid potential sources of ignition and should keep containers of materials closed when not in use.

**B.1.2** API Publs 2217 and 2026, API RP 2003, and any applicable regulations should be consulted when gauging and sampling. Information regarding particular materials and conditions should be obtained from the employer, the manufacturer or supplier of that material, or the material safety data sheet.

## B.2 Safety and Health Considerations

**B.2.1** Potential health effects can result from exposure to any chemical and are dependent on the toxicity of the chemical, concentration, and length of the exposure. Everyone should minimize his or her exposure to workplace chemicals. The following general precautions are suggested:

a. Minimize skin and eye contact and breathing of vapors.
b. Keep chemicals away from the mouth; they can be harmful or fatal if swallowed or aspirated.
c. Keep containers closed when not in use.
d. Keep work areas as clean as possible and well ventilated.
e. Clean up spills promptly and in accordance with pertinent safety, health, and environmental regulations.
f. Observe established limits and use proper protective clothing and equipment.

**B.2.2** 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 ACGIII publication Threshold Limit Values for Chemical Substances and Physical Agents in the Work Environment. Information concerning safety and health risks and proper precautions with respect to particular materials and conditions should be obtained from the employer, the manufacturer, or the material safety data sheet.

# APPENDIX C—PROCEDURE FOR CALCULATING TRIM AND LIST CORRECTION IN THE FIELD

The following formulae will be found useful in determining a level gauge where trim and list corrections are not provided in the capacity tables. For further definitive information regarding the calculation of a vessel's trim corrections, refer to API *MPMS* Chapter 2, Section 8A. To calculate trim correction for any condition, solve this equation:

$((T \times D)/L\ d) \pm (H \times (T/L_d)^2)(C - 1)$

where

$L_d$ = Length between draft mark.

$T$ = Draught fore and aft difference, which is trim.

$D$ = Distance from tank mid-length to gauge point

[($^1/_2$ Lt - U) Half Tank length minus U distance]

$H$ = Ullage (from reference point to liquid surface)

For example:

SHIP

4.6 m trim

290 m length between draft marks

8.4 m to mid-length

3.6 m ullage

4.6 x 8.4 = 38.64 ÷ 290 = 0.144 m or

13 $^1/_2$ cm plus 3.6 • 0.00025 + 0.1339 m or

13 $^1/_2$ cm

BARGE

10 ft trim

300 ft length between draft marks

15 ft to mid-length

12 ft ullage 10 x 15 = 150 ÷ 300 = 0.5 or

6 in. plus 12 x 0.00111 = 0.51333 or 6 $^1/_8$ in.

If the gauging point is forward of the mid-length of the tank, the sign (+ or –) of the correction is reversed. The first half of the equation (see C-1) is the raw trim correction; the second part corrects for the deflection of the tape from the vertical, sometimes called drift, and is usually minor in value though not always insignificant. List is treated similarly by substituting transverse dimensions for longitudinal ones.

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