Manual of Petroleum Measurement Standards Chapter 3—Tank Gauging

Section 6—Measurement of Liquid Hydrocarbons by Hybrid Tank Measurement Systems

FIRST EDITION, FEBRUARY 2001

ERRATA, SEPTEMBER 2005

REAFFIRMED, OCTOBER 2011

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Measurement of liquid hydrocarbons by hybrid tank measurement systems

1 Introduction

A Hybrid Tank Measurement System (HTMS) is a method of combining direct product level measured by an automatic tank gauge (ATG), temperature measured by an automatic tank thermometer (ATT), and pressures from one or more pressure sensors. These measurements are used, together with the tank capacity table and applicable volume and density correction tables, to provide level, temperature, mass, observed and standard volume, and observed and reference density.

The product level is directly measured by the ATG. The product temperature is directly measured by the ATT. The true (observed) density is determined from hydrostatic pressure measured by the pressure sensor(s) and the product height above the bottom pressure sensor, as measured by the ATG. Total static mass is computed by a hybrid processor from the true density and the tank capacity table. Gross observed volume, standard volume, and reference density are computed using industry practice for static calculations (See MPMS Chapter 12.1).

2 Scope

This standard covers selection, installation, commissioning, calibration and verification of Hybrid Tank Measurement Systems (HTMSs) for the measurement of level, static mass, observed and standard volume, and observed and reference density in tanks storing petroleum and petroleum products. It is up to the user to define which measurements are required for custody transfer or inventory control purposes (standard volume, mass, or both). Therefore, this standard also provides a method of uncertainty analysis, with examples, to enable users to select the correct components and configure an HTMS to more closely address the intended application. (See Appendix B.)

This standard covers HTMSs for stationary storage tanks storing liquid hydrocarbons with a Reid Vapor Pressure below 15 psi (103.42 kPa). This standard applies to vertical cylindrical tanks, and can also be applied to tanks with other geometries (e.g., spherical and horizontal cylindrical) which have been calibrated by a recognized oil industry method. Examples of uncertainty analysis for spherical and horizontal cylindrical tanks are also given in Appendix B. This standard does not apply to pressurized tanks or marine applications.

This standard covers the installation and calibration of HTMSs for custody transfer and inventory control.

Note: 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. Guidance is provided on the calculation of both mass and apparent mass in air (See Appendix A).

3 Referenced Publication

API *Manual of Petroleum Measurement Standards*

Chapter 1	"Vocabulary"
Chapter 2.2A	"Measurement and Calibration of Upright Cylindrical Tanks by the Manual Strapping Method"
Chapter 2.2B	"Calibration of Upright Cylindrical Tanks Using the Optical Reference Line Method"
Chapter 3	"Tank Gauging"
Chapter 3.1A	"Manual Gauging of Petroleum and Petroleum Products"
Chapter 3.1B	"Standard Practice for Level Measurement of Liquid Hydrocarbons in Stationary Tanks by Automatic Tank Gauging"
Chapter 7	"Temperature Determination"
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 8.3	"Mixing and Handling of Liquid Samples 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 12.1	"Calculation of Static Petroleum Quantities in Upright Cylindrical Tanks and Marine Tank Vessels"
Chapter 15	"Guidelines for Use of the International System of Units (SI) in the Petroleum and Allied Industries"
Chapter 16.2	"Mass Measurement of Liquid Hydrocarbons in Vertical Cylindrical Storage Tanks by Hydrostatic Tank Gauging"

ASTM Standards[1]

D1250	"Volume Correction Factors" (joint standard with API MPMS Chapter 11.1)
D5002-94	"Density and Relative Density of Crude Oils by Digital Density Analyzer"
D4052-96	"Density and Relative Density of Liquids by Digital Density Meter"

4 Definitions

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

4.1 HTMS: A Hybrid Tank Measurement System (HTMS) is a system which uses the product level measured by an automatic tank gauge (ATG), the product temperature measured by an automatic tank thermometer (ATT), and the static head of the liquid measured by one or more pressure sensors. These measurements are used, together with the tank capacity table and the product volume/density correction tables, to provide (i.e., display and/or print out) level, temperature, mass, observed and standard volume, and observed and reference density.

4.2 hybrid processor: The computing device component of the HTMS which uses the level, temperature, and pressure sensor measurements of the HTMS, in addition to stored tank parameters, to compute density, volume, and mass.

4.3 hybrid reference point: A stable and clearly marked point on the outside of the tank wall, from which the position of the pressure sensor(s) is (are) measured. The hybrid reference point is also measured relative to the datum plate.

4.4 zero error of a pressure transmitter: The indication of the gauge pressure transmitter when no pressure difference between input pressure and ambient pressure is applied to the pressure transmitter. This value is expressed in units of pressure measurement (Pascal, in-H_2O, psi, etc.)

4.5 linearity error of a pressure transmitter: The deviation of the indicated value of the pressure transmitter from the applied pressure as input to the transmitter. This value should not include the zero error and should be expressed as a fraction or percent value of the applied pressure reading.

4.6 stable/stability: A measurement is considered stable if the measured deviation has not exceeded its acceptable tolerance, as defined in this standard, during the last year.

[1]American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428-2959.

5 General

This standard presents both Metric (SI) and US Customary units, and may be implemented in either system of units. The presentations of both units are for convenience of the user, and are not necessarily exact conversions. The units of implementation are typically determined by contract, regulatory requirement, the manufacturer, or the user's calibration program. Once a system of units is chosen for a given application, it is not the intent of this standard to allow arbitrarily changing units within this standard.

5.1 SAFETY PRECAUTIONS

The following recommended practices and guidelines on safety should be followed:

API RP 500	*Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities*
API RP 2003	*Protection Against Ignition Arising Out of Static, Lightning and Stray Currents*
API RP 2510	*The Design and Construction of Liquefied Petroleum Gas Installations at Marine and Pipeline Terminals, Natural Gasoline Plants, Refineries, and Tank Farms*
API RP 2511	*Bulletin on Precautionary Labels*
ISGOTT	*International Safety Guide for Oil Tankers and Terminals*

Other applicable safety codes and regulations should be complied with.

5.2 EQUIPMENT PRECAUTIONS

Safety and material compatibility precautions should be taken when using HTMS 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.

5.2.1 Mechanical Safety

HTMS sensor connections form an integral part of the tank structure. All HTMS equipment should be capable of withstanding the pressure, temperature, operating, and environmental conditions that are likely to be encountered in the service

5.2.2 Electrical Safety

All electric components of HTMSs for use in electrically classified areas should be appropriate to the classification of the area and should conform to appropriate National (UL, FM, FCC, NEC, etc.) electrical safety standards, and/or International (IEC, CSA, etc.) electrical safety standards.

6 Selection and Installation of Hybrid Tank Measurement System Equipment

6.1 GENERAL

A Hybrid Tank Measurement System (HTMS) consists of four major components: an automatic tank gauge (ATG), an automatic tank thermometer (ATT), one or more pressure sensors, and a hybrid processor which stores the tank parameters and performs calculations. The requirements of these individual components are described below.

The user should define whether the HTMS is to be used primarily for standard volume or mass measurements (or both), whether the measurements are to be used for custody transfer or inventory control application, and the corresponding degree of measurement accuracy desired.

The user or manufacturer should select the HTMS components and configure the system appropriately to meet the application requirements. The accuracy requirements of the user's application determines the individual accuracy requirements of the HTMS components. Section 7 and Appendix B provide guidance and methods to estimate the effects on overall HTMS accuracy of the individual component selection.

To achieve standard volume custody transfer accuracy, the ATG and ATT components should be selected to meet the applicable custody transfer requirements defined in *MPMS* Chapters 3.1B and 7. To achieve mass custody transfer accuracy, the pressure sensors should meet the applicable custody transfer requirements defined in *MPMS* Chapter 16.2.

If the HTMS is to be customized for a specific application where high accuracy is required for some parameters but not all, refer to Section 7 for additional guidance. Accuracy prediction equations with examples are given in Appendix B to assist users in selection of individual component accuracy requirements.

6.2 AUTOMATIC TANK GAUGE (ATG)

The automatic tank gauge (ATG) component and its installation and mounting should meet the requirements described in MPMS Chapter 3.1B, where applicable. Note that Chapter 3.1B defines different levels of accuracy for ATGs used for either custody transfer or inventory control purposes. The ATG accuracy requirements for HTMS are consistent with Chapter 3.1B for HTMS systems intended primarily for volumetric measurements. However, the ATG accuracy requirements for mass HTMS applications are somewhat different. Both are summarized in Table 1, below. The accuracy of the ATG installation will determine the accuracy of the HTMS density and standard volume measurements.

The intrinsic accuracy of the ATG, demonstrated by the factory calibration, and the installed accuracy, demonstrated during field verification, should be within the following maximum values:

Table 1—Recommended Maximum ATG Tolerances

	Custody Transfer		Inventory Control	
	Volume	Mass	Volume	Mass
Intrinsic Accuracy	± 1 mm (± 1/16 inch)	± 3 mm (± 1/8 inch)	± 3 mm (± 1/8 inch)	± 3 mm (± 1/8 inch)
Installed Accuracy	± 4 mm (± 3/16 inch)	+ 12 mm (± 1/2 inch) See Note	± 12 mm (± 1/2 inch)	± 25 mm (± 1 inch) See Note

Note: For mass-based applications (both custody transfer and inventory control), accuracy of the ATG has minimal effect on the mass calculated above the *P*1 level because of the canceling effect of density/volume errors. However, the uncertainty of calculated density due to errors in the ATG has an effect on heel mass (i.e., at levels below the *P*1 position). Therefore, the choice of ATG accuracy in Table 1 for mass-based applications is made for the purpose of minimizing error in heel mass. In addition, by minimizing uncertainty in calculated density, a means is provided to independently monitor the performance of the pressure transmitters.

Where loss control or inventory accounting requirements suggest, maximum inventory control ATG tolerances should be more rigorous (i.e., less than ± 25 mm (1 inch)).

