

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, JANUARY 2017



AMERICAN PETROLEUM INSTITUTE

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Manual of Petroleum Measurement Standards

Chapter 3—Tank Gauging

Section 6—Measurement of Liquid Hydrocarbons by Hybrid Tank Measurement

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 Standards¹

- 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 plane.

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-H₂O, 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.

¹American 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 P1 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 P1 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 (P1 near the tank bottom, and P3 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 (*P2*) may be installed between *P1* and *P3* 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 *P3* should be much smaller than the span chosen for pressure sensor *P1* 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 *P2*

A middle transmitter (*P2*) 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 ($P1$ and $P3$) directly affect the observed and reference density, and the mass. However, errors in $P1$ or $P3$ 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-H₂O, 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-H₂O, etc.),

$U_{P\text{-zero}}$ = zero error of pressure sensor (expressed in Pascal, in-H₂O, etc.),

P_{applied} = pressure as input to the pressure sensor (expressed in Pascal, in-H₂O, 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 $P3$ 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 ($P1$), 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 $P1$ 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 (ie., standard volume or mass), and depending on the characteristics of the product (ie., uniform or density stratified) two modes are defined for HTMS