BS ISO 15169:2003

Petroleum and liquid petroleum products — Determination of volume, density and mass of the hydrocarbon content of vertical cylindrical tanks by hybrid tank measurement systems

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British Standards

National foreword

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The UK participation in its preparation was entrusted by Technical Committee PTI/12, Petroleum measurement and sampling, to Subcommittee PTI/12/1, Static and dynamic petroleum measurement, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

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Petroleum and liquid petroleum products — Determination of volume, density and mass of the hydrocarbon content of vertical cylindrical tanks by hybrid tank measurement systems

Pétrole et produits pétroliers liquides — Détermination du volume, de la masse volumique et de la masse d'hydrocarbures contenus dans les réservoirs cylindriques verticaux à l'aide de systèmes hybrides de mesurage

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 15169 was prepared by Technical Committee ISO/TC 28, *Petroleum products and lubricants*, Subcommittee SC 3, *Static petroleum measurement*.

Petroleum and liquid petroleum products — Determination of volume, density and mass of the hydrocarbon content of vertical cylindrical tanks by hybrid tank measurement systems

1 Scope

This International Standard gives guidance on the selection, installation, commissioning, calibration and verification of hybrid tank measurement systems (HTMS) for the measurement of level, static mass, observed and standard volume, and observed and reference density in tanks storing petroleum and petroleum products in fiscal or custody transfer application. As it is a matter for the user to decide which measurements (i.e. volume, or mass or both) are used for custody transfer purposes, this International Standard includes an uncertainty analysis, with examples, to enable users to select the correct components of an HTMS to address the intended application.

This International Standard is applicable to stationary, vertical cylindrical tanks storing liquid hydrocarbons with a Reid Vapour Pressure (RVP) below 103,42 kPa.

This International Standard is not applicable to pressurized tanks or marine applications.

NOTE 1 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 Annex A).

NOTE 2 The calculation procedures in this International Standard can also be applied to tanks with other geometries, which have been calibrated by a recognized oil-industry method (e.g. ISO 7507). Examples of uncertainty analysis for spherical and horizontal cylindrical tanks are given in Annex B.

2 Normative references

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

ISO 91-1:1992, *Petroleum measurement tables — Part 1: Tables based on reference temperatures of 15 °C and 60 °F*

ISO 1998 (all parts), *Petroleum industry — Terminology*

ISO 3170:—[1], *Petroleum liquids — Manual sampling*

ISO 3675:1998, *Crude petroleum and liquid petroleum products — Laboratory determination of density — Hydrometer method*

ISO 4266 (all parts), *Petroleum and liquid petroleum products — Measurement of level and temperature in storage tanks by automatic methods*

ISO 7507 (all parts), *Petroleum and liquid petroleum products — Calibration of vertical cylindrical tanks*

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[1] To be published. (Revision of ISO 3170:1988)

ISO 11223-1:1995, *Petroleum and liquid petroleum products — Direct static measurements — Contents of vertical storage tanks — Part 1: Mass measurement by hydrostatic tank gauging*

ISO 12185:1996, *Crude petroleum and petroleum products — Determination of density — Oscillating U-tube method*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 1998 and the following apply.

3.1
hybrid tank measurement system (HTMS)
system which uses product level measured by an automatic level gauge (ALG), the product temperature measured by an automatic tank thermometer (ATT), and the static head of the liquid measured by one or more pressure sensors

NOTE These measurements are used, together with the tank capacity table and the product volume/density correction tables, to provide level, temperature, mass, observed and standard volume, and observed and reference density.

3.2
hybrid processor
computing device which uses the level, temperature, and pressure sensor measurements of the HTMS, in addition to stored tank parameters, to compute density, volume and mass

3.3
hybrid reference point
stable and clearly marked point on the outside of the tank wall, from which the hybrid pressure sensor position(s) of the pressure sensors(s) is (are) measured

NOTE The hybrid reference point is measured relative to the datum plate.

3.4
zero error of pressure transmitter
indication of the pressure transmitter when no pressure difference between input and ambient pressure is applied to the pressure transmitter

NOTE This value is expressed in units of pressure measurement, such as pascals.

3.5
linearity error of a pressure transmitter
deviation of the indicated value of the pressure transmitter in relation to the applied pressure as input to the transmitter

NOTE This value should not include the zero error and is expressed in fractional or percent values, related to the applied pressure (i.e. as a fraction or percentage of reading).

4 General precautions

4.1 Safety precautions

4.1.1 General

ISO standards and applicable national and local regulations on safety and material compatibility precautions should be followed when using HTMS equipment. Manufacturers' recommendations on the use and installation of the equipment should be followed. All regulations covering entry into hazardous areas should be observed.