6.3 HTMS PRESSURE SENSOR(S)

The HTMS pressure sensor installation should be in accordance with the recommendations given in *MPMS* Chapter 16.2. The HTMS pressure sensor(s) should be selected in accordance with the accuracy uncertainty calculation for the specific application (See Section 7 and Appendix B). The accuracy requirements of the pressure sensor(s) depends on the HTMS's intended application (e.g., for volume or mass custody transfer, or volume or mass inventory control). The following maximum values of allowable zero and linearity errors are recommended for various configurations of HTMS:

Table 2—Recommended Maximum Pressure Sensor Tolerances

	Custody Transfer		Inventory Control	
	Volume	Mass	Volume	Mass
P1 zero error	100 Pa	50 Pa	150 Pa	150 Pa
Linearity error	0.1%	0.07%	0.2%	0.2%
P3 zero error	40 Pa	24 Pa	60 Pa	60 Pa
Linearity error	0.5%	0.2%	1.0%	1.0%

The HTMS pressure sensor(s) are mounted at specific locations on the tank shell (or immersed at specific locations above the reference datum plate). HTMS pressure sensor(s) in atmospheric storage tank applications should be gauge pressure transmitters (one port open to atmosphere).

Use of electronic analog output or digital output should depend upon the overall accuracy requirement of the pressure transmitter for its intended application.

The naming convention for the pressure sensors (*P*1 near the tank bottom, and *P*3 in the ullage space) is chosen for consistency with existing standards which describe hydrostatic tank gauging (MPMS Chapter 16.2).

Note: An optional middle pressure sensor (*P*2) may be installed between *P*1 and *P*3 for redundant density calculations or comparisons using the calculation method described in *MPMS*, Chapter 16.2.

For an HTMS installed on an atmospheric storage tank, the span of pressure sensor *P*3 should be much smaller than the span chosen for pressure sensor *P*1 because the gauge vapor pressure is typically limited to a maximum of approximately 5 kPa (corresponding to the maximum RVP of 103.421 kPa, or 15 psia).

6.4 AUTOMATIC TANK THERMOMETER (ATT)

The automatic tank thermometer (ATT) should meet the requirements of MPMS Chapter 7, where applicable. The intrinsic accuracy of the ATT, demonstrated by the factory calibration, and the installed accuracy, demonstrated during field verification, for various configurations of HTMS should be within the limits below:

Table 3—Recommended Maximum ATT Tolerances

	Custody Transfer		Inventory Control	
	Volume	Mass	Volume	Mass
Intrinsic Accuracy	0.25 degC (0.5 degF)	0.5 degC (1 degF)	0.5 degC (1 degF)	0.5 degC (1 degF)
Installed Accuracy	0.5 degC (1 degF)	1 degC (2 degF)	1 degC (2 degF)	1 degC (2 degF)

Depending on the HTMS application and the accuracy requirements, the ATT may be an averaging ATT consisting of multiple fixed temperature sensors, a series of spot temperature sensors installed at appropriate elevations, or a single spot temperature sensor. HTMSs designed primarily to compute standard volumes should use an ATT that provides average temperature. For HTMSs designed primarily for measuring mass, a single point or spot RTD is considered adequate.

The ATT may optionally be used in the calculation of vapor density if multiple elements exist which can independently measure vapor temperature apart from the remaining elements which are submerged. Optionally, the submerged element(s) of an ATT may be used for vapor temperature determination in an insulated tank.

6.5 HYBRID PROCESSOR

The hybrid processor may be implemented in various ways, which includes a locally mounted microprocessor, a remote computer, or the user's Distributed Control System (DCS). The hybrid processor may be dedicated to a single tank or shared among several tanks.

The hybrid processor receives data from the sensors and uses the data together with the tank and product parameters to compute the observed density, reference density, mass, observed volume and standard volume inventories for the product in the storage tank.

The stored parameters fall into six groups: Tank data, ATG data, ATT data, pressure sensor data, product data, and ambient data (see Table 4).

All parameters in Table 4 which are required by the application should be programmed into the hybrid processor.

The hybrid processor may also perform linearization and/or temperature compensation corrections of the various HTMS components.

All variables measured and computed by the hybrid processor should be capable of being either displayed, printed, or communicated to another processor. Computations normally performed by the hybrid processor are described in Appendix A.

6.6 OPTIONAL SENSORS

6.6.1 Pressure Transmitter *P*2

A middle transmitter (*P*2) may be employed for an alternate (i.e., HTG) density calculation for comparison or alarming purposes, or as a backup density calculation should the ATG component become inoperative. Refer to *MPMS* Chapter 16.2.

6.6.2 Instrumentation for Ambient Air Density Determination

Ambient air density is a second order term found in the HTMS density calculation. Methods for determination of ambient air density are not addressed by this standard. However, ambient temperature and pressure sensors may be used for more accurate determination of ambient air density, if desired.

Single measurements of ambient temperature and pressure may be used for all tanks at the same location.

7 Accuracy Effects of HTMS Components and Installation

The accuracy of each component of the HTMS affects one or more of the measured or calculated parameters. For certain applications HTMSs may be designed to provide high accuracy of certain parameters, but some compromise may be accepted with the remaining parameters. For example, if the HTMS is designed primarily for standard volume measurement using the density of the product as measured by the HTMS, components should be chosen such that the accuracy of the average product density would not affect the determination of VCF (See examples in Section B.6).

The effects of component accuracy on measured and calculated parameters are discussed below. Equations are given in

Appendix B to assist the user in determining the magnitudes of errors of spot (ie., static) measurement of observed density, mass, and standard volume due to uncertainty of each of the HTMS system primary measurements (level, pressure, and temperature).

7.1 ACCURACY EFFECTS OF THE ATG

The accuracy of the ATG component and its installation has the most effect on level, observed and reference density, and observed and standard volume.

Refer to MPMS Chapter 3.1B for guidance on the ATG accuracy as related to calibration and installation.

Errors in the measured level have little effect on the computed mass because of error cancellation in the arithmetical product of volume and density.

Note: The mass error cancellation effect is greatest in vertical cylindrical tanks. In spherical or horizontal cylindrical tanks the mass error cancellation is somewhat less. The effects of ATG accuracy on mass for various tank geometries can be predicted using the uncertainty equations in Appendix B, Section B.2.

If an HTMS is used to determine standard volume for custody transfer or inventory control, then the accuracy of the ATG should meet the corresponding requirements set forth in MPMS Chapter 3.1B. If the HTMS is used primarily for mass or density determination, then less rigorous requirements of ATG accuracy than those specified in MPMS Chapter 3.1B for custody transfer may be employed. Refer to Table 1 for recommended maximum allowable ATG tolerances.

7.2 ACCURACY EFFECTS OF THE PRESSURE SENSOR(S)

The accuracy of the pressure sensors (*P*1 and *P*3) directly affect the observed and reference density, and the mass. However, errors in *P*1 or *P*3 have no effect on observed volume, and only a minor effect on standard volume.

The overall accuracy of the pressure sensor(s) will depend on both the zero and linearity errors. The zero error is an absolute error expressed in the pressure unit of measurement (e.g., Pascal, in-H_20, psig, etc.). The linearity error is typically stated in percent of reading. At low levels the zero error is the dominating factor in the uncertainty analysis. The manufacturer should unambiguously state both the zero and linearity errors over the anticipated operating temperature range to allow the end user to verify that the error contribution of the pressure sensor(s) to the overall uncertainty will be acceptable for the required HTMS accuracy (see Appendix B.). Refer to Table 2 for recommended maximum allowable zero and linearity errors.

The total error in pressure units of a pressure sensor can be calculated by:

$$U_{P\text{-total}} = U_{P\text{-zero}} + (P_{\text{applied}} * U_{P\text{-linearity}}) / 100$$

where

$U_{P\text{-total}}$= total error of pressure sensor (expressed in Pascal, in-H_2O, etc.),

$U_{P\text{-zero}}$= zero error of pressure sensor (expressed in Pascal, in-H_2O, etc.),

P_{applied}= pressure as input to the pressure sensor (expressed in Pascal, in-H_2O, etc.),

$U_{P\text{-linearity}}$=linearity error of pressure sensor, expressed as percent of reading.

The applied pressure for pressure sensor $P1$ ($P1_{\text{applied}}$) is approximately the sum of the liquid head, the vapor head, and the maximum setting of the pressure relief valve (See Appendix B).

For the *P*3 pressure sensor, the vapor pressure is not related to the liquid level, and therefore the maximum value of the pressure relief valve ($P3_{\text{max}}$) should be taken for $P3_{\text{applied}}$.

7.3 ACCURACY EFFECTS OF THE ATT

The accuracy of the ATT directly affects the reference density and standard volume accuracy. Averaging temperature measurement is required for accurate determination of reference density or standard volume.

ATT accuracy has no effect on the observed density in any tank geometry, and only minor effects on the mass. For HTMSs designed primarily for measuring mass, a single point or spot RTD is considered adequate.

Note: A temperature error can affect the accuracy of the calculated volume and mass if a thermal expansion correction is required because the tank operating temperature is different from the tank calibration reference temperature. Refer to *MPMS* Chapter 12.1A

Refer to *MPMS* Chapter 7 for guidance on the ATT accuracy as related to calibration and installation.

Refer to Table 3 for recommended maximum allowable ATT tolerances.

8 HTMS Measurements and Calculations

When the product level approaches the bottom pressure sensor (*P*1), the uncertainty of the calculated (observed) density becomes greater. This is because of both the increasing uncertainty in the ATG level measurement as a fraction of level, and the increasing uncertainty of the *P*1 pressure measurement as a fraction of liquid head pressure, as level drops. This effect must be considered in how various parameters are calculated at low product levels.

Depending on which measurements the user considers as the primary measurement (i.e., standard volume or mass), and depending on the characteristics of the product (i.e., uniform or density stratified) two modes are defined for HTMS measurements and calculations. These modes (Mode 1 and Mode 2) should be user-configurable.

8.1 HTMS MODE 1

HTMS Mode 1 is preferred where standard volume is the primary value of concern, and where product density remains relatively uniform at low levels. When the level is above a pre-determined level (H_{min}), in Mode 1 the HTMS calculates the average density of the tank contents continuously. Below H_{min}, Mode 1 uses the last calculated reference density (D_{ref}) from when the level was above H_{min}. Alternatively, below H_{min}, D_{ref} may be manually entered if the product is stratified or if new product is introduced into the tank.

The value of H_{min} should be user configurable and should be determined and loaded into the hybrid processor before completion of commissioning. Equation B.5 is provided to enable the user to establish a value for H_{min}.

Table 5a (Method A) and Table 5b (Method B) specify the HTMS measurements and calculations required for Mode 1 at and above H_{min}, and below H_{min}, respectively.

Refer to Figure 1 for additional clarification of how Calculation Methods A and B apply to HTMS Mode 1 as level changes.

8.2 HTMS MODE 2

HTMS Mode 2 is preferred where mass is the primary value of concern. Mode 2 is also preferred where standard volume is the primary output value and the user expects that a stored reference density (Mode 1) would not be representative of actual density at low levels (due to stratification or the introduction of new product).

HTMS Mode 2 does not use an H_{min} or stored Dref. HTMS Mode 2 calculates the reference density (D_{ref}) at all levels above $P1$. However, to insure that the pressure sensor $P1$ is always fully submerged, a "$P1$ cut-off" level is introduced in Mode 2 (See Figure 1.). If the product level is at or below this "cut-off" level, the last calculated D_{ref} is held constant. Above this level all measurements and calculations are performed in accordance with Method A (Table 5a). Below this level the measurements and calculations follow Method B (Table 5b).

Refer to Figure 1 for additional clarification of how Calculation Methods A and B apply to HTMS Mode 2 as level changes.

9 Commissioning and Initial Field Calibration

Some HTMS components (pressure sensors, for example) are normally calibrated at the factory before installation. Other HTMS components (the ATG, for example) should be configured and verified following installation. The process of commissioning the HTMS is performed before putting the HTMS system in service, and involves not only calibration, but other tasks as listed below:

9.1 INITIAL PREPARATION

9.1.1 Tank Capacity Table Validation

The hybrid processor will normally store sufficient data to reproduce the tank capacity table. These data should be checked against the tank capacity table.

9.1.2 Establishment of the Hybrid Reference Point

It is essential that the positions of both the P1 transmitter and ATG are referenced to the reference datum/datum plate specified in the tank calibration table. For practical purposes, the hybrid reference point is introduced. The hybrid reference point is referenced to the tank datum/datum plate by the dimension H_o (See Figure A-1).

It is advised that the hybrid reference point be located close to the $P1$ pressure transmitter's process connection, and should be clearly and permanently marked on the tank shell.

The relative position of the hybrid reference point in relation to the tank datum plate (H_o) should be accurately measured, recorded, and entered into the hybrid processor. From the hybrid reference point the elevation of the pressure sensor effective center can be measured (H_b). The pressure sensor position in relation to the tank datum plate ($Z = H_o + H_b$) can then be calculated by the hybrid processor. Alternately, the value of Z may be entered into the hybrid processor directly. (See Figure A-1.)

Note: The hybrid reference point can be used for future $P1$ transmitter position verification or determination after reinstallation of the transmitter. This eliminates the need for re-measuring the relative position of the $P1$ transmitter to the datum plate.

9.1.3 HTMS Parameter Entry

All applicable HTMS parameters should be established and entered into the hybrid processor. These parameters include tank data such as the capacity table, dimensions between hybrid reference point, ATG reference height and $P1$ sensor, the HTMS Mode, the value of Hmin, "$P1$ Cut-off", ambient data, pressure sensor parameters, ATG and ATT component parameters, and product parameters. Refer to Table 4.

9.2 INITIAL HTMS COMPONENT CALIBRATIONS

9.2.1 General

Each of the HTMS components should be independently calibrated, e.g., the ATG should not be calibrated using measurements derived from the pressure sensors, and vice-versa.

9.2.2 ATG Calibration

The ATG should be field-calibrated in accordance with MPMS Chapters 3.1B and 3.1A, but using the appropriate tolerance for either custody transfer or inventory control, as specified in Table 1 of this standard.

9.2.3 Pressure Sensor Calibration and Zero Adjustment

HTMS pressure sensors are normally factory-calibrated. Apart from pressure sensor zero adjustments, no other pressure sensor adjustments are normally practical in the field. Installed pressure sensors should be checked for calibration using traceable precision pressure calibrators traceable to national standards (NIST). If the pressure sensors are found to be out of specification, they should be replaced.

Zero adjustments of pressure sensors should be done using the procedure given in *MPMS* Chapter 16.2.

9.2.4 ATT Calibration

The ATT should be calibrated in accordance with *MPMS* Chapter 7, but using the appropriate tolerance for either custody transfer or inventory control as specified in Table 3 of this standard.

9.3 VERIFICATION OF HYBRID PROCESSOR CALCULATIONS

Hybrid processor calculations should be checked against manual calculations for verification of proper data entry.

9.4 INITIAL FIELD VERIFICATION OF HTMS

The final step of commissioning before putting the HTMS in service is verifying against manual measurement. If manual checks indicate that HTMS measurements do not fall within the tolerances expected of the system, part or all of the commissioning calibrations and manual verifications should be repeated.

9.4.1 Initial Field Verification of Volume-based HTMS Applications

A volume-based HTMS should be verified as follows:

a. ATG—The ATG should be verified in accordance with the procedure for initial verification of calibration for either custody transfer or inventory control as described in *MPMS*, Chapter 3.1B, as applicable, but using the appropriate tolerance as specified in Table 1 of this standard.

b. ATT—The ATT should be verified in accordance with the procedure for initial verification of calibration described in *MPMS*, Chapter 7, but using the appropriate tolerance for either custody transfer or inventory control, as specified in Table 3 of this standard.

c. Pressure Sensors—The pressure sensors (including transmitters, if they are separate devices) should be zeroed and verified for linearity. These verifications should be done in-situ. Therefore, means should be provided to read out the digital pressure values of these sensors by either a local display, hand held terminal, or separate computer.

1. Zero adjustment: The transmitter should be isolated from the process (using block valve) and zeroed with the high pressure port vented to atmosphere. The zero error after this adjustment should be approximately zero.

2. Linearity verification: Linearity should be verified using a high precision pressure calibration reference traceable to NIST. The linearity verification should be performed at a minimum of 2 test pressures of approximately 50% and 100% of range.

   Linearity error is determined by calculating the difference between the pressure sensor indication (minus any observed zero error) and the pressure reference. This value is divided by the applied reference pressure to give a fractional linearity error, which may be converted to percent (%). The resulting linearity error shall not exceed the maximum linearity error as specified in Table 2 for any of the test pressures.

Note: For high precision pressure transmitters it may be difficult or impractical to adjust transmitter linearity under field conditions.

3. After the sensors/transmitters have been zeroed and verified for linearity, a final check should be performed to determine if the zero error remains within the accuracy set forth in Table 2. The zero reading and linearity error "as left" values should be documented.

d. Product Reference Density—The reference density as determined by the HTMS should be compared with the average product density determined by testing of a representative tank sample. Sampling should be performed in accordance with *MPMS* Chapter 8.1 and 8.3. The analysis should be performed in accordance with *MPMS*, Chapter 9.1 and 9.2. Either the hydrometer or the digital densitometer method may be used.

The density comparison should be performed at a level of 4 ± 0.5 meters (13 ± 1.5 feet) above P1, when the HTMS provides on-line measurement of density, i.e., with level above H_{min}. The tolerance between the product density by the HTMS and by tank sample should be within ± 0.5% of reading for custody transfer applications, and within ± 1.0% of reading for inventory control applications. If the tank contents are homogeneous, the uncertainty due to manual sampling will be reduced. In this situation, a more stringent tolerance (i.e., less than ± 0.5% of reading for custody transfer applications) should be used. This tolerance can be established using statistical quality control methods.

Note: The ± 0.5% tolerance for custody transfer applications is based on estimated uncertainty of manual sampling and the repeatability of laboratory analysis. The uncertainty of manual sampling can vary significantly in tanks with density stratification, and is also affected by the access for sampling, and the procedure actually used.

Note 2: The acceptable uncertainty of the HTMS density is determined based on the impact on the uncertainty of the volume correction factor (VCF, or temperature effect on liquid, or Ctl).

Alternately, for non-stratified products, if an on-line densitometer is available and it has been recently calibrated against a reference traceable to NIST, the average density by the densitometer for a batch transferred into or out of the tank against the average density measured by the HTMS for the batch can be compared, using the tolerances described above.

Note 3: If the tank content is a pure, homogeneous product (e.g., some pure petrochemical liquids) and its reference density can be determined accurately from physical science, and if it is well recognized as an accurate representation of the density property of the product, then the density by the HTMS can be compared with this reference density.

9.4.2 Initial Field Verification of Mass-based HTMS Applications

A mass-based HTMS should be verified as follows:

a. ATG—The ATG should be verified in accordance with the procedure for initial verification of calibration described in MPMS, Chapter 3.1B, but using the appropriate tolerance for either custody transfer or inventory control, as specified in Table 1 of this standard.
b. ATT—The ATT should be verified in accordance with the procedure for initial verification of calibration described in MPMS, Chapter 7, but using the appropriate tolerance as specified in Table 3 of this standard.
c. Pressure Sensor(s)—The pressure sensors (including transmitters, if they are separate devices) affect the accuracy of the mass measurement, and should be verified in accordance with the method set forth in Section 9.4.1 (c). Table 2 summarizes the requirements on pressure sensor tolerances.
d. Density comparison of HTMS density with product density should be made in accordance with 9.4.1 (d).
e. HTMS mass transfer accuracy should be verified using the method described in *MPMS* Chapter 16.2, Section 7.3.6.

Note: The tolerance set forth in *MPMS* Chapter 16.2 is for “transfer accuracy” and therefore the verification involves transfer of liquid into or out of the tank.

10 Regular Verification of HTMS

10.1 GENERAL

After commissioning and initial field verification, an HTMS should be regularly verified in the field. This subsequent, or regular verification is also called “validation”.

The sections below cover post-commissioning HTMS verification and any necessary re-calibrations. Post-commissioning re-calibration uses the same procedure involved in the original installation and startup of the HTMS. Verification is the subsequent procedure performed regularly to ensure that the HTMS remains in proper calibration. Verification differs from calibration in that it does not involve any corrections of the sensors or the HTMS hybrid processor parameters.

10.2 OBJECTIVES

The objectives of the regular verification are:

1. to ensure that the performance of HTMS remains within the required accuracy;
2. to allow use of statistical quality control to establish frequency of re-calibration provided this is acceptable to parties involved in custody transfer.

10.3 ADJUSTMENT DURING REGULAR VERIFICATION

If the verification process identifies that a drift in HTMS performance has occurred exceeding predetermined limits, the HTMS should be re-calibrated and/or re-adjusted. Otherwise, no adjustments should be made during the verification process. The limits should take into account the expected combined measurement uncertainties of the HTMS, the reference equipment, and the HTMS performance requirements.

10.4 REGULAR VERIFICATION OF HTMS IN VOLUME-BASED CUSTODY TRANSFER APPLICATIONS

10.4.1 Regular Verification of Major Components

a. ATG —The ATG should be verified in accordance with the procedure for subsequent verification of calibration for custody transfer described in *MPMS*, Chapter 3.1B, using the tolerance as specified in Table 1 of this standard.
b. ATT—The ATT should be verified in accordance with the procedure for subsequent verification of calibration for custody transfer described in *MPMS* Chapter 7 (for upright cylindrical tanks) using the tolerance as specified in Table 3 of this standard.
c. Pressure Sensor(s)—The stability of the pressure sensor/transmitter(s) should be verified as follows:

1. Zero verification: The transmitter zero should be verified in-situ. The zero reading (“as found” value) should not exceed the manufacturer’s specifications, or the maximum recommended value of zero error as specified in Table 2. If the zero reading is greater than the maximum recommended value given in Table 2, and has not exceeded the manufacturer’s specifications, the transmitter should be zeroed, or a software zero correction may be made. The zero reading “as found” and “as left” values should be documented. If the manufacturer’s specifications are exceeded, the manufacturer should be consulted.

Table 4—Typical Hybrid Processor Data 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 non-insulated
	Tank wall material	Thermal expansion constants
	Tank capacity table	Volumes at given levels
	Tank calibration temperature	Temperature to which the tank capacity table was corrected
	H_o (offset of hybrid reference point to datum plate)	All tanks (See Figure A-1)
	H_{min} and "$P1$ cut-off"	All tanks (See Sections 8.1,8.2)
ATG component data	Type of ATG Measurement	Innage, Outage
	Reference height	Vertical distance from datum plate to ATG mounting
Pressure sensor data	Sensor configuration	Tank with 1 or more sensors
	Pressure sensor location(s)	Relative to applicable reference point(s). (See Figure A-1)
ATT component data	Type of ATT	Single Point, Variable Length, Multiple Spot, Upper, middle and lower
	Element type	Resistance, Other
	Number of elements	
	Vertical location of elements	
Product data	Liquid parameters	API 2540, for example
	Vapor parameters	
	Free water level	Optional
Ambient data	Local acceleration due to gravity	Obtained from a recognized source
	Ambient temperature	Optional
	Ambient pressure	Optional

Table 5A—HTMS Measurements and Overview of Calculations—
Calculation Method A

Parameter	Method of Measurement or Calculation
Product level (L)	Measured by ATG
Average product temperature (t)	Measured by ATT
Observed product density (D_{obs})	Calculated using Equation A.3
Reference density (D_{ref})	Calculated from D_{obs} and t, by iteration (Note 4)
Volume correction factor (VCF)	Calculated as VCF = D_{obs} / D_{ref}
Gross observed volume (GOV)	Calculated from L by ATG and tank capacity table (Note 3)
Gross standard volume (GSV)	Calculated as GSV = GOV x VCF
Mass (in vacuum)	Calculated as Mass = GOV x D_{obs}

Note: This table is applicable to Mode 1 at levels at and above H_{min}.

Note 2: This table is applicable to Mode 2 at all levels above "P1cut-off".

Note 3: After deducting for Free Water (FW), if any, from the total observed volume (TOV) of the liquid in the tank. GOV = TOV – FW.

Note 4: Manual density may be used if the HTMS measured density is not reliable or not available.

Note 5: For further information on calculation procedures, see *MPMS* Chapter 12.1.

Table 5B—HTMS Measurements and Overview of Calculations—
Calculation Method B

Parameter	Method of Measurement or Calculation
Product level (L)	Measured by ATG
Average product temperature (t)	Measured by ATT
Observed product density (D_{obs})	Calculated as $D_{obs} = D_{ref}$/VCF
Reference density (D_{ref})	Use the last calculated value of D_{ref}. D_{ref} will be held constant when L is below H_{min} in Mode 1, or when L is below "P1 cut-off" in Mode 2. (See Note 4)
Volume correction factor (VCF)	Calculated from t measured by ATT, and from D_{ref} which is held constant when L is below H_{min} in Mode 1, or when L is below "P1 cut-off" in Mode 2.
Gross observed volume (GOV)	Calculated from L by ATG and tank capacity table (See Note 3)
Gross standard volume (GSV)	Calculated as GSV = GOV x VCF
Mass (in vacuum)	Calculated as Mass = GSV x D_{ref}

Note: This table is applicable to Mode 1 at levels below H_{min} only.

Note 2: This table is applicable to Mode 2 at levels below "P1cut-off" only.

Note 3: After deducting for Free Water (FW), if any, from the total observed volume (TOV) of the liquid in the tank. GOV = TOV – FW.

Note 4: Manual density may be used if the HTMS measured density is not reliable or not available.

Note 5: For further information on calculation procedures, see *MPMS* Chapter 12.1.

2. The transmitter linearity should be verified in-situ using the method described in Section 9.4.1 (c), except that only one test pressure at approximately 100% of range is required. The linearity error should not exceed the manufacturer's specification or the maximum recommended value of linearity error as specified in Table 2. If the manufacturer's specifications are exceeded, the manufacturer should be consulted. The linearity error "as found" and "as left" values should be documented.

Note: For high precision pressure transmitters it may be difficult or impractical to adjust transmitter linearity under field conditions.

10.4.2 Regular Verification of HTMS Density

The HTMS density should be compared with the product density determined by representative tank sample and laboratory analysis. Sampling should be performed in accordance with API *MPMS* Chapter 8.1 and 8.3. The sample should be analyzed in accordance with applicable API/ASTM standards (API *MPMS*, Chapters 9.1 and 9.2). Either the hydrometer or digital densitometer method may be used.

The density comparison should be performed at a level of approximately 4.0 ± 0.5 meter, and when HTMS provides on-line measurement of density, i.e., with level above Hmin. The tolerance between the product density by the HTMS and by tank sample should be with ± 0.5% of reading. If the tank contents are homogeneous, the uncertainty due to manual sampling is reduced. In this situation, a more stringent tolerance should be used. This tolerance can be established using statistical quality control methods.

10.4.3 Frequency of Regular Verification

The frequency of regular verification of the major components / measurements of the HTMS in volume-based custody transfer applications should be as follows:

a. ATG—A newly installed or repaired ATG should be verified according to the frequency of subsequent verification of calibration established in *MPMS*, Chapter 3.1B.
b. ATT—A newly installed or repaired ATT should be verified according to the frequency of subsequent verification of calibration established in *MPMS*, Chapter 7.
c. Pressure Sensor(s)—The zero stability and the linearity stability of the pressure sensors/transmitters should be verified at least once per year following initial verification.
d. Product Density—The comparison of product density with sample analysis should be performed at least quarterly following initial verification.

Note 1: The use of statistical quality control methods rather that the above pre-determined time may also determine the frequency of regular verification.

Note 2: More frequent comparison of product density will insure early detection of problems in the ATG, ATT, or pressure sensor/ transmitter(s), and it provides valuable statistical data on the HTMS.

10.5 REGULAR VERIFICATION OF HTMS IN MASS-BASED CUSTODY TRANSFER APPLICATIONS

10.5.1 Regular Verification of Major Components

a. ATG—The ATG should be verified in accordance with the procedure for subsequent verification of calibration described

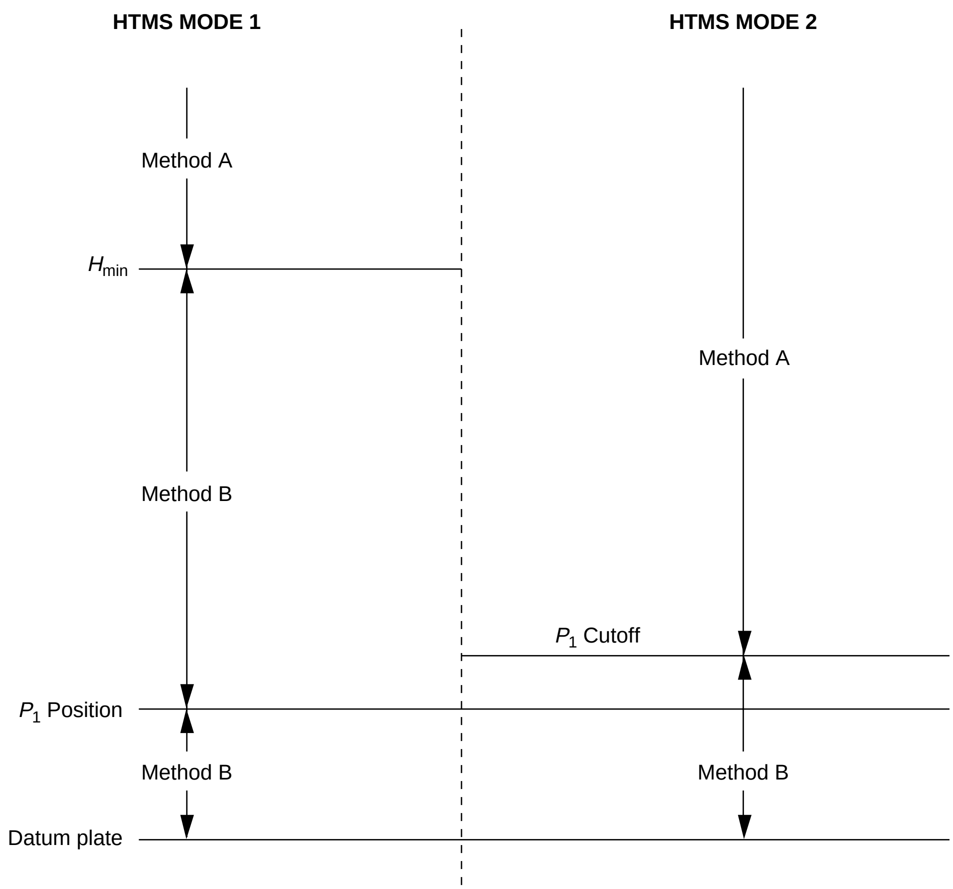


Figure 1—Summary of HTMS Calculation Methods as They Relate to Level for Modes 1 and 2

in MPMS, Chapter 3.1B, but using the tolerance specified in Table 1 of this standard.

b. ATT—The ATT should be verified in accordance with the procedure for subsequent verification of calibration described in MPMS Chapter 7, but using the tolerance specified in Table 3 of this standard.

c. Pressure Sensor/Transmitter(s)—The pressure sensor/transmitter(s) zero and linearity stability should be verified in accordance with the method set forth in 10.4.1 (c).

Table 2 summarizes the requirements on pressure sensor tolerances.

10.5.2 Regular Verification of HTMS Density

Density comparison of HTMS density with product density determined by manual methods is optional in mass-based custody transfer applications. This comparison, if desired, should be made in accordance with 10.4.2.

10.5.3 Frequency of Regular Verification

The frequency of regular verification of the major components/measurements of the HTMS used in mass-based custody transfer applications should be as follows:

a. ATG—A newly installed or repaired ATG should be verified once per quarter. If the performance of the ATG is stable, the frequency may be reduced to once every six months, provided that density comparisons are performed on a quarterly basis, and statistical data indicates the overall system is stable.

b. ATT—A newly installed or repaired ATT should be verified on the same frequency as the ATG.

c. Pressure Sensor(s)—The pressure sensor/transmitter(s) zero and linearity stability should be verified quarterly following initial verification. If the pressure sensor/transmitter(s) linearity is stable, the frequency of verification of linearity may be reduced to once per six months.

d. Product Density—The comparison of product density by an HTMS with density determined by manual methods is optional. The exception to this is if the density comparison is to be used as a basis for reducing the frequency of the ATG subsequent verification (10.5.3 (a) above), in which case the density comparison should be done quarterly.

Note: More frequent comparison of product density will insure early detection of problems in the ATG, ATT, or pressure sensor/transmitter(s), and it provides valuable statistical data.

10.6 HANDLING OUT-OF-TOLERANCE SITUATIONS DURING REGULAR VERIFICATION OF HTMS IN CUSTODY TRANSFER APPLICATION

10.6.1 If a component of the HTMS is found to be out of tolerance during the regular field verification, the cause should be investigated to determine if the component should be adjusted, calibrated or re-set, or repaired.

10.6.2 After adjustment or repair, the component should be re-verified following the procedure described under initial field verification. (Refer to 9.4)

10.7 REGULAR VERIFICATION OF HTMS IN INVENTORY CONTROL APPLICATION

The requirements for regular verification of HTMS systems used in inventory control applications are less stringent than for custody transfer. In general, the procedures listed in Sections 10.4 and 10.5 are advised, using the suggested maximum tolerances for the HTMS components and density comparisons found below:

	Volume-Based HTMS	Mass-Based HTMS
ATG	± 12 mm (_ in.)	± 25 mm (1 in.)
ATT	1°C (2° F)	1°C (2°F)
*P*1 Span	150 Pa	150 Pa
*P*1 Linearity	0.2%	0.2%
*P*3 Span	60 Pa	60 Pa
*P*3 Linearity	1.0%	1.0%
Density	± 1% at 4 m (13 ft)	±1.2% at 4 m (13 ft)

Frequency of regular verifications of HTMS used in inventory control applications should be established by the user.

APPENDIX A—CALCULATION OVERVIEW

A.1 General

This APPENDIX describes the calculations performed by the HTMS hybrid processor to compute the density of the tank contents and other variables. Specific calculations and features which may be unique to a particular manufacturer's design of an HTMS are not included (e.g., pressure sensor linearization formulae).

Symbols used in this APPENDIX are illustrated in Figure A1.

HTMS calculations are the same for all tank geometries, including floating roof tanks.

For atmospheric tanks, in-tank vapor density and ambient air densities have only second order effects on the calculated variables. They can be considered constant, or for high accuracies can be calculated. 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.

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.

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

All values to be substituted in the equations in this Appendix may be in either US Customary (USC) or SI units. (see *MPMS* Chapter 15). Refer to Table A-1.

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

A.1.1 US CUSTOMARY (USC) UNITS

See Notes 1 and 2 below for pressure, [foot] for level, [square foot] for area, [cubic foot] for volume, [pound] for mass, [pound per cubic foot] for density, [foot/sec^2] for acceleration.

A.1.2 SI UNITS

See Note 1 below for pressure, [meter] for level, [square meter] for area, [cubic meter] for volume, [kilogram] for mass, [kilogram per cubic meter] for density, [meter /sec^2] for acceleration.

Note 1: Within either system of units, users may prefer different units for pressure for the output readings of the pressure sensors, $P1$ and $P3$. To account for different pressure units, a constant "N" appears in Equation A3. The value of "N" for various pressure units is shown in Table A-1 below:

Note 2: Inches of H_2O at 68°F.

A.2 GOV—Gross Observed Volume

$$GOV = [(TOV - FW) \times CTSh] \pm FRA$$

where

GOV= Gross Observed Volume. The total volume of all product liquids at observed temperature and pressure, excluding free water,

TOV = Total Observed Volume from ATG innage level (L),

L = the ATG innage level referenced to the tank datum plate,

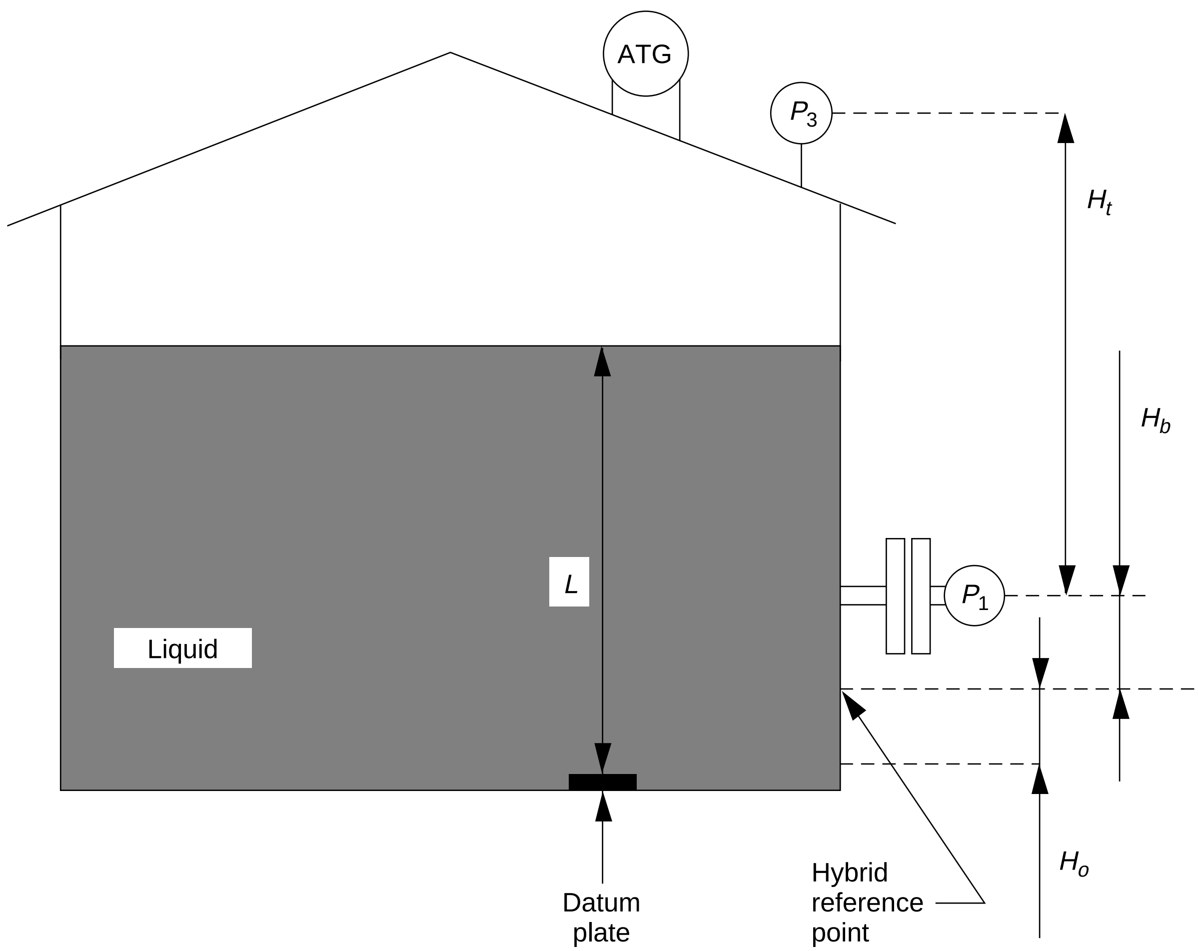
FW = Free non-suspended water quantity including bottom sediments,

FRA = Floating roof adjustment, if applicable,

CTSh = Cross-sectional area correction for temperature of the shell (Refer to *MPMS* Chapter 12.1.).

Table A-1—Units Table for HTMS Equations

Constant	Units Used in the Equations						
	Inputs			Calculated Results			
N	Gauge Pressure	Capacity Table Volume	Local Gravity Accel.	Level	Observed and Std Volume	Observed and Ref. Density	Mass
1.000	Pa	m^3	m/s^2	m	m^3	kg/m^3	kg
1000.0	kPa	m^3	m/s^2	m	m^3	kg/m^3	kg
100.0	mbar	m^3	m/s^2	m	m^3	kg/m^3	kg
100,000	bar	m^3	m/s^2	m	m^3	kg/m^3	kg
167.0791	in-H_2O @ 68°F	ft^3	ft/s^2	ft	ft^3	lb/ft^3	lb
4633.063	psig	ft^3	ft/s^2	ft	ft^3	lb/ft^3	lb



Note:
1) $Z = H_b + H_o$
2) ATT not shown

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

A.3 D_{obs} – Observed Product Density (in vacuum)

The basis of the hybrid density calculation (D_{obs}) is pressure balance. 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.

Also, head pressure in either liquid or vapor may be approximated by the product of average density and head, thus:

Liquid head pressure	$= g \times (L - Z) \times D_{obs}$	(at $P1$ elevation)
In tank vapor head	$= g \times [H_t - (L - Z)] \times D_v$	(at liquid surface)
Ambient air head	$= g \times H_t \times D_a$	(at $P1$ elevation)

Thus, the value of D_{obs} may be calculated from:

$$D_{obs} = \frac{N \times (P1 - P3) - g \times (D_v - D_a) \times H_t}{g \times (L - Z)} + D_v$$

where

D_{obs} = the observed liquid density in vacuo,

N = units constant. See Table A-1,

L = the ATG (innage) level reading,

Z = $H_b + H_o$ (the heel under $P1$ transmitter to tank datum plate. See Figure A-1),

H_b = the vertical distance of the center of force on sensor $P1$ from the hybrid reference point,

H_o = the vertical distance from the tank datum plate to the hybrid reference point,

g = the local acceleration due to gravity,

H_t = the vertical distance of the centers of force on the sensors $P1$ and $P3$ diaphragms,

D_v = the in-tank vapor density,

D_a = the ambient air density.

Note: H_O is zero if the hybrid reference point is at the same elevation as the tank datum plate.

A.4 M – Product Mass Calculation (in vacuum)

$$M = \text{GOV} \times D_{obs} - \text{WR}$$

where

GOV = Gross observed volume from A.2,

D_{obs} = the observed product density (in vacuum) from A.3,

WR = the floating roof mass (if applicable).

Note: For atmospheric storage tanks mass of product in vapor may be assumed to be zero.

A.5 M_a – Product Apparent Mass in Air

$$M_a = M \times (1 - D_a / D_{obs})$$

where

M = The total product mass (in vacuum) from A.4,

D_a = the ambient air density,

D_{obs} = the observed liquid density (in vacuum) from A.3.

A.6 GSV – Gross Standard Volume

$$\text{GSV} = \text{GOV} \times \text{VCF}$$

where

GOV = the gross observed volume from A.2,

VCF = the volume correction factor, typically obtained from *MPMS* Chapter 11.1, ASTM D-1250.

APPENDIX B—MEASUREMENT ACCURACY

Providing that the ATG and the pressure sensor installations are correct, the calculated density, mass, and standard volume accuracies depend upon the combined accuracies of the pressure sensor(s), the ATG sensor, the ATT sensor, the measurement of the hybrid reference point, the tank capacity table, and the local acceleration of gravity. Local acceleration of gravity can be estimated with an uncertainty of 0.005%. The uncertainty in the gravitational term is neglected in the accuracy equations below. The uncertainty values listed in the tables below were calculated using SI units. To avoid confusion, all parameters and results are stated in terms of SI units. The terms used in the inventory accuracy equations below are defined as follows:

			Units
L	=	ATG innage level reading	m
$P1$	=	Reading of pressure sensor $P1$	Pa
$P3$	=	Reading of pressure sensor $P3$	Pa
$P3_{max}$	=	Reading of $P3$ corresponding with the setting of the Breather valve (i.e., maximum pad pressure)	Pa
t	=	Reading of AT T temperature sensor	°C
Z	=	Offset of $P1$ from tank datum plate (= $H_o + H_b$)	m
D_v	=	Vapor density	kg/m^3
g	=	Local acceleration due to gravity	m/s^2
D_{15}	=	Standard density at 15°C	kg/m^3
D	=	Actual density	kg/m^3
		Note: For uncertainty calculation purposes, this density (D) is a hypothetical actual density, which would be the same as observed density if there were no measurement errors.	
U_{AE}	=	Percent uncertainty of tank capacity table	%
U_{D15}	=	Percent uncertainty in standard density	%
U_D	=	Percent uncertainty of observed density	%
U_L	=	Uncertainty in ATG level measurement	m
$U_{P1\text{-zero}}$	=	Uncertainty of $P1$ when no pressure is applied	Pa
$U_{P1\text{-linearity}}$	=	Uncertainty of $P1$, related to applied pressure	fraction of reading
$U_{P1\text{-total}}$	=	Total uncertainty of $P1$ (combination of zero error and linearity)	Pa
$U_{P3\text{-zero}}$	=	Uncertainty of $P3$ when no pressure is applied	Pa
$U_{P3\text{-linearity}}$	=	Uncertainty of $P3$, related to applied pressure	fraction of reading
$U_{P3\text{-total}}$	=	Total uncertainty of $P3$ (combination of zero error and linearity)	Pa
U_Z	=	Uncertainty of heel height Z	m
U_t	=	Uncertainty in ATT temperature measurement	°C
t_{ref}	=	Reference temperature for standard volume	°C
K_1, K_0 are constants of thermal expansion factor defined by API MPMS Chapter 11.1			
F_Q =Tank geometry factor (= 1.0 for upright cylindrical tanks) See Appendix B.4 for equations.			

The uncertainty examples given in B.1 through B.5 below each consist of several cases, which are intended to represent typical configurations of HTMS. In each case, the maximum allowable uncertainty of measurement for each parameter which contributes uncertainty to the final measurement is used. Note that these maximum uncertainties are the same as those listed in Tables 1, 2 and 3 of this standard. The cases are defined as follows:

Case 1: HTMS configured for both mass and volume-based custody transfer
Case 2: HTMS configured for volume-based custody transfer
Case 3: HTMS configured for mass-based custody transfer
Case 4: HTMS configured for volume-based inventory control
Case 5: HTMS configured for mass-based inventory control

B.1 Accuracy Equation for Observed Density

The accuracy of observed density (in percent) may be estimated from:

$$U_D = \sqrt{\left[\frac{U^2_{P1-total} + U^2_{P3-total}}{g^2 D^2 (L-Z)^2} + \frac{U_L^2 + U_Z^2}{(L-Z)^2} \times \frac{(D-Dv)^2}{D^2}\right]} \times 100$$

where

$$U_{P1-\text{total}} = U_{P1-\text{zero}} + P1_{\text{applied}} \times U_{P1-\text{linearity}}$$

$$P1_{\text{applied}} = g(L-Z)D + g\{H_t - (L-Z)\}D_v + P3_{\max} - gH_tD_a \approx g(L-Z)(D-D_V) + P3_{\max}$$

$$U_{P1-\text{total}} = U_{P1-\text{zero}} + \{g(L-Z)(D-D_V) + P3_{\max}\}U_{P1-\text{linearity}}$$

$$U_{P3-\text{total}} = U_{P3-\text{zero}} + P3_{max}U_{P3-\text{linearity}}$$

Table B.1.1—Example of Observed Density Accuracies

Product: Gasoline in floating roof tank						D = 741.0 kg/m^3 D_v = 1.2 kg/m^3 Z = 0.2 m g = 9.81 m/s^2
Sensor or Measurement Uncertainty						
		Case 1	Case 2	Case 3	Case 4	Case 5
P_1 zero error ($U_{P1-\text{zero}}$)	[Pa]	50	100	50	150	150
P_1 linearity error ($U_{P1-\text{linearity}}$)	[%]	0.070	0.100	0.070	0.200	0.200
U_L	[m]	0.004	0.004	0.012	0.012	0.025
U_Z	[m]	0.003	0.003	0.003	0.005	0.005
Observed Density Accuracy [±% reading]						
Vertical cylindrical tank						
L = 4 m		0.283	0.480	0.411	0.817	1.000
L = 10 m		0.149	0.246	0.188	0.431	0.486
L = 16 m		0.118	0.190	0.138	0.340	0.367

Table B.1.2—Example 2 of Observed Density Accuracies

Product: Diesel (or miscellaneous liquid) in fixed roof atmospheric tanks of various geometries		D = 842.9 kg/m^3 D_v = 1.2 kg/m^3 Z = 0.2 m g = 9.81 m/s^2				
Sensor or Measurement Uncertainty						
		Case 1	Case 2	Case 3	Case 4	Case 5
P_1 zero error ($U_{P1-\text{zero}}$)	[Pa]	50	100	50	150	150
P_1 linearity error ($U_{P1-\text{linearity}}$)	[%]	0.070	0.100	0.070	0.200	0.200
P_3 zero error ($U_{P3-\text{zero}}$)	[Pa]	24	40	24	60	60
P_3 linearity error ($U_{P3-\text{linearity}}$)	[%]	0.200	0.500	0.200	1.000	1.000
U_L	[m]	0.004	0.004	0.012	0.012	0.025
U_Z	[m]	0.003	0.003	0.003	0.005	0.005
Observed Density Accuracy [±% reading]						
Vertical cylindrical tank						
L = 4 m		0.294	0.498	0.418	0.861	1.036
L = 10 m		0.151	0.248	0.190	0.440	0.494
L = 16 m		0.118	0.190	0.138	0.343	0.370
Spherical tank, Diameter = 20 m						
L = 4 m		0.294	0.498	0.418	0.861	1.036
L = 10 m		0.151	0.248	0.190	0.440	0.494
L = 16 m		0.118	0.190	0.138	0.343	0.370
Horizontal cylindrical tank, Diameter = 4 m						
L = 1 m		1.194	2.050	1.849	3.501	4.444
L = 2 m		0.560	0.957	0.841	1.640	2.042
L = 3.5 m		0.330	0.561	0.476	0.967	1.173

B.2 Accuracy Equation for Mass

The accuracy of a spot measurement for mass (in percent) may be estimated from:

$$U_M = \sqrt{\left[\left(\frac{U_L}{L}\left(F_Q - \frac{L}{L-Z}\times\frac{D-D_V}{D}\right)\right)^2 + \frac{U^2_{P1-\text{total}} + U^2_{P3-\text{total}}}{g^2D^2(L-Z)^2} + \frac{U_Z^2}{(L-Z)^2}\times\frac{(D-D_V)^2}{D^2} + U^2_{AE}\right]}\times 100$$

where:

$$U_{P1-\text{total}} = U_{P1-\text{zero}} + P1_{\text{applied}} \times U_{P1-\text{linearity}}$$

$$P1_{\text{applied}} = g(L-Z)D + g\{H_t - (L-Z)\}D_V + P3_{\max} - gH_tD_a \approx g(L-Z)(D-D_V) + P3_{\max}$$

$$U_{P1-\text{total}} = U_{P1-\text{zero}} + \{g(L-Z)\times(D-D_V) + P3_{\max}\}\times U_{P1-\text{linearity}}$$

$$U_{P3-\text{total}} = U_{P3-\text{zero}} + P3_{\max} \times U_{P3-\text{linearity}}$$

Table B.2.1—Example 1 of Mass Measurement Accuracies

Note: These examples apply to static conditions (i.e., product level and temperature are constant) and are not to be confused with parcel transfer accuracy.

Product: Gasoline in floating roof tank						D = 741.0 kg/m^3 D_v = 1.2 kg/m^3 Z = 0.2 m g = 9.81 m/s^2
Sensor or Measurement Uncertainty						
		Case 1	Case 2	Case 3	Case 4	Case 5
P_1 zero error ($U_{P1-\text{zero}}$)	[Pa]	50	100	50	150	150
P_1 linearity error ($U_{P1-\text{linearity}}$)	[%]	0.070	0.100	0.070	0.200	0.200
U_L	[m]	0.004	0.004	0.012	0.012	0.025
U_Z	[m]	0.003	0.003	0.003	0.005	0.005
U_{AE} (fractional uncertainty)		0.001	0.001	0.001	0.003	0.003
Mass Measurement Accuracy [±% reading]						
Vertical cylindrical tank						
L = 4 m		0.281	0.479	0.282	0.812	0.812
L = 10 m		0.175	0.262	0.175	0.511	0.511
L = 16 m		0.152	0.213	0.152	0.447	0.447

Table B.2.2—Example 2 of Mass Measurement Accuracies

Note: These examples apply to static conditions (i.e., product level and temperature are constant) and are not to be confused with parcel transfer accuracy.

Product: Diesel (or miscellaneous liquid) in fixed roof atmospheric tanks of various geometries						D = 842.9 kg/m^3 D_v = 1.2 kg/m^3 Z = 0.2 m g = 9.81 m/s^2
Sensor or Measurement Uncertainty						
		Case 1	Case 2	Case 3	Case 4	Case 5
P_1 zero error ($U_{P1-\text{zero}}$)	[Pa]	50	100	50	150	150
P_1 linearity error ($U_{P1-\text{linearity}}$)	[%]	0.070	0.100	0.070	0.200	0.200
P_3 zero error ($U_{P3-\text{zero}}$)	[Pa]	24	40	24	60	60
P_3 linearity error ($U_{P3-\text{linearity}}$)	[%]	0.200	0.500	0.200	1.000	1.000
U_L	[m]	0.004	0.004	0.012	0.012	0.025
U_Z	[m]	0.003	0.003	0.003	0.005	0.005
U_{AE} (fractional uncertainty)		0.001	0.001	0.001	0.003	0.003
Mass Measurement Accuracy [±% reading]						
Vertical cylindrical tank						
L = 4 m		0.293	0.497	0.293	0.856	0.856
L = 10 m		0.177	0.265	0.177	0.518	0.518
L = 16 m		0.153	0.213	0.153	0.449	0.449
Spherical tank, Diameter = 20 m						
L = 4 m		0.303	0.504	0.377	0.888	0.990
L = 10 m		0.178	0.265	0.186	0.522	0.532
L = 16 m		0.153	0.213	0.153	0.449	0.450
Horizontal cylindrical tank, Diameter = 4 m						
L = 1 m		1.091	1.992	1.106	3.184	3.204
L = 2 m		0.525	0.937	0.533	1.532	1.543
L = 3.5 m		0.325	0.557	0.336	0.949	0.964

B.3 Accuracy Equation for Standard Volume

The accuracy of standard volume inventory (in percent) may be estimated from:

$$U_{Vs} = \sqrt{\left[\left(F_Q \frac{U_L}{L}\right)^2 + (U_{AE})^2 + \left(\frac{K_1}{D_{15}} + 2\frac{K_0}{D_{15}^2}\right)^2 (t - t_{\text{ref}})^2 (U_{D15})^2 + \alpha^2 U_t^2\right]} \times 100$$

Table B.3.1—Example 1 of Standard Volume Inventory Accuracies

Product: Gasoline in floating roof tank		t_{ref} = 15°C t = 25°C D_{15} = 750 kg/m^3 K_0 = 346.4228/°C K_1 = 0.4388/°C				
Sensor or Measurement Uncertainty						
		Case 1	Case 2	Case 3	Case 4	Case 5
U_L	[m]	0.004	0.004	0.012	0.012	0.025
U_t	[°C]	0.500	0.500	1.000	1.000	1.000
U_{AE} (fractional uncertainty)		0.001	0.001	0.001	0.003	0.003
U_{D15} (fractional uncertainty)	[m]	0.003	0.005	0.005	0.005	0.010
Standard Volume Inventory Accuracy [±% reading]						
Vertical cylindrical tank						
L = 4 m		0.154	0.154	0.338	0.441	0.704
L = 10 m		0.124	0.124	0.197	0.345	0.409
L = 16 m		0.120	0.120	0.174	0.332	0.359

Table B.3.2—Example 2 of Standard Volume Inventory Accuracies

Product: Diesel (or miscellaneous liquid) in fixed-roof atmospheric tanks of various geometries		t_{ref} = 15°C t = 25°C D_{15} = 850 kg/m^3 K_0 = 186.9696/°C K_1 = 0.4862/°C				
Sensor or Measurement Uncertainty						
		Case 1	Case 2	Case 3	Case 4	Case 5
U_L	[m]	0.004	0.004	0.012	0.012	0.025
U_t	[°C]	0.500	0.500	1.000	1.000	1.000
U_{AE} (fractional uncertainty)		0.001	0.001	0.001	0.003	0.003
U_{D15} (fractional uncertainty)		0.003	0.005	0.005	0.005	0.010
Standard Volume Inventory Accuracy [±% reading]						
Vertical cylindrical tank						
L = 4 m		0.147	0.147	0.327	0.432	0.698
L = 10 m		0.116	0.116	0.117	0.334	0.399
L = 16 m		0.111	0.111	0.150	0.320	0.348
Spherical tank, Diameter = 20 m						
L = 4 m		0.214	0.214	0.569	0.635	1.195
L = 10 m		0.124	0.124	0.222	0.360	0.487
L = 16 m		0.111	0.111	0.145	0.318	0.339
Horizontal cylindrical tank, Diameter = 4 m						
L = 1 m		0.574	0.574	1.697	1.720	3.539
L = 2 m		0.277	0.277	0.775	0.825	1.622
L = 3.5 m		0.141	0.141	0.302	0.414	0.647

B.4 Tank Geometry Factor F_Q

The factor F_Q is used to adjust inventory accuracy equations B.2 (mass) and B.3 (standard volume) for difference in tank geometry.

B.4.1 UPRIGHT VERTICAL CYLINDRICAL TANKS

$$F_Q = 1.0$$

B.4.2 Spherical tanks (of internal diameter D_i)

$$F_Q = \frac{6 - 6\left(\frac{L}{D_i}\right)}{3 - 2\left(\frac{L}{D_i}\right)}$$

B.4.3 HORIZONTAL CYLINDRICAL TANKS (OF INTERNAL DIAMETER D_i)

$$F_Q = \frac{2\left(\frac{L}{D_i}\right)^2 \sqrt{\frac{D_i}{L} - 1}}{\left(0.25\arccos\left(1 - 2\left(\frac{L}{D_i}\right)\right) + \left(\frac{L}{D_i} - 0.5\right)\right) \times \sqrt{\left[\frac{L}{D_i} - \left(\frac{L}{D_i}\right)^2\right]}}$$

B.5 Determination of H_{min}

H_{min} is a liquid level, below which the accuracy of the observed density is less than the permissible value defined by the user. The value of H_{min} may be calculated from:

$$H_{min} = Z + \frac{\left(A \times (D - D_V) \times U_{P1-\text{linearity}} + \sqrt{A^2 \times U_D^2 \times D^2 + \left\{D^2 \times U_D^2 - (D - D_v)^2 \times U_{P1-\text{linearity}}^2\right\} \times B^2}\right)}{g\left\{D^2 \times U_D^2 - (D - D_v)^2 \times U_{P1-\text{linearity}}^2\right\}}$$

where:

$$A = U_{P1-\text{zero}} + P3_{\text{max}} \times U_{P1-\text{linearity}}$$

$$B^2 = (U_{P1-\text{zero}} + P3_{\text{max}} \times U_{P3-\text{linearity}})^2 + (g^2 \times U_L^2 + g^2 \times U_Z^2) \times (D - D_v)^2$$

Table B.5.1—Example 1 of H_{min} Calculation

Product: Gasoline in floating roof tank (vertical cylindrical tank)

D = 741 kg/m^3
D_v = 1.2 kg/m^3
Z = 0.2 m
g = 9.81 m/s^2

Sensor or Measurement Uncertainty		Case 1	Case 2	Case 3	Case 4	Case 5
P_1 zero error (U_{P1}-zero)	[Pa]	50	100	50	150	150
P_1 linearity error (U_{P1}-linearity)	[%]	0.070	0.100	0.070	0.200	0.200
U_L	[m]	0.004	0.004	0.012	0.012	0.025
U_Z	[m]	0.003	0.003	0.003	0.005	0.005
H_{min} (m)						
User defined limits of permissible observed density uncertainty (*** = Not achievable within 20 m)						
Density uncertainty = 0.1%		***	***	***	***	***
Density uncertainty = 0.2%		6.31	14.30	9.24	***	***
Density uncertainty = 0.3%		3.73	7.37	5.64	***	***
Density uncertainty = 0.5%		2.12	3.81	3.26	7.83	9.57
Density uncertainty = 1.0%		1.10	1.82	1.67	3.15	4.00

Table B.5.2—Example 2 of H_{min} Calculation

Product: Diesel (or miscellaneous liquid) in fixed roof atmospheric tanks of various geometries

D = 842 kg/m^3
D_v = 1.2 kg/m^3
Z = 0.2 m
g = 9.81 m/s^2

Sensor or Measurement Uncertainty		Case 1	Case 2	Case 3	Case 4	Case 5
P_1 zero error (U_{P1}-zero)	[Pa]	50	100	50	150	150
P_1 linearity error (U_{P1}-linearity)	[%]	0.070	0.100	0.070	0.200	0.200
P_3 zero error (U_{P3}-zero)	[Pa]	24	40	24	60	60
P_3 linearity error (U_{P3}-linearity)	[%]	0.200	0.500	0.200	1.00	1.00
U_L	[m]	0.004	0.004	0.012	0.012	0.025
U_Z	[m]	0.003	0.003	0.003	0.005	0.005
H_{min} (m)						
User defined limits of permissible observed density uncertainty (*** = Not achievable within 20 m)						
Density uncertainty = 0.1%		***	***	***	***	***
Density uncertainty = 0.2%		6.54	14.44	9.35	***	***
Density uncertainty = 0.3%		3.91	7.57	5.74	***	***
Density uncertainty = 0.5%		2.24	3.99	3.33	8.17	9.82
Density uncertainty = 1.0%		1.16	1.92	1.70	3.37	4.16

B.6 Effect on Volume Corrector Factor (VCF) Due to Uncertainty of Density

The effect on the computation of VCF due to the uncertainty of observed density (D_{obs}) for crude oils and refined products can be seen in the examples in tables B.6.1, B.6.2, and B.6.3 below:

Table B.6.1—Example in API Gravity Units of Effect on Volume Correction Factor (VCF) for a Crude Oil Due to Uncertainty of Density

For heavy oils such as crude oil, the change of VCF is less sensitive to the error in product density, as can be seen in the table:

Basis: Product Temperature = 70°F. "True" API gravity is 29° API (shown in bold)
VCF Table: API *MPMS* Ch. 11.1 / ASTM D1250 Table 6A

API Gravity @ 60°F	28.0	28.2	28.4	28.6	28.8	**29.0**	29.2	29.4	29.6	29.8	30.0
Relative Density ($\rho_{60/60}$)	0.8871	0.8860	0.8849	0.8838	0.8827	**0.8816**	0.8805	0.8794	0.8783	0.8772	0.8762
Uncertainty $\rho_{60/60}$ (% Reading)	– 0.63	– 0.50	– 0.38	– 0.25	– 0.13	**0.00**	0.12	0.25	0.37	0.50	0.62
VCF Computed	0.9957	0.9956	0.9956	0.9956	0.9956	**0.9956**	0.9956	0.9956	0.9956	0.9956	0.9955

Table B.6.2—Example in API Gravity Units of Effect on Volume Correction Factor (VCF) for a Refined Product Due to Uncertainty of Density

Basis: Product Temperature = 70°F. "True" API gravity is 59.1°API (shown in bold)
VCF Table: API *MPMS* Ch. 11.1 / ASTM D1250 Table 6 B

API Gravity @ 60°F	58.1	58.2	58.3	58.5	58.7	58.9	**59.1**	59.3	59.5	59.7	60.0	60.1
Relative Density ($\rho_{60/60}$)	0.7463	0.7459	0.7455	0.7447	0.7440	0.7432	**0.7424**	0.7416	0.7408	0.7401	0.7389	0.7385
Uncertainty $\rho_{60/60}$ (% Reading)	0.53	0.47	0.42	0.32	0.21	0.11	**0.00**	– 0.10	– 0.21	– 0.31	– 0.47	– 0.52
VCF Computed	0.9933	0.9932	0.9932	0.9932	0.9932	0.9932	**0.9932**	0.9932	0.9932	0.9932	0.9932	0.9931

Table B.6.3—Example in SI Units of Effect on Volume Correction Factor (VCF) for a Refined Product Due to Uncertainty of Density

Basis: Product Temperature = 25 °C. "True" standard density is 750.00 kg/m^3 (shown in bold)
VCF Table: API MPMS Ch. 11.1 / ASTM D1250 Table 54 B

$D_{15°C}$ (kg/m^3)	**750.00**	750.75	751.50	752.25	753.75	757.50
Uncertainty of $D_{15°C}$ [as% of reading]	**0**	0.1	0.2	0.3	0.5	1.0
VCF Computed	**0.9879**	0.9880	0.9880	0.9880	0.9880	0.9881

APPENDIX C—ILLUSTRATIVE EXAMPLE

C.1 Derivation of Constant "N"

Basic relationships:

Standard gravitational field g	=	9.80665000	[m/s^2]	(SI Units)
	=	32.17404856	[ft/s^2]	(US Customary units)
1.0 [inch-H_20 @ 68°F]	=	5.19297667	[lbs/ft^2]	(approximately)
1.0 [inch-H_20 @ 68°F]	=	248.64107000	[Pa]	(approximately)
1.0 [psig]	=	6894.75700000	[Pa]	(approximately)
1.0 [lb/ft^3]	=	16.01846000	[kg/m^3]	(approximately)

Rounding and Tolerance of Results:

The constants "N" (See also Table A-1) developed below are rounded to 7 significant digits, which 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%).

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

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

II. Pressure inputs in inches-H_20 @ 68°F (N = 167.0791):

$$\text{Density [lbs/ft}^3] = \frac{\text{Pressure [in-H}_2\text{O]} \times 5.19297667\ [\text{lbs/ft}^2/\text{in H}_2\text{O} \times 32.17404856\ [\text{ft/sec}^2]}{\text{Head [ft]} \times \text{g [ft/s}^2]}$$

$$= \frac{167.0791 \times \text{Pressure [in-H}_2\text{O]}}{\text{Head [ft]} \times \text{g [ft/s}^2]}$$

C.2 Example Calculations

Note: 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 Appendix B for guidance in computing inventory accuracy.

Liquid density (*D*, in vacuo)	=	1000	[kg/m^3]	=	62.42796	[lb/ft^3]
Liquid head (*L*)	=	10	[m]	=	32.8084	[ft]
Tank volume at 10 m	=	1000	[m^3]	=	1067.391	[ft^3] (approximately)
Vapor head	=	10	[m]	=	32.8084	[ft]
H_t	=	20	[m]	=	65.6168	[ft]
H_b	=	0	[m]	=	0	[ft]
H_o	=	0	[m]	=	0	[ft]
Local acceleration of gravity	=	9.815	[m/s^2]	=	32.20144	[ft/s^2]
Ullage pressure (at *P*3)	=	3500	[Pa]	=	14.07646	[in-H_2O] (approximately)
Vapor space density (D_V)	=	1.25	[kg/m^3]	=	0.078035	[lb/ft^3] (approximately)
Ambient air density (D_A)	=	1.2	[kg/m^3]	=	0.074914	[lb/ft^3] (approximately)

From the pressure balance equation:

$$(P1 - P3)/g = D \times \text{Head (liquid)} + D_V \times \text{Head (vapor)} - H_t \times D_A$$

Therefore, for these conditions, the pressure seen at P1 is:

$$P1 = 101{,}537.1275[\text{Pa}] = 408.3683 \ [\text{in-H}_2\text{O @ 68¡F}] \ (\text{approximately})$$

Example using SI units (Pa):

$$D_{obs} = D_V + \frac{N \times (P1 - P3) - g \times (D_V - D_A) \times H_t}{g \times (L - H_b)}$$

$$= 1.25 + \frac{1.0 \times (101{,}537.1275 - 3500.0) - 9.815 \times (1.25 - 1.2) \times 20}{9.815 \times (10.0 - 0)}$$

$$= 1000.0 \ [\text{kg/m}^3]$$

$$(= 62.42796 \ [\text{lb/ft}^3])$$

$$M = D_{obs} \times V = 1000.0 \ [\text{kg/m}^3] \times 1000.0 \ [\text{m}^3] = 10{,}000.0 \ [\text{kg}]$$

Example using US Customary units (in H_2O):

$$D_{obs} = D_V + \frac{N \times (P1 - P3) - g \times (D_V - D_A) \times H_t}{g \times (L - H_b)}$$

$$= 0.078035 + \frac{167.0791 \times (408.3683 - 14.07646) - 32.20144 \times (0.078035 - 0.074914) \times 65.6168}{32.20144 \times (32.8084 - 0)}$$

$$= 62.42798 \ [\text{lb/ft}^3]$$

$$= 1000.0 \ [\text{kg/m}^3]$$

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Product No. H03061

Date of Issue: September 2005
Affected Publication: API *Manual of Petroleum Measurement Standards*, Chapter 3—*Tank Gauging*, Section 6—*Measurement of Liquid Hydrocarbons by Hybrid Tank Measurement Systems,* First Edition, February 2001

ERRATA

Page iv, Contents 9.3, replace:

9.3 Verification fo Hybrid Processor Calculations

with

9.3 Verification of Hybrid Processor Calculations

Page v, Contents, add:

Page 1, Title/main header, replace:

Chapter 3—Tank Gauging

with:

Manual of Petroleum Measurement Standards

Chapter 3—Tank Gauging

Section 6—Measurement of Liquid Hydrocarbons by Hybrid Tank Measurement

Page 3,Table 1—Recommended Maximum ATG Tolerance, replace:

[Installed Accuracy for custody transfer application, based on volume shown as only plus:]

+ 4 mm

with:

± 4 mm

Page 3, Table 1—Recommended Maximum ATG Tolerance, replace:

[Installed Accuracy for inventory control application, based on volume shown as only plus:]

+ 12 mm

with:

± 12 mm

Page 10, 10.4.3, replace:

Pressure Sensor(s)

with:

c. Pressure Sensor(s)

Page 10, 10.4.3, replace:

c. Product Density

with:

d. Product Density

Page 15, Appendix A.3, replace:

[Within the equation for the value of D_{obs}*]*

$g \times (D_v + D_a)$

with:

$g \times (D_v - D_a)$

Page 24, Appendix B.6, Table B 6.3, replace:

Basis: Product temperature = 15 ºC.

with:

Basis: Product temperature = 25 ºC.

Page 5, 7.1, third paragraph, replace:

Errors in the measured level have little effect on the computed mass because of error cancellation in the product of volume and density.

with:

Errors in the measured level have little effect on the computed mass because of error cancellation in the arithmetical product of volume and density.

Page 15, Appendix A.3, replace:

Liquid head pressure= g × (L – Z) x D_{obs} (at P1 elevation)

In tank vapor head= g × [Ht – (L – Z)] x Dv(at liquid surface)

Ambient air head= g × Ht x Da(at P1 elevation)

with:

Liquid head pressure	=	$g \times (L - Z) \times D_{obs}$	(at P1 elevation)
In tank vapor head	=	$g \times [H_t - (L - Z)] \times D_v$	(at liquid surface)
Ambient air head	=	$g \times H_t \times D_a$	(at P1 elevation)

Page 15,Appendix A.3, replace:

[Iin parenthetical remark for the explanation of "Z"]

See Figure A1

with:

See Figure A-1

Page 18, Appendix B.1, replace:

[In the equation for UP1-total]

$U_{P1\,-\,\mathrm{linearity}}$

with:

$U_{P1\text{-zero}}$

The equation should read:

$U_{P1\text{-total}} = U_{P1\text{-zero}} + \{g(L - Z)(D - D_v) + P3_{\max}\}\ U_{P1\text{-linearity}}$