Manual of Petroleum Measurement Standards Chapter 16—Measurement of Hydrocarbon Fluids By Weight or Mass

Section 2—Mass Measurement of Liquid Hydrocarbons in Vertical Cylindrical Storage Tanks By Hydrostatic Tank Gauging

FIRST EDITION, NOVEMBER 1994

REAFFIRMED, MARCH 2012

energy API

AMERICAN PETROLEUM INSTITUTE

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FOREWORD

This publication covers standard practice for mass measurement of liquid hydrocarbons in vertical cylindrical storage tanks by hydrostatic tank gauging systems that use pressure sensors with one port open to the atmosphere.

This standard is based entirely on ISO 11223-1, *Petroleum and liquid petroleum products - Direct static measurements - Contents of vertical storage tanks*, Part 1 - “Mass measurement by hydrostatic tank gauging.” International standard ISO 11223-1 was prepared by the Technical Committee ISO/TC 28, Petroleum products and lubricants, Subcommittee 3, Static petroleum measurement.

Changes have been made to use American spelling and vocabulary, to provide customary units in addition to SI units, and to provide API instead of ISO reference publications.

Appendices A and B are required.

Appendices C and D are for information only.

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Suggested revisions are invited and should be submitted to Measurement Coordination, Exploration and Production Department, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.

CONTENTS

Chapter 16—Measurement of Hydrocarbon Fluids by Weight or Mass

SECTION 2—MASS MEASUREMENT OF LIQUID HYDROCARBONS IN VERTICAL CYLINDRICAL STORAGE TANKS BY HYDROSTATIC TANK GAUGING

1 Scope

This standard provides guidance on the installation, commissioning, maintenance, validation, and calibration of hydrostatic tank gauging systems for the direct measurement of static mass in petroleum storage tanks.

This standard is applicable to hydrostatic tank gauging systems that use pressure sensors with one port open to the atmosphere.

This standard is applicable to the use of hydrostatic tank gauging on vertical cylindrical atmospheric storage tanks with either fixed or floating roofs.

This standard is not applicable to the use of hydrostatic tank gauging on pressurized tanks.

Safety and material compatibility precautions should be taken when using HTG equipment. Manufacturer's recommendations on the use and installation of the equipment should be followed. Users should comply with all applicable codes and regulations, API standards, and the National Electric Code.

2 Introduction

Hydrostatic tank gauging is a method for the determination of total static mass of liquid petroleum and petroleum products in vertical cylindrical storage tanks.

HTG uses high precision stable pressure sensors mounted at specific locations on the tank shell.

Total static mass is derived from the measured pressures and the tank capacity table. Other variables, such as level, observed and standard volumes, and observed and reference densities, can be calculated from the product type and temperature using the established industry standards for inventory calculations.

The term "mass" is used to indicate mass in vacuum (true mass).

In the petroleum industry, it is not uncommon to use apparent mass (in air) for commercial transactions.

3 Required Referenced Publications

The following standards contain provisions that, through reference in the text, constitute provisions in this standard.

API

Manual of Petroleum Measurement Standards (MPMS)

Chapter 1, "Vocabulary"
Chapter 2.2A, "Calibration of Upright Cylindrical Tanks"
Chapter 2.2B, "Calibration of Upright Cylindrical Tanks Using the Optical Reference Line Method"
Chapter 3.1A, "Standard Practice for Manual Gauging of Petroleum and Petroleum Products in Stationary Tanks"
Chapter 3.1B, "Standard Practice for Level Measurement of Liquid Hydrocarbons in Stationary Tanks by Automatic Tank Gauging"
Chapter 7.1, "Static Temperature Determination Using Mercury-in-Glass Tank Thermometers"
Chapter 7.3, "Static Temperature Determination Using Portable Electronic Thermometers"
Chapter 7.4, "Static Temperature Determination Using Fixed Automatic Tank Thermometers"
Chapter 8.1, "Manual Sampling of Petroleum and Petroleum Products"
Chapter 9.1, "Hydrometer Test Method for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products"
Chapter 9.2, "Pressure Hydrometer Test Method for Density or Relative Density"
Chapter 11.1, "Volume Correction Factors"
Chapter 15, "Guidelines for Use of the International System of Units (SI) in the Petroleum and Allied Industries"

RP 500 *Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities*

RP 2001 *Protection Against Ignition Arising Out of Static, Lightning, and Stray Currents*

4 Definitions

For the purpose of this standard, the following definitions apply:

4.1 ambient air density: The density of air at the tank side on which the pressure sensors are mounted.

4.2 ambient air temperature: The representative temperature of the ambient air at the tank side on which the hydrostatic tank gauging (HTG) pressure sensors are mounted.

4.3 critical zone height: The upper limit of the critical zone; the level at which one or more of the floating roof or floating cover legs first touch the tank bottom.

4.4 critical zone: The level range through which the floating roof or floating cover is partially supported by its legs.

4.5 floating roof mass: The manually entered value of the floating roof mass inclusive of any mass load on the roof.

4.6 free water level: The level of any water and sediment that exist as separate phases from the product and lie beneath the product.

4.7 gauge pressure sensor: A sensor that uses the ambient atmospheric air pressure as the pressure reference.

4.8 head mass: The total measured mass between the HTG bottom sensor and the top of the tank.

4.9 head space: The space inside the tank, above the bottom HTG sensor. Product and in-tank vapor are present in the head space.

4.10 heel space: The space inside the tank, below the bottom HTG sensor.

4.11 HTG reference point: A stable reference point from which the HTG sensor positions are measured.

4.12 hydrostatic tank gauging: A method of direct measurement of liquid mass in a storage tank based on measuring static pressures caused by the liquid head above the pressure sensor.

4.13 innage volume: The observed volume of product, sediment, and water calculated from the innage level and the tank capacity table.

4.14 in-tank vapor density: The density of the gas or vapor (mixture) in the ullage space at the observed conditions (product temperature and pressure).

4.15 pin height: The lower limit of the critical zone; the level at which the floating roof or floating cover rests fully on its legs.

4.16 pressure sensor effective center: The point on the sensor from which the hydrostatic pressure head is measured.

4.17 product heel mass: The mass of product below the bottom HTG sensor.

4.18 product heel volume: The observed volume of product below the bottom HTG sensor, calculated by subtracting the water volume from the total heel volume.

4.19 product mass: The sum of the head mass and the product heel mass reduced by the floating roof mass (if applicable) and the vapor mass.

4.20 product temperature: The temperature of the tank liquid in the region where the HTG measurements are performed.

4.21 reference density: The density at the reference temperature.

4.22 reference temperature: The temperature to which reference density and standard volumes are referred.

4.23 tank average cross sectional area: The average cross sectional area between the elevation of the bottom HTG sensor and the innage level over which the hydrostatic pressures are integrated in order to obtain the mass.

4.24 tank lip: The tank bottom plate on the outside of the tank shell.

4.25 total heel volume: The observed volume below the bottom HTG sensor, calculated from the bottom sensor elevation and the tank capacity table corrected for observed temperature.

4.26 ullage pressure: The absolute pressure of the gas (air or vapor) inside the tank, above the product.

4.27 ullage volume: The observed volume of the vapor/air mixture in the ullage space, calculated as the difference between the total tank volume and the innage volume.

4.28 vapor relative density: The ratio of molecular mass of vapor (mixture) to that of air (mixture).

4.29 water volume: The observed volume of free sediment and water, calculated from the free water level and the tank capacity table.

5 System Description

5.1 GENERAL

An HTG system is a tank inventory static mass measuring system. It uses pressure and temperature inputs and the parameters of the tank and of the stored liquid to compute the mass of the tank contents and other variables as described in Table A-1. See Figure 1.

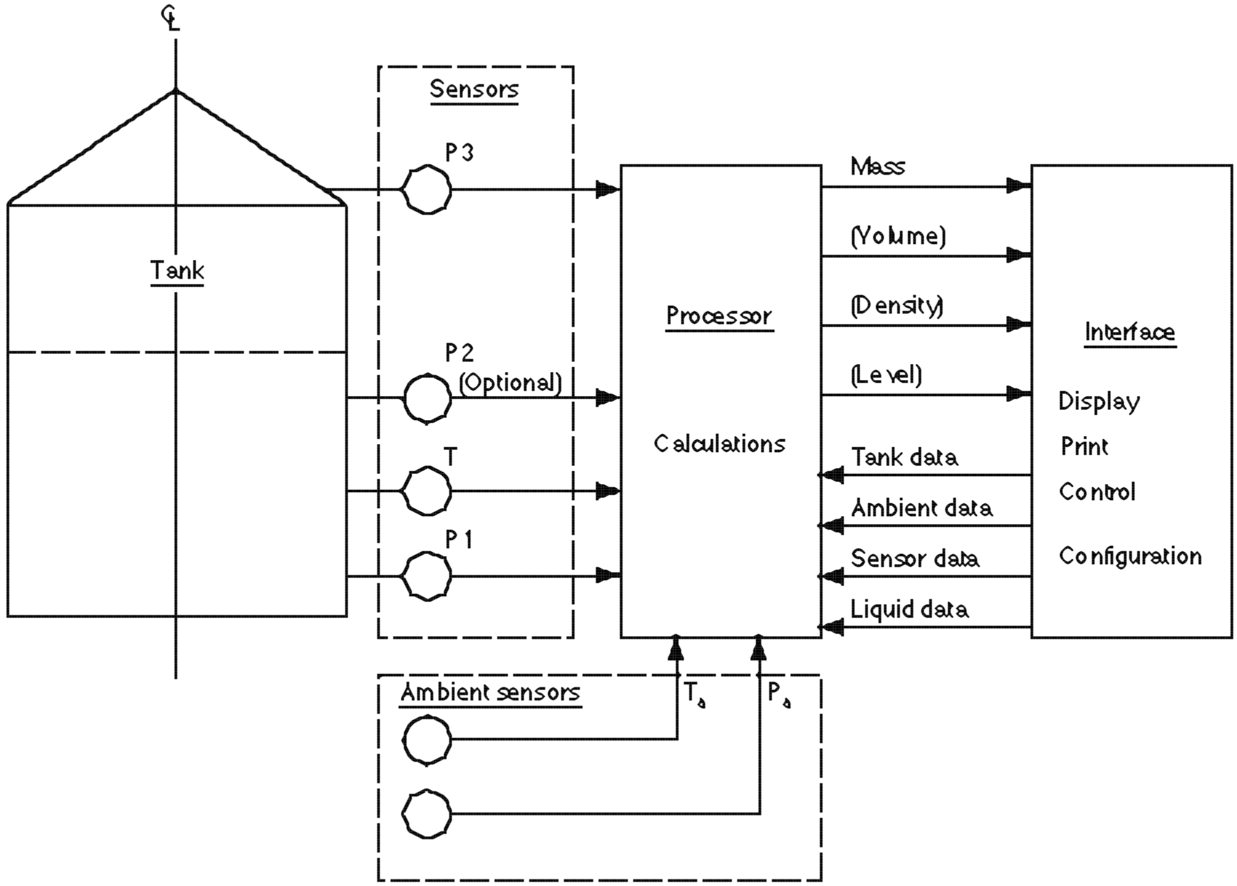
5.2 SENSORS

5.2.1 Pressure Sensors

The HTG system consists of up to three pressure sensors mounted on the tank shell. Additionally, temperature sensors can be included to measure the temperature of the tank contents (T) and of the ambient air (Ta). An ambient air pressure sensor (Pa) may be installed for high accuracy measurements.

Sensor P1 is installed at or near the tank bottom.

Sensor P2 is the middle pressure sensor and is required for the calculation of density and levels. If the product density is known, the HTG can operate without P2. In the absence of P2, the density should be manually entered. Sensor P2, if installed, should be at a fixed vertical distance above sensor P1.



Note 1: The other variables shown in parentheses in Figure 1 are not part of this standard.

Figure 1—HTG System Functional Diagram

Sensor P3 is the tank ullage space pressure sensor. P3 is not required on floating roof tanks. If the tank is freely vented, the HTG can operate without P3. P3 is normally installed on the tank roof.

5.2.2 Temperature Sensors

The following are the reasons for measuring the product temperature:

a. Calculation of the volumetric expansion of the tank shell.
b. Calculation of the reference density from observed density (used in HTG systems that calculate level and density as well as mass).

If the reference density is known and P2 is not used, the temperature sensor may still be required for the observed density calculations.

The following are the reasons for measuring ambient temperature:

a. Calculation of ambient air density.
b. Calculation of the volumetric expansion of the tank shell.
c. Correction for thermal expansion of the P1 and P1–P2 tie-bars.

5.2.3 System Configuration

The configurations vary depending on the application. Some of the more common variations are as follows:

a. **Known liquid density:** P2 is normally used for the tank liquid density measurement. It is not required if the average liquid density is known.
b. **Known ullage pressure:** P3 is not required for those tanks that are vented to atmosphere (ullage gauge pressure equals zero). This includes all floating roof tanks and all fixed roof tanks that are freely vented or that have gauging hatches that are not sealed. Note that tank ullage pressure on atmospheric fixed roof tanks may differ slightly from atmospheric pressure during transfers to and from the tank. Since inventory measurements are not taken during a transfer, errors due to this effect are not significant. If the ullage pressure is known, P3 can be entered as a constant and the P3 sensor omitted on non-vented tanks.
c. **Known tank liquid temperature:** Tank liquid and ambient temperatures are used to correct the shell thermal expansion. The tank liquid temperature sensor is not required

for mass measurement if the temperature of the liquid in the tank is known (see Chapter 7.4).

d. **Varying atmospheric conditions:** Ambient temperature and pressure sensors can be used to remove secondary errors for high accuracy measurements. Single measurements of ambient temperature and pressure may be used for all tanks at the same location.

5.3 HTG PROCESSOR

A processor receives data from the sensors and uses the data together with the tank and liquid parameters to compute the mass inventory in the storage tank (see Figure 1).

The stored parameters fall into four groups: tank data, sensor data, liquid data, and ambient data (see Table 1). Those parameters in Table 1 that are required by the application should be programmed into the HTG system.

When the product level drops below the level of P2, density can no longer be measured by HTG. Below P2, the last measured value of product density is used.

The processor may be dedicated to a single tank or it may be shared among several tanks. The processor may also perform linearization and/or temperature compensation corrections for the pressure sensors.

All variables provided by the processor can be displayed, printed, or communicated to another processor.

Computations normally performed by the HTG processor are described in Appendix A.

6 Installation

6.1 PRESSURE SENSORS

6.1.1 Tank Preparation

Prior to installation of the HTG pressure sensors, it is necessary to perform the following activities:

Selection of sensor positions. All HTG pressure sensors external to the tank should be installed on the same side of the tank and, if necessary, should be protected from the sun and the wind.

The pressure taps on the tank wall should be located where the product is relatively static. Product movements caused by pumping or mixing operations can produce additional static pressures.

Pressure sensor P1 is the lowest of the pressure sensors, mounted a distance Hb from the HTG reference point. P1 should be installed as low as possible on the tank but above the level of any sediment or water.

Table 1— HTG Stored Parameters

Parameter Group	Parameter	Note
Tank data	Tank roof type	Fixed or floating or both
	Tank roof mass	Floating roofs only
	Critical zone height	Floating roofs only
	Pin height	Floating roofs only
	Tank wall type	Insulated or noninsulated
	Tank wall material	Two thermal expansion constants (see Ch. 2.2A)
	Tank capacity table	Volumes at given levels
	Tank calibration temperature	Temperature to which the tank capacity table was corrected
HTG sensor data	Sensor configuration	Tank with 1, 2, or 3 sensors
	P1 sensor elevation	To HTG reference point
	P2 sensor elevation	Referenced to P1
	P3 sensor elevation	Referenced to P1
Liquid data	Liquid density	If no P2 sensor, refer to API 2540
	Liquid expansion coefficients	
	Free water level	
Ambient data	Local acceleration due to gravity	Obtained from a recognized source
	Ambient temperature	Optional
	Ambient pressure	Optional

Note 2: The HTG processor can also calculate level, observed, and standard volumes and observed and reference densities, but these are not part of this standard.

P2, if used, is located a vertical distance H above sensor P1. The maximum P2 to P1 vertical distance is not given, the only restriction being that when the liquid level drops below P2, the observed density can no longer be measured. The minimum P2 to P1 vertical distance depends on the requirements for density measurement accuracy and on the sensor performance. Usually, P2 is installed approximately 7 to 10 feet or 2 to 3 meters above P1.

P3, if used on fixed roof tanks, should be installed so that it always measures the vapor phase pressure. If it is mounted on the roof, a sun/wind shade should be provided.

Process taps. Process taps and block valves should be fitted to the tank either when the tank is out of service, or by using prescribed hot tap techniques.

HTG reference point. The location of the HTG reference point for each tank should be established. If necessary, the elevation of the HTG reference point for each tank may be referred to the tank datum point using optical surveying techniques.

Tie-bars. Tie-bars are used to prevent excessive movement of the HTG pressure sensors in relation to the HTG reference point due to the bulging of the tank as the tank is filled (see 6.1.4 and Appendix B). The need for tie-bars can be assessed by direct measurement on the tanks or from an assessment of the tank construction parameters. If they are necessary, detailed technical evaluation should be undertaken into the need for and the design of the tie-bars.

6.1.2 Pressure Sensor Installation

6.1.2.1 Process connections

All pressure sensor installations should allow in-situ isolation from the tank and connection to a testing/calibration device (prover). Block valves should be used to isolate the pressure sensors from the tank. Bleed vents may be sufficient for connections to provers. Sensors should be installed such that the sensor diaphragm remains covered with liquid during operation. Drain valves should be provided to allow draining of the process fluid when calibration or verification of the system is required.

6.1.2.2 Over-pressure protection

Closing the block valves without opening the bleed vent will create a pocket of trapped liquid whose thermal expansion or contraction may over-pressure the sensor. Depending on the design of the block valve, closing the valve may result in the displacement of fluid,which can also result in over-pressuring the sensors.

Pressure snubbers between the block valves and the sensors may be required to avoid over-pressuring the sensors. Alternatively, the bleed vent may be open to relieve pressure build-up as the block valve is closed.

6.1.3 Pressure Sensor Position Determination

Sensor positions should be measured to the pressure sensor effective centers. Since the diaphragms are not normally accessible, external reference markings on the sensor body should be provided. An estimate of the uncertainty in the external reference marking also should be provided.

The accuracies of the sensor positions and the distances between sensors are important in achieving high HTG measurement accuracy. Guidelines for distance measurement accuracy are as follows:

a. P1 elevation Hb above the HTG reference point is used to calculate the tank bottom mass. The error in P1 elevation measurement should not exceed ± 1/32 inch or 1 mm.
b. P1-P2 vertical distance H is used to calculate the observed density, which in turn is used to calculate the heel mass. The error in the vertical distance P1-P2 should not exceed ± 1/32 inch or 1 mm.
c. P1-P3 vertical distance Ht is used to calculate the magnitude of vapor mass and the effects of ambient air. Both the vapor mass and the ambient air are secondary correction factors that are subject to a number of approximations. The error in the vertical height Ht should not exceed ± 2 inches or 50 mm.

6.1.4 Pressure Sensor Movement Limitation

Tank walls undergo hydrostatic deformations during tank filling and discharge. This results in movements of the sensors such that the elevation of P1 above the HTG reference point and the vertical distance of P2 above P1 may not be constant.

Changes in P1 elevation will have a direct effect on measured mass and should therefore be minimized. P1 is normally mounted on the lower part of the tank where the movements of the tank shell are small (tank datum plates fixed to the tank shell may incur similar movements). P1 elevation above the HTG reference point should be measured with the tank full and again with the tank empty. If the elevation changes by more than 1/32 inch or 1 mm, a tie-bar should be considered to maintain a constant vertical distance between P1 and P2.

Changes in P2 vertical distance above P1 only affect the HTG density and level calculation. In vertical tanks, the effect on measured mass is negligible. If the HTG is used to compute levels and densities as well as mass, the use of a tie-bar between P1 and P2 should be considered to maintain a constant vertical distance between P1 and P2.

HTG sensor movement is described in Appendix B (see paragraph B.1). If any tie-bars are used, the pressure sensor connections to the tank should be made flexible enough to satisfy the mechanical safety requirements. The tie-bar should be fitted to the process end of the pressure sensors to avoid overstressing the sensors.

6.1.5 Wind Effect

Wind impacting on the tank causes variations of the static ambient air pressure. Depending on local circumstances, the ambient air pressure could be different at P1, P2, and P3. Since the sensors measure gauge pressures (referenced to atmosphere), wind-induced differences in ambient pressures at each of the sensors will cause additional measurement errors. Wind effects will be minimal when all three pressure sensors are mounted on one side of the tank in a vertical straight line.

The differences between the ambient pressures of sensors P1 and P3 will have a direct impact on the HTG mass measurement. If exposed to strong winds, the outside ports of the P1 and P3 sensors should be connected together by a pressure equalization pipe. The pipe should be essentially vertical, with no seals or traps, closed at the top, and open at the bottom to eliminate risks of becoming filled with condensed water.

If the P3 sensor is not used, variations in P1 ambient pressure will have a direct impact on the HTG mass measurement accuracy (note that atmospheric tanks do not require P3). If the HTG installation is exposed to strong winds, the outside port of the P1 sensor should be connected to a pipe that slopes down and away from the tank and is open to a point where the ambient pressure variations due to wind are minimal. A minimum of 2 feet or 0.5 m away from the tank at the ground level is recommended.

6.1.6 Thermal Effect

For high accuracy measurements, the HTG performance can be improved by the following:

a. Elimination of temperature gradients through the sensor bodies.
b. Maintaining the sensors at constant temperatures.

The sensor manufacturer's recommendations on the need for and the types of thermal insulation required for performance improvements should be sought and followed.

6.2 TEMPERATURE SENSORS

6.2.1 General

The temperature input should be either automatic or manual. HTG systems are generally installed with a tank temperature measuring device (see Chapter 7.4) and may also include an ambient air temperature measuring device.

Note 3: If product or air temperature is determined by other means, the value(s) may be inputted manually to the HTG processor.

6.2.2 Sensor Positions

The product temperature sensor may be a single point temperature element installed between P1 and P2, or an averaging bulb system.

The ambient air temperature sensor (if required) should be installed on the same side and as near to the tank as the pressure sensors, with the same environmental protection.

6.3 HTG AND LEVEL GAUGE REFERENCES

The HTG reference point should be on the outside of the tank, directly under the sensor P1.

Note 4: The preferred reference point is the tank lip. If the tank lip is not accessible, a reference point can be a mark on the tank shell.

The HTG reference point differs from the level gauge reference point. The level gauge reference point is either the manual gauging datum point or the mark on the tank gauge hatch, a fixed distance above the manual gauging datum point. The vertical distance between the HTG and the manual level gauge reference points should be measured using a standard survey technique.

6.4 COMMISSIONING

6.4.1 General

Commissioning is performed following HTG installation. Some or all parts of the commissioning procedure may also be repeated if some or all of the HTG system is replaced after a hardware failure or a system update. Records should be kept of all data for future use during maintenance (see Section 7).

6.4.2 HTG Parameter Entry

All tank, ambient, HTG sensor, and liquid parameters listed in Table 1 should be established and entered into the HTG processor.

Note 5: The tank parameters will normally remain unchanged. HTG sensor parameters may change if any item of HTG hardware is replaced. Liquid parameters may change if a new product is introduced into the tank.

If any parameters have changed, their new values should be entered into the HTG processor.

6.4.3 Pressure Sensor Zero Adjustment

To check and adjust the pressure sensor zero, follow these procedures.

a. If the outside ports of the sensors are connected to prevent the wind effects, the connections should be removed when adjusting the sensor zeros.
b. The sensor should be isolated from the tank by shutting the block valve.
c. All liquid should be removed from the process connection to the sensor by draining.
d. The process connection to the sensor should be vented to the atmosphere.
e. The sensor zero should be adjusted following the manufacturer's instructions.

f. Following the adjustment, the zero reading of the sensor should be monitored for approximately one hour and further adjustments made if necessary.

6.4.4 Tank Capacity Table Validation

Some tanks currently in service have been calibrated using out-of-date, nonstandard methods. Highly accurate mass measurements assume a minimal error in the tank capacity table. It is recommended that the tank capacity table be verified as conforming with Chapter 2.2A or B and a new calibration performed if needed.

Capacity tables are normally derived from calibration reports that give break points in the volume/level table. Refer to Chapter 2.2 A or B for development of the tank calibration report.

A capacity table is subject to second order influences (see Appendix B, paragraphs B.2 and B.3).

An HTG processor will normally store sufficient data to reproduce the tank capacity table. This data should be checked against the tank capacity table.

6.4.5 Checking Against Manual Measurement

The values measured by the HTG should be compared with those provided by manual measurements. The comparison is an interim action for information only, and its results should be interpreted as follows.

If HTG and manual or mass measurements agree within the uncertainties of the HTG and the manual measurement, the HTG can be assumed to be operating properly. If HTG and manual mass do not agree, further investigation is required.

In any acceptable mass comparison between HTG and another mass measurement, it is important to note that due account is taken of the differences between mass in air (e.g., as measured by a weigh-scale) and true mass as computed by the HTG. Since weigh-scales normally indicate apparent mass in air, it is recommended that apparent mass in air is used when comparing HTG and weigh-scales.

6.4.6 Temperature Sensor Checks

The readings of the temperature sensors (if used) should be compared to the temperature readings obtained via an alternative temperature measurement device.

The product liquid temperature sensor should be verified by measuring the product temperature in the immediate vicinity of the HTG product temperature sensor whenever practical.

The ambient air temperature sensor should be verified by measuring the ambient temperature in the immediate vicinity of the HTG ambient air temperature sensor.

If the HTG and reference temperatures do not agree within the arithmetic sum of their uncertainties, the HTG parameters (if any) should be adjusted or the sensor(s) replaced.

7 Maintenance

7.1 GENERAL

The operations described below cover the system validation and system calibration. Validation differs from calibration in that it does not involve any corrections of the HTG processor parameters.

7.2 VALIDATION

The objective of HTG validation is to show that the HTG still works within the required accuracy. The validation is usually performed on a regular basis, following the local code of practice. The objective of validation is to monitor performance and to establish frequency of system calibration.

The process of validation does not require the use of traceable standards as long as the comparisons are made against stable repeatable references using standard procedures. No adjustments should be made during the validation procedure. If the validation process identifies that a drift in system performance has occurred exceeding predetermined limits, the HTG should be recalibrated. The limits should take into account the expected combined measurement uncertainties of the HTG, the reference equipment, and HTG performance requirements.

7.2.1 HTG Sensor Elevations

HTG sensor elevations should be compared with those obtained in 6.4.2 and any deviations recorded.

7.2.2 Pressure Sensor Zeros

Pressure sensor zeros should be checked using the procedure given in 6.4.3, without any adjustments.

7.2.3 On-Tank Measurements

If the comparison is to be carried out against a manual method, the procedure described in 6.4.5 should be followed.

Alternatively, measurements obtained by other methods can be used for comparison if available for the same tank.

7.2.4 Off-Tank Measurements

Comparisons on mass measurements should be carried out if any of the following are available:

a. Volumetric flow meter with on-line densitometer.
b. Volumetric flow meter with sampled line density.
c. Mass flow meter.
d. Weigh-scale.

7.2.5 Temperature Sensors

Temperature sensors should be checked using the procedure given in 6.4.6, without any adjustments.

7.3 CALIBRATION

7.3.1 General

The objective of HTG calibration is to verify performance of HTG to specified accuracy and to undertake appropriate corrective actions when warranted. HTG system calibration should be performed following performance degradation detected by system validation or at regular intervals.

Traceable standards and existing approved measurement procedures should be used in the calibration of HTG.

Apart from pressure sensor zero, no sensor adjustments are normally possible. If the pressure sensors are found to be out of specification, they should be replaced.

7.3.2 HTG Parameters

All HTG parameters established on commissioning should be reviewed by a suitably qualified person and, if necessary, changes entered into the HTG processor.

7.3.3 Adjustment of Pressure Sensor Zero

The validation records should be examined, and if the pressure sensor zero is found to be out of the manufacturer's specification, the sensor should be replaced and the new sensor commissioned.

If the sensor is found to be within the manufacturer's specification, the validation records should be used to work out the optimal magnitude of the pressure sensor zero adjustment. Zero adjustment should be done using the procedure given in 6.4.3.

7.3.4 Temperature Sensor Calibration

The validation records should be examined, and if needed, further checks should be made as described in 6.4.6. The temperature sensors should be adjusted or replaced if found to be out of limits established at commissioning (see 6.4.6).

7.3.5 Pressure Sensor Calibration

7.3.5.1 General

This method of calibration of HTG mass measurement is the only one where calibration equipment can be obtained whose accuracy is sufficiently better than the accuracy of the HTG itself. If such equipment is not available, the HTG can be calibrated to less accuracy using the method described in 7.3.6.

The accuracy of the mass measurement obtained by the HTG will correspond to the accuracy of its pressure sensors providing that the pressure sensor positions are known and stable and that the calculations are performed with correct parameters (see 7.3.2).

Depending on which calibration equipment is available, either of the two following methods should be used.

7.3.5.2 Reference pressure source method

The reference device for calibration is a traceable dead-weight tester accurate to within ± 0.005 psi or 25 Pa and suitable for use in the field.

All pressure sensors remain mounted on the tank. They are isolated from the tank by block valves, purged and connected, one by one, to the dead-weight tester. The dead-weight tester is used to generate pressures to span the full height of the tank to ensure that all hydrostatic heads normally experienced by the pressure sensors are exercised, i.e., the mass ranges are covered.

The pressure measurements from the HTG are compared with those from the dead-weight tester. If the two are equal within combined measurement uncertainties, the contribution to mass error from the HTG sensors will be within the equipment specification. When carrying out the comparisons, note additional hydrostatic pressure heads in the connections between the dead-weight tester and the pressure sensor.

7.3.5.3 Reference pressure sensor method

The reference device for calibration is a traceable pressure sensor accurate to within ± 0.005 psi or 25 Pa and suitable for use in the field.

All pressure sensors remain mounted on the tank. They are isolated from the tank by block valves and connected, one by one, to the reference pressure sensor. The pressure span corresponding to the full height of the tank should be covered by either changing the liquid level in the tank or by using an external pressure source.

The pressure measurements from the HTG are compared with those from the reference pressure sensor. If the two are equal within combined measurement uncertainties, then the contribution to mass error from the HTG sensors will be within the equipment specification. When doing the comparisons, note hydrostatic pressure heads in the connections between the reference pressure sensor and the pressure sensor under test.

7.3.6 Calibration by Manual Tank Measurements

This calibration method compares the mass measured by HTG with mass calculated from indirect manual measurements of level, density, and temperature. Because of high uncertainties associated with density measurements, it should be used only if the direct pressure sensor calibration cannot be performed for lack of suitable equipment.

Standard procedures should be used to obtain measurements of level (Chapter 3.1A or Chapter 3.1B), temperature (Chapter 7.1, 7.3, or 7.4), and density (Chapter 8.1, 9.1, or 9.2) to calculate standard volume (Chapter 12.1) and reference density (Chapter 9.1 or 9.2). Mass should be calculated as the product of standard volume and reference density.

Since the manual and the HTG measurements are performed using different reference points, two mass readings should be taken to remove the effects of any offset. The calibration should be carried out at the levels that are approximately 12 feet or 4 m apart, preferably with the same liquid.

If:

$$\frac{|\text{HTG mass transferred} - \text{manual mass transferred}|}{\text{manual mass transferred}} < 0.2 \text{ percent}$$

then the HTG should be assumed to be operating correctly.

Note 6: The limit of 0.2 percent is based on the following uncertainties:

Level error, opening and closing innage:	+/– ⅛ inch or 3 mm
Temperature error:	+/– 2˚F or 1˚C
Tank capacity table error:	+/– 0.08 percent
Other errors:	+/– 0.05 percent

Errors in level measurements due to the movement of the level gauge reference caused by tank bulging will add to the manual measurement uncertainty.

8 Safety

8.1 MECHANICAL SAFETY

HTG sensors and sensor connections form an integral part of the tank surface. They should be able to withstand the same mechanical stresses or strains as the tank surface. They should also withstand an impact of product such as corrosion or erosion.

8.2 ELECTRICAL SAFETY

All electrical systems should comply with the local safety regulations. Additionally, the requirements given in the *National Electrical Code* should be considered.

APPENDIX A—CALCULATIONS OVERVIEW

A.1 General

This appendix describes the calculations performed by the HTG processor to compute the mass of the tank contents and other variables. Specific calculations and features that may be particular to one manufacturer's design of HTG system are not included (e.g., pressure sensor linearization formulas).

Symbols used in this appendix are illustrated in Figures A-1 and A-2.

All values to be substituted in the equations in this appendix may be either in customary or SI units (see Chapter 1).

If values are obtained in other units, they should be converted into values in the following customary or SI units:

Customary Units

[see Note 7 below] for pressure, [foot] for level, [square foot] for area, [cubic foot] for volume, [pound] for mass, [pound per cubic foot] for density, [foot per second per second] for acceleration.

SI Units

[see Note 7 below] for pressure, [meter] for level, [square meter] for area, [cubic meter] for volume, [kilogram] for mass, [kilogram per cubic meter] for density, [meter per second per second] for acceleration.

Note 7: Within either system of units, it is recognized that users may have a different preference for the units for pressure for the output readings of the pressure sensors, P1, P2, and P3. To account for different pressure units, a constant "N" appears in equations A3, A4, and A6. The value of "N" for various pressure units is shown in Table A-1.

Note 8: Inches of H_20 is at 68˚F (20˚C).

Calculations are the same for both fixed and floating roof tanks.

In-tank vapor and ambient air densities have only second order effects on the calculated variables. They can be considered constant, or for high accuracies, they can be calculated.

Ambient air density can be calculated using the gas equation of state from absolute ambient pressure and absolute ambient temperature. Changes in ambient air density have only a second order effect on the observed density.

In-tank vapor density can be calculated using the gas equation of state from absolute vapor pressure and absolute vapor temperature together with the vapor relative density.

All sensor input data presented to the HTG processor should be essentially synchronous.

A.2 Pressure Balance

The basis of the HTG calculation is that the sum of pressure increments between any two points is the same regardless of the path along which they have been added.

Thus :

P1 – P3 = total liquid product head + in-tank vapor head – ambient air head between P1 and, P3.

P1 – P2 = liquid product head between P1 and P2 – ambient air head between P1 and P2.

In fixed roof tanks, the in-tank vapor is either a mix of product vapor and air or a "blanket" gas. The concentration of the vapor/air mix will vary with vapor temperature and pressure. In floating roof tanks, the in-tank vapor is ambient air that may be contaminated by product vapor.

Floating roof load has both constant (roof mass) and variable (roof load mass) components. For the purposes of this standard, both components are user-entered constants.

A.3 Density Calculations

Observed density (calculated from pressures):

$$D = N \times (P1 - P2) / (g \times H) + DA$$

Table A-1—Units Table for HTG Equations

Constant	Units Used in the Equations						
	Inputs			Calculated Results			
N	Gauge Pressure	Tank Equiv. Area	Local Gravity Accel.	Level	Volume	Density	Mass
1.000	Pa	m^2	m/sec^2	m	m^3	kg/m^3	kg
1000.0	kPa	m^2	m/sec^2	m	m^3	kg/m^3	kg
100.0	mbar	m^2	m/sec^2	m	m^3	kg/m^3	kg
100,000	bar	m^2	m/sec^2	m	m^3	kg/m^3	kg
167.0791	in-H_2O	ft^2	ft/sec^2	ft	ft^3	lb/ft^3	lb
4633.063	psig	ft^2	ft/sec^2	ft	ft^3	lb/ft^3	lb

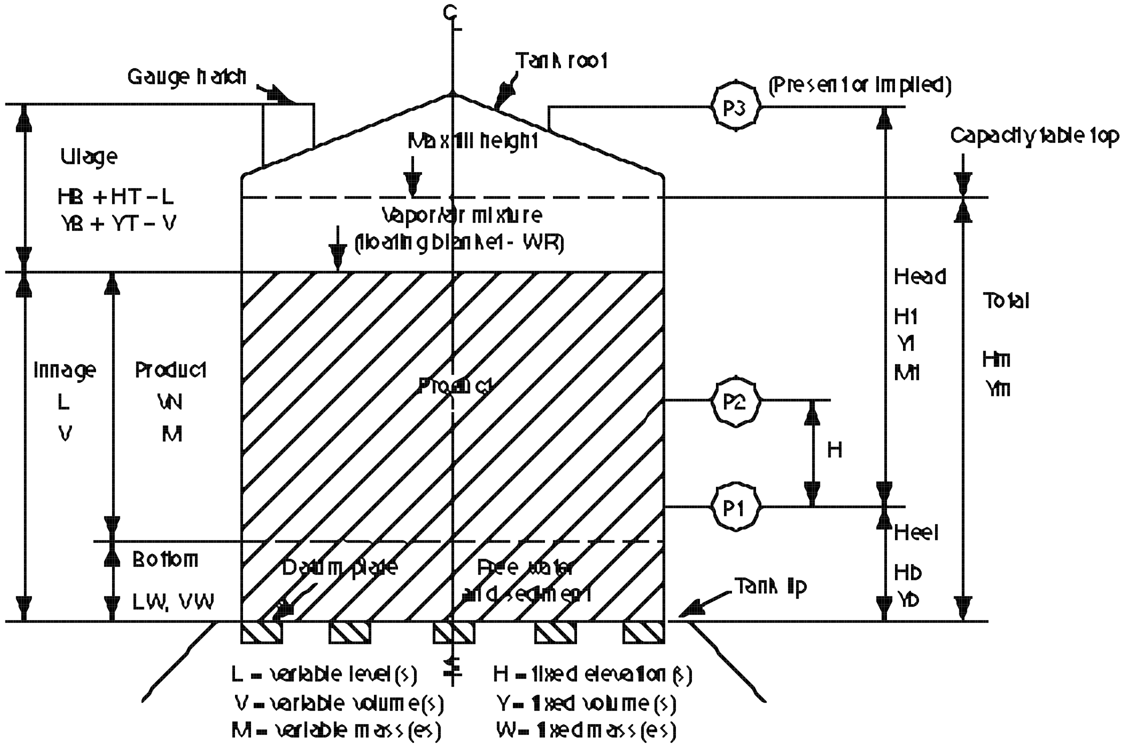


Figure A-1—Measurement Parameters and Variables—Fixed Roof Tank

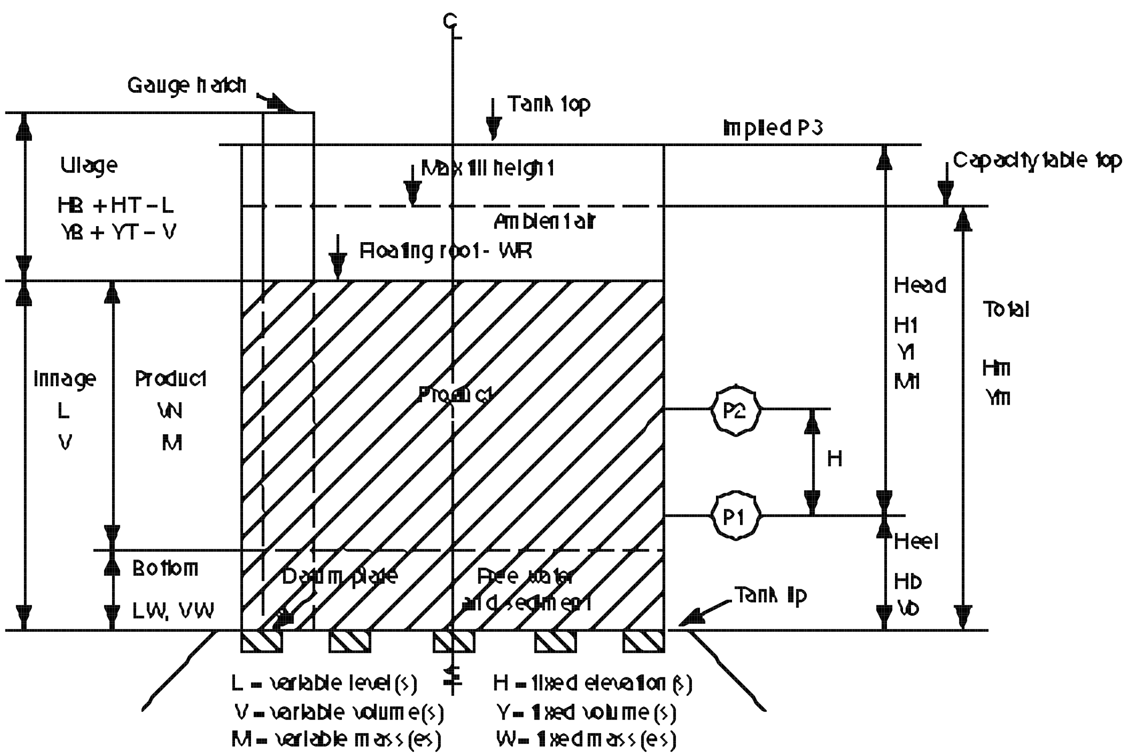


Figure A-2—Measurement Parameters and Variables—Floating Roof Tank

Where:

N = the constant for different pressure measurement units. See Table A-1.
H = the vertical distance of the centers of force on the sensors P1 and P2 diaphragms. See Figure A-1 or A-2.
g = the local acceleration due to gravity.
DA = the ambient air density.

Note 9: Observed density can be calculated from manually entered reference density. The calculations should follow existing standards such as those in Chapter 11.1.

Observed density can also be manually entered.

A.4 Innage Level Calculations

Innage level:

$$L = Ho + Hb + [N \times (P1 - P3) / g - Ht \times (DV - DA)] / (D - DV)$$

Where:

N = the constant for different pressure measurement units. See Table A-1.
Ho = the vertical distance from the tank calibration reference point to the HTG reference point.
Hb = the vertical distance of the center of force on sensor P1 from the HTG reference point. See Figure A-1 or A-2.
g = the local acceleration due to gravity.
Ht = the vertical distance of the centers of force on the sensors P1 and P3 diaphragms. See Figure A-1 or A-2.
DV = the in-tank vapor density.
DA = the ambient air density.
D = the liquid density calculated in A.3.

Note 10: If DV is not available, it may be assumed as equal to DA.

A.5 Tank Equivalent Area Calculations

Tank equivalent area:

$$AE = (V - Yb) / (L - Hb - Ho)$$

Where:

L = the innage level calculated in A.4.
Hb = the vertical distance of the center of force on sensor P1 from the HTG reference point. See Figure A-1 or A-2.
Ho = the vertical distance from the tank calibration reference point to the HTG reference point.
V = the innage volume (at innage level).
Yb = the total heel volume.

Innage volume and total heel volume should be calculated from innage level and the sensor P1 elevation (Hb + Ho), respectively, as described in Chapter 2.2A or B.

A.6 Head Mass Calculations

Product head mass:

$$Mt = AE \times [N \times (P1 - P3) / g - DV \times (Ht + Hb - L) + DA \times Ht]$$

Where:

N = the constant for different pressure measurement units. See Table A-1.
AE = the tank equivalent area calculated in A.5.
L = the innage level calculated in A.4.
g = the local acceleration due to gravity.
Hb = the vertical distance of the center of force on sensor P1 from the HTG reference point. See Figure A-1 or A-2.
Ht = the vertical distance of the centers of force on the sensors P1 and P3 diaphragms respectively. See Figure A-1 or A-2.
DV = the in-tank vapor density.
DA = the ambient air density.

Note 11: If DV is not available, it may be assumed to be equal to DA.

A.7 Heel Mass Calculations

Product heel volume:

$$Vb = Yb - VW$$

Where:

Yb = the total heel volume calculated from the P1 sensor elevation (Hb + Ho) and the tank capacity table.
VW = the free water volume calculated from the free water level and the tank capacity table.

Product heel mass:

$$Mb = Vb \times D$$

Where:

Vb = the product heel volume calculated above.
D = the observed product density calculated in A.3.

Accuracy of the observed product density in the heel space can be affected by liquid stratification (see B.4).

A.8 Product Mass Calculations

Product mass:

$$M = Mt + Mb - WR$$

Where:

Mt = the product head mass calculated in A.6.
Mb = the product heel mass calculated in A.7.
WR = the floating roof mass.

The calculations for product mass are identical for fixed and floating roof tanks provided that the floating roof mass is set equal to zero for the fixed roof tanks.

When the floating roof enters the critical zone, the floating roof mass and the floating roof load mass will be gradually taken up by the floating roof legs. Refer to Chapter 2.2A or B for calculations within and below the critical zone.

A.9 Product Apparent Mass in Air Calculations

Product apparent mass in air:

$$Ma = M \times (1 - DA/D)$$

Where:

M = the product mass calculated in A.8.
DA = the ambient air density.
D = the observed product density calculated in A.3.

A.10 Inventory Accuracy

Providing that the pressure sensor installation parameters are correct, the calculated mass accuracy depends only on the accuracies of the pressure sensors, the tank capacity table, and the local acceleration due to gravity. For HTG systems, typical accuracy calculations are given below.

Neglecting P3 and considering that

$$\textbf{Product head mass} = \frac{P1 \times \text{tank average cross sectional area}}{\text{local acceleration due to gravity}}$$

Assuming that all errors are statistically independent, then

$$E(M)^2 = E(P1)^2 + E(G)^2 + E(AE)^2$$

Where:

E(M) = error of reading of mass (absolute mass error / absolute mass).
E(P1) = error of reading of P1.
E(G) = error of reading of the local acceleration due to gravity.
E(AE) = error of reading of the tank average cross sectional area.

The error of reading of the tank average cross sectional area is the same as the error in the tank capacity table. This is normally in the region of ± 0.05 percent to ± 0.1 percent.

Table A-2 shows that the error in the average area (based on the tank capacity table) has a dominant influence in inventory accuracy.

Table A-2—Example of Inventory Accuracies

Sensor Accuracies:					
Pressure P1	[±percent reading]	0.01	0.02	0.05	0.1
Local g	[±percent reading]	0	0	0	0
Average area	[±percent reading]	0.1	0.1	0.1	0.1
Inventory Accuracies:					
Mass	[±percent reading]	0.10	0.10	0.11	0.14

APPENDIX B—SECOND ORDER INFLUENCES

The following effects have second-order influences on HTG measurements. The effects cannot be calibrated out. For high accuracy measurements, precautions should be taken to minimize them.

B.1 HTG Sensor Movement

In modern tanks, higher stresses and more elastic deformations in the constructional steel plates of the tank are allowed. Depending on the tank height and diameter, this can lead to the following:

a. Horizontal movement of the tank wall.
b. Angular rotation of (parts of) the tank wall.
c. Vertical movement of the fixed tank roof.

The magnitude of the movements depends on the tank construction and the density and the level of the product in the tank. Horizontal movements of P1 and P2 have no effect on the HTG measurements. The angular rotation of the tank wall in places where the sensors P1 and P2 are mounted will result in HTG measurement errors. Tie-bars should be used to reduce these errors (see Section 6).

HTG measurement errors caused by the fixed tank roof movements are not significant.

B.2 Hydrostatic Expansion

The tank capacity tables are corrected for hydrostatic pressure variations. The corrections assume a liquid with density typical for the tank contents according to Chapter 2.2A or B. If the stored liquid density is significantly different from that used for the tank calibration, the tank capacity table should be corrected and the HTG processor updated with the new parameters. HTG should not make any automatic compensation to the tank capacity table due to changing product density. In most practical cases, small liquid density changes will have no significant effect on the HTG measurements.

B.3 Thermal Expansion

The volume within the tank shell expands and contracts with the shell temperature. This causes changes in the tank capacity tables and requires correction of all measured volumes. Corrections as given in Chapter 2.2A or B should be performed by the HTG processor.

B.4 Liquid Stratification

The only effect that liquid stratification has on the product mass is to cause uncertainty in the product heel mass below P1, which is calculated from volume and density. Heel density is assumed to be the same as the observed density measured above P1.

The magnitude of the error caused by liquid stratification will depend on the ratio of head and heel masses as well as the degree of product stratification. The effect is normally insignificant.

APPENDIX C—TERMINOLOGY

The following terms are included in this appendix for information only. The terms are defined in other standards.

C.1 apparent mass in air: The value obtained by weighing in air against standard masses without making correction for the effect of air buoyancy on either the standard masses or the object weighed (Chapter 9.1).

C.2 capacity table: A table, often referred to as a tank table or a tank calibration table, showing the capacities of, or volumes in, a tank corresponding to various liquid levels measured from a stable reference point (Chapter 2.2A or B).

C.3 density: The mass of the substance divided by its volume (Chapter 9.1). When reporting the density, the unit of density used, together with the temperature, shall be explicitly stated. The standard reference temperature for international trade in petroleum and its products is 15˚C (Chapter 15). Other reference temperatures may be required for legal metrology or other special purposes (Chapter 9.2).

C.4 innage: The depth of a liquid in a tank (synonymous with dip) (Chapter 2.2A or B).

C.5 fixed roof tank: A vertical cylindrical storage vessel with either a cone- or domed-shaped roof. The tank may be of the nonpressurized or freely vented type or it may be of the low pressure type (Chapter 7.4).

C.6 floating cover (screen): A lightweight cover of metal or plastic material designed to float on the surface of the liquid in a fixed roof tank. The cover is used to retard the evaporation of volatile products in a tank (Chapter 2.2A or B).

C.7 floating roof tank: A tank in which the roof floats freely on the surface of the liquid except at low levels when the weight of the roof is taken, through its supports, by the tank bottom (Chapter 2.2A or B).

C.8 gauge reference point: The point from which the liquid depths are measured (Chapter 3.1A).

C.9 gross standard volume: The total volume of all petroleum liquids and sediment and water, excluding free water, also corrected by the appropriate volume correction factor, (Chapter 1).

C.10 net standard volume: The total volume of all petroleum liquids, excluding sediment and water and free water, corrected by the appropriate volume correction factor (Chapter 1).

Note 12: For clean, refined product, the total standard volume and the net standard volume are usually equal (Chapter 12.1).

C.11 observed density: The value obtained at a test temperature, which differs from the calibration temperature of the apparatus (Chapter 9.1).

C.12 tank shell: The outer casing of a storage tank that on land is secured to the ground and includes the roof, if it is a fixed roof tank (Chapter 2.2A or B).

C.13 total volume: The indicated volume without correction for temperature and pressure. It includes all water and sediment (Chapter 12.1).

C.14 ullage: The capacity of the tank not occupied by the liquid (synonymous with outage) (Chapter 2.2A or B).

APPENDIX D—ILLUSTRATIVE EXAMPLE

D.1 Derivation of Constant "N"

Basic relationships:

Standard gravitational field g	=	9.80665	[m/sec^2]	(SI units)
	=	32.17404856	[ft/sec^2]	(Customary units)
1.0 [inch $H_2$0 (68˚F/20˚C)]	=	5.19297667	[lbs/ft^2]	(approximately)
1.0 [inch $H_2$0 (68˚F/20˚C)]	=	248.64107	[Pa]	(approximately)
1.0 [psig]	=	6894.757	[Pa]	(approximately)
1.0 [lb/ft^3]	=	16.01846	[kg/m^3]	(approximately)

Rounding and tolerance of results:

The constants "N" developed below are rounded to seven significant digits. This provides a tolerance of 1 part in 10^7. Typical transmitter uncertainties are greater than 1 part in 10^4. Tank capacity table uncertainties are typically greater than 1 part in 2000 (0.05 percent).

I. Pressure inputs in psig (N = 4633.063):

$$\textbf{Density}\ [\text{lbs/ft}^3] = \frac{\text{Pressure [psi]} \times 144\ [\text{in}^2 / \text{ft}^2] \times 32.17404856\ [\text{ft/sec}^2]}{\text{Head [ft]} \times g\ [\text{ft/sec}^2]} = \frac{4633.063 \times \text{Pressure [psi]}}{\text{Head [ft]} \times g\ [\text{ft/sec}^2]}$$

II. Pressure inputs in inches $H_2$0 (N = 167.0791):

$$\textbf{Density}\ [\text{lbs/ft}^3] = \frac{\text{Pressure [in } H_20] \times 5.19297667\ [\text{lbs/ft}^2 / \text{in } H_20] \times 32.17404856\ [\text{ft/sec}^2]}{\text{Head [ft]} \times g\ [\text{ft/sec}^2]}$$

$$= \frac{167.0791 \times \text{Pressure [in } H_20]}{\text{Head [ft]} \times g\ [\text{ft/sec}^2]}$$

D.2 Example Calculations

The examples below serve to illustrate order of calculation. Uncertainty of inputs or calculated results are not implied by the significant digits carried in either inputs or results. Refer to equation A.10 for guidance in computing inventory accuracy.

Tank Equivalent Area (AE)	=	100.0	[m^2]	=	1067.391	[ft^2]	(approximately)
Liquid Density (D, in vacuo)	=	1000	[kg/m^3]	=	62.42796	[lb/ft^3]	
Liquid Level	=	10	[m]	=	32.8084	[ft]	
Vapor Head	=	10	[m]	=	32.8084	[ft]	
Ht	=	20	[m]	=	65.6168	[ft]	
H	=	2.5	[m]	=	8.2021	[ft]	
Hb	=	0.0	[m]	=	0.0	[ft]	
Ho	=	0.0	[m]	=	0.0	[ft]	
Yb	=	0.0	[m^3]	=	0.0	[ft^3]	
Local Accel.of Gravity	=	9.815	[m/sec^2]	=	32.20144	[ft/sec^2]	
Ullage Pressure (at P3)	=	3500	[Pa]	=	14.07646	[in H_2O]	(approximately)
Vapor Space Density (DV)	=	1.25	[kg/m^3]	=	0.078035	[lb/ft^3]	(approximately)
Ambient Air Density (DA)	=	1.2	[kg/m^3]	=	0.074914	[lb/ft^3]	(approximately)

From pressure balance equation:

$$(P1 - P2) / g = D \times H - DA \times H$$
$$(P1 - P3) / g = D \times \text{Head (liquid)} + DV \times \text{Head (vapor)} - Ht \times DA$$

Therefore, for these conditions, the pressures seen at P1 and P2 are

P1 = 101,537.1275 [Pa] = 408.3683 [in H_2O] (approximately)

P2 = 77,029.0725 [Pa] = 309.8003 [in H_2O] (approximately)

Example using SI units (Pa):

$$\mathbf{D} = \frac{N \times (P1 - P2)}{H \times g} + DA = \frac{1.0 \times (101{,}537.1275 - 77{,}029.0725)}{2.5 \times 9.815} + 1.2 = 1000.0\ [kg/m^3]\ (= 62.42796\ [lb/ft^3])$$

$$\mathbf{L} = Ho + Hb + \frac{N \times (P1 - P3) / g - Ht \times (DV - DA)}{(D - DV)} = \frac{1.0 \times (101{,}537.1275 - 3{,}500) / 9.815 - 20 \times (1.25 - 1.2)}{1000.0 - 1.25}$$

$$= 10.0\ [m]\ (= 32.8084\ [ft])$$

$$\mathbf{AE} = (V - Yb) / (L - Hb - Ho) = 100.0\ [m^2]$$

$$\mathbf{Mt} = AE \times [\,N \times (P1 - P3) / g - DV \times (Ht + Hb - L) + DA \times Ht]\ [kg]$$

$$= 100.0 \times [\,1.0 \times (101{,}537.1275 - 3{,}500) / 9.815 - 1.25 \times (20.0 - 10.0) + 1.2 \times 20.0]\ [kg]$$

$$= 10{,}000\ [kg]\ (= 2{,}204{,}623\ [lb])$$

Example using customary units (in H_20):

$$\mathbf{D} = \frac{N \times (P1 - P2)}{H \times g} + DA = \frac{167.0791 \times (408.3683 - 309.8003)}{8.2021 \times 32.20144} + 0.074914 = 62.42797\ [lb/ft^3]$$

$$\mathbf{L} = Ho + Hb + \frac{N \times (P1 - P3) / g - Ht \times (DV - DA)}{(D - DV)}\ [ft]$$

$$= \frac{167.0791 \times (408.3683 - 14.07646) / 32.20144 - 65.6168 \times (0.078035 - 0.074914)}{62.42797 - 0.078035}\ [ft]$$

$$= 32.8084\ [ft]$$

$$\mathbf{AE} = (V - Yb) / (L - Hb - Ho) = 1076.391\ [ft^2]$$

$$\mathbf{Mt} = AE \times [\,N \times (P1 - P3) / g - DV \times (Ht + Hb - L) + DA \times Ht]\ [lb]$$

$$= 1076.391 \times [\,167.0791 \times (408.3683 - 14.07646) / 32.20144$$

$$- 0.078035 \times (65.6168 - 32.8084 + 0.074914 \times 65.6168]\ [lb]$$

$$= 2{,}204{,}623\ [lb]$$

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