4.1.2 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 service.

4.1.3 Electrical safety

All electric components of an HTMS for use in electrically classified areas should be appropriate to the classification of the area and should conform to appropriate national and/or international (e.g. IEC, CSA, CENELEC, ISO) electrical safety standards.

4.2 Equipment precautions

4.2.1 The HTMS equipment should be capable of withstanding the pressure, temperature, operating and environmental conditions likely to be encountered in service.

4.2.2 All electrical equipment and components should be certified for use in the hazardous area classification appropriate to their installation.

4.2.3 Measures should be taken to ensure that all exposed metal parts of the HTMS have the same electrical potential as the tank.

4.2.4 All parts of the HTMS in contact with the product or its vapour should be chemically compatible with the product, to avoid both product contamination and corrosion of the equipment.

4.2.5 All HTMS equipment and components should be maintained in safe operating condition and the manufacturers' maintenance instructions should be complied with.

NOTE The design and installation of an HTMS or its components may be subject to the approval of the national measurement organization, who will normally have issued a type approval for the design of the HTMS for the particular service for which it is to be employed. Type approval is normally issued after an HTMS has been subjected to a specific series of tests and is subject to the HTMS being installed in an approved manner.

Type approval tests may include the following: visual inspection, performance, vibration, humidity, dry heat, inclination, fluctuations in power supplies, insulation, resistance, electromagnetic compatibility, and high voltage.

5 Selection and installation of hybrid tank measurement system equipment

5.1 General

A hybrid tank measurement system consists of four major components: an automatic level gauge (ALG), an automatic tank thermometer (ATT), one or more pressure sensors, and a hybrid processor, which stores the tank parameters and performs calculations. The requirements for these individual components are given in 5.2 to 5.6.

The user should specify whether the HTMS is to be used primarily for standard volume or mass measurements and the measurement accuracy required for custody transfer.

The user or manufacturer should select the HTMS components and configure the system to meet the application requirements. The accuracy requirements of the user's application determine the individual accuracy requirements of the HTMS components.

NOTE Annex A provides an overview of the HTMS theory and calculations. Clause 6 and Annex B provide guidance and methods to estimate the effects on overall HTMS accuracy of the individual component selection.

5.2 Automatic level gauge

5.2.1 The automatic level gauge (ALG) should be selected based on the intended application(s) of the HTMS, e.g. for volume-based custody transfer application, or for mass-based custody transfer application, or both. Likewise, the installation of the ALG should allow the installed accuracy to be suitable for the intended application(s).

NOTE 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 ISO 11223-1, which describes hydrostatic tank gauging (see Figure A.1).

5.2.2 The intrinsic accuracy of the ALG, demonstrated by the factory calibration, and the installed accuracy, demonstrated during field verification, should be as given in Table 1.

Table 1 — Maximum permissible error for ALG

	Volume-based custody transfer application mm	**Mass-based custody transfer application** mm
Intrinsic accuracy	1	3
Installed accuracy	4	12

The accuracy of the ALG has no effect on the mass calculated above the level where P_1 is located because of the cancelling effect of density/volume errors. However, the uncertainty of calculated density due to error in the ALG has an effect on the heel mass (i.e. at levels below location P_1). Therefore, the choice of ALG accuracy in Table 1 for the mass-based custody transfer case is made for the purpose of minimizing error in heel mass. In addition, by minimizing uncertainty in calculated density, the accuracy provides a means to independently monitor the performance of the pressure transmitters.

5.2.3 In general, the accuracy of an ALG for an HTMS in a volume-based custody transfer application should comply with ISO 4266-1 for vertical cylindrical tanks.

5.3 Pressure sensor(s)

5.3.1 The HTMS pressure sensor(s) should be selected in accordance with the uncertainty calculation for the specific application (see clause 6 and Annex B). The pressure-sensor installation should be in accordance with the recommendations given in ISO 11223-1. The accuracy requirements of the pressure sensor(s) depend on the intended application of the HTMS, i.e. for volume-based custody transfer application, or for mass-based custody transfer application, or both. The maximum permissible errors are given in Table 2.

Table 2 — Maximum permissible errors for pressure sensor(s)

Maximum error of pressure sensor	**For volume-based custody transfer application**	**For mass-based custody transfer application**
P_1 – Zero error	100 Pa	50 Pa
Linearity error	0,1 % of reading	0,07 % of reading
P_3[a] – Zero error	40 Pa	24 Pa
Linearity error	0,5 % of reading	0,2 % of reading

[a] If P_3 is used.

The span of pressure sensor P_3 can be much smaller than the span chosen for pressure sensor P_1 because the gauge vapour pressure is typically limited to a maximum of approximately 5 kPa.

5.3.2 The HTMS pressure sensor(s) should be stable, with precision pressure sensors 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 opens to atmosphere).

5.3.3 Use of electronic analogue output or digital output depends upon the overall accuracy requirement of the pressure transmitter for its intended application.

5.4 Automatic tank thermometer (ATT)

5.4.1 The automatic tank thermometer (ATT) should be selected, based on the intended application(s) of the HTMS, e.g. for volume-based custody transfer application, or for mass-based custody transfer application, or both. Likewise, the installation of the ATT should allow the installed accuracy to be suitable for the intended application(s).

5.4.2 The intrinsic accuracy of the ATT, demonstrated by the factory calibration, and the installed accuracy, demonstrated during field verification, should be as shown in Table 3.

Table 3 — Maximum permissible errors for ATT

	Volume-based custody transfer application	Mass-based custody transfer application
Intrinsic accuracy	a) as a “system”: 0,25 °C including sensor, converter/transmitter/display b) by components: 0,20 °C for sensor, 0,15 °C for transmitter/ converter/ readout	0,5 °C
Installed accuracy	0,5 °C	1,0 °C

5.4.3 In general, the accuracy of an ATT for an HTMS in volume-based custody transfer application should be as given in ISO 4266-4 for vertical cylindrical tanks.

5.4.4 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. HTMS designed primarily to compute standard volumes should use an ATT that provides average temperature. For HTMS designed primarily for measuring mass, a single point or spot resistance thermometer (RTD) is often considered adequate.

5.4.5 The ATT may, optionally, be used in the calculation of vapour density if multiple elements exist that can measure vapour temperature independently from the remaining elements that are submerged. Alternatively, the submerged elements(s) of an ATT may be used for vapour temperature estimation in an insulated tank.

5.5 Hybrid processor

5.5.1 The hybrid processor may be implemented in various ways, which include a locally mounted microprocessor, a remote computer, or the user's computer system. The hybrid processor may be dedicated to a single tank or shared among several tanks.

5.5.2 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 (see Figure A.1). The stored parameters fall into six groups: tank data, ALG data, ATT data, pressure sensor data, product data and ambient data (see Table 4).

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

5.5.4 All variables measured and computed by the hybrid processor should be capable of being displayed, printed, or communicated to another processor.

NOTE Computations normally performed by the hybrid processor are given in Annex A.

5.6 Optional sensors

5.6.1 Pressure transmitter

A middle transmitter (P_2) may be employed for an alternate (i.e. hydrostatic tank gauge, or HTG) density calculation for comparison or for alarming purposes, or as a backup density calculation should the ALG component become inoperative. (See ISO 11223-1 for further information.)

5.6.2 Instrumentation for ambient density determination

5.6.2.1 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 International Standard. However, ambient temperature and pressure sensors may be used for more accurate determination of ambient air density, if desired.

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

6 Accuracy effects of HTMS components

6.1 General

The accuracy of each component of the HTMS affects one or more of the measured or calculated parameters. For certain applications, HTMS 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 gross 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 Volume Correction Factor (VCF). (See the example in Table B.6.)

The effects of component accuracy on measured and calculated parameters are given in 6.2 to 6.4. Equations are given in Annex B to assist the user in determining the magnitudes of errors of spot (i.e. static) measurement of observed density, mass, and gross standard volume due to uncertainty of each of the HTMS system primary measurements (level, pressure and temperature).

6.2 Accuracy effects of the ALG

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

Errors in the measured level have little effect on the computed mass because of error cancellation of product 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 ALG accuracy on mass for various tank geometries can be predicted using the uncertainty equations in B.3.

If an HTMS is used to determine standard volume for custody transfer, the accuracy of the ALG should meet the corresponding requirements given in ISO 4266-1. If the HTMS is used primarily for mass or density determination, ALG accuracy should meet less rigorous requirements than those given in ISO 4266-1 (see Table 1 for maximum permissible errors for ALG).

6.3 Accuracy effects of the pressure sensor(s)

The accuracy of the pressure sensors (P_1 and P_3) directly affects 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 will depend on both the zero and linearity errors. The zero error is an absolute error, expressed in a unit of pressure measurement (e.g. pascals, in H_2O). The linearity error is typically expressed as percent of reading. At low levels, this zero error is the dominating factor in the uncertainty analysis. The manufacturer should unambiguously state both the zero and linearity errors (the zero error expressed in absolute units, the span error in percent of reading) over the anticipated operating temperature range. This is to enable the user to verify that the error contribution of the pressure sensor to the overall uncertainty will be acceptable for the required HTMS accuracy (see Annex B). (See Table 2 for maximum permissible zero and linearity errors.)

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

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

where

$U_{\text{P-total}}$ is the total error of pressure sensor, expressed in pascals;

$U_{\text{P-zero}}$ is the zero error of pressure sensor, expressed in pascals;

p_{applied} is the pressure as input to the pressure sensor, expressed in pascals;

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

The applied pressure for pressure sensor P_1 ($p_{1\ \text{applied}}$) is approximately the sum of the liquid head, the vapour head and the maximum setting of the pressure relief valve (see Annex B).

For the P_3 pressure sensor, the vapour pressure is not related to the liquid level, and therefore the maximum value of the pressure relief valve (i.e. $p_{3\ \text{max}}$) should be taken for $p_{3\ \text{applied}}$. (See Table 2 for maximum permissible errors for pressure sensor(s).)

6.4 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. (See ISO 4266-4.)

ATT accuracy has no effect on the observed density in any tank geometry and only minor effects on the mass determined by an HTMS. For HTMS designed primarily for measuring mass, a single-point or spot temperature (e.g. RTD) should be 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.

7 HTMS measurement and calculations

7.1 General

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 uncertainties in the ALG 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 should be considered in how various parameters are calculated at low product levels.

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

7.2 HTMS Mode 1

HTMS Mode 1 is preferable where standard volume is the primary value of concern, and when product density remains relatively uniform at low levels. When the level is above a predetermined level (h_{min}), Mode 1 calculates the average density for the tank contents continuously. Below this h_{min}, Mode 1 uses the last calculated reference density (D_{ref}) from when the level was falling to reach 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.

Table 5 (method A) and Table 6 (method B) specify the HTMS measurements and calculations required for Mode 1 at and above h_{min}, and below h_{min}, respectively.

See Figure 1 for additional clarification of how calculation methods A and B apply to HTMS Mode 1 as the level changes.

7.3 HTMS Mode 2

HTMS Mode 2 is preferable where product mass is the primary output value of concern. Mode 2 is also preferable when 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 liquid levels (due to stratification or the introduction of new product).

HTMS Mode 2 does not use an h_{min} or store the product density. In this mode, the HTMS calculates the reference density (D_{ref}) at all levels above P_1. However, to ensure that the pressure sensor is always fully submerged, a “P_1 cut-off level” is introduced in this mode. If the product level is at or below this “cut off” level, the last calculated D_{ref} is used and is held constant. Above this level, all measurements and calculations are performed in accordance with method A (Table 5). Below this level, the measurements and calculations follow method B (Table 6). (See Figure 1 for additional clarification of how calculation methods A and B apply to HTMS Mode 2 as the level changes.)

8 Commissioning and initial field calibration

8.1 General

All measuring components are normally calibrated at the factory before installation. The process of commissioning the HTMS is performed before putting the HTMS system in service, and involves not only calibrations, but also configuration and verification.

8.2 Initial preparation

8.2.1 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 calibration table.

8.2.2 Establishment of the hybrid reference point

It is essential that the positions of both the P_1 transmitter and the ALG be defined relative to the reference datum 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 by the dimension h_o. (See Figure A.1.)

It is advised that the hybrid reference point be located close to the P_1 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 centre h_b should be measured. The pressure sensor position in relation to the tank datum plate ($z = h_o + h_b$) should then be calculated and entered into the hybrid processor. (See Figure A.1.)

NOTE The hybrid reference point can be used for future P_1 transmitter position verification or determination after reinstallation of the transmitter. This eliminates the need for remeasuring the position of the P_1 transmitter relative to the tank datum.

8.2.3 HTMS parameter entry

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, ALG reference height and P_1 sensor, the HTMS Mode, the value of h_{min}, “P_1 cut off”, ambient data, pressure sensor parameters, ALG and ATT component parameters, and product parameters. (See Table 4.)

8.3 Initial calibration and verification of HTMS components

8.3.1 General

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

8.3.2 ALG calibration

The ALG should be field-calibrated in accordance with ISO 4266-1, but using the appropriate tolerance given in Table 1 of this International Standard.

8.3.3 Pressure sensor calibration and zero adjustment

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

Zero adjustments of pressure sensors should be carried out using the procedure given in ISO 11223-1.

8.3.4 ATT calibration

The ATT should be calibrated in accordance with ISO 4266-4, but using the appropriate tolerance given in Table 3 of this International Standard.

8.4 Verification of hybrid processor calculations

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

8.5 Initial field verification of HTMS

8.5.1 General

The final step in commissioning and initial verification of an HTMS system is to verify it against manual measurements. 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 verification procedures should be repeated.

8.5.2 Initial field verification of volume-based HTMS applications

8.5.2.1 The major components of a volume-based HTMS for fiscal/custody transfer application should be verified as follows:

a) The ALG should be verified in accordance with the procedure and tolerances given in ISO 4266-1.

b) The ATT should be verified in accordance with the procedure and tolerances given in ISO 4266-4.

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

   1) For zero adjustment, the transmitter should be isolated from the pressure port vented to atmosphere. The zero error after this adjustment should be approximately zero.

   2) Linearity should be verified using a high-precision pressure calibration reference traceable to national standards. The linearity verification should be performed at a minimum of two test pressures of approximately 50 % and 100 % of range. Linearity error should be determined by calculating the difference between the pressure sensor indication (minus any observed zero error) and the pressure reference to give a fractional linearity error, which may be converted to a percentage error. The resulting linearity error should not exceed the maximum linearity error given 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 given in Table 2. The zero reading and linearity error “as left” should be documented.

8.5.2.2 The reference product density determined by the HTMS should also be compared with the average product density determined by testing of a representative tank sample. Sampling should be performed in accordance with ISO 3170. The density should be determined in accordance with either ISO 3675 or ISO 12185.

The density comparison should be performed at a level of approximately (4 ± 0,5) m above P_1, when HTMS provides on-line measurement of density, i.e. with a level above h_{min}. The difference between the product density given by the HTMS and by the tank sample should be within ± 0,5 % of the reading. 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 the reading) should be used. This tolerance can be established using statistical quality control methods.

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

NOTE 1 The ± 0,5 % tolerance 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 will depend on the location of the gauging access point used for sampling and the procedure actually used.

NOTE 2 The acceptable uncertainty of the HTMS density is determined, based on the impact of the uncertainty on the volume correction factor, VCF, or correction for the effect of temperature on liquid, CTL.

Alternately, for non-stratified products, if an on-line densitometer is available and has been recently calibrated against a reference traceable to the national standard, the density measured by the densitometer for a batch transferred into or out of a tank can be compared with the mean density measured by the HTMS for the batch, and the above tolerance can be used.

8.5.3 Initial field verification of mass-based HTMS applications

8.5.3.1 The major components of a volume-based HTMS for fiscal/custody transfer application should be verified as follows.

a) The ALG should be verified in accordance with the procedure given in ISO 4266-1, except that the tolerance may be relaxed to 12 mm.

b) The ATT should be verified in accordance with the procedure and tolerances given in ISO 4266-4, except that the tolerance may be relaxed to 1 °C.

c) The pressure sensors (including transmitters, if they are separate devices) affect the accuracy of the mass measurement and should be zeroed and spanned using a suitable calibration reference (e.g. a hand-held terminal and a precision pressure calibrator) traceable to the national standard. The calibration should be performed to determine if the sensors/transmitter remains within the accuracy given in Table 2.

NOTE For high-precision pressure transmitters, it may be difficult or impractical to span the transmitter under field conditions. Under these circumstances, this procedure cannot be performed.

8.5.3.2 Density comparison of the HTMS should be verified by the method given in 8.5.2.2.

8.5.3.3 The HTMS mass transfer accuracy should be verified using the method given in ISO 11223-1.

NOTE The tolerance given in ISO 11223-1 is for “transfer accuracy” and therefore the verification involves a transfer of liquid into or out of the tank.

9 Subsequent verification

9.1 General

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

Post-commissioning HTMS verification and any necessary recalibrations are given in 9.2 to 9.6.

NOTE Verification differs from calibration in that it generally does not involve correction of the sensors or the HTMS hybrid processor parameters.

9.2 Objectives

The objectives of regular verification are as follows:

a) to ensure that the performance of HTMS remains within the required accuracy limits; and

b) to allow use of statistical quality control to establish the frequency of recalibration, provided that this is acceptable to parties involved in custody transfer.

9.3 Adjustment during regular verification

If the verification process identifies that a drift in HTMS performance has occurred exceeding the predetermined limits, the HTMS should be recalibrated and/or readjusted. 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.

9.4 Subsequent verification of HTMS in volume-based custody transfer application

9.4.1 Procedures and tolerances

9.4.1.1 The major components of a volume-based HTMS should be verified as follows.

a) The ALG should be verified in accordance with the procedures and tolerances for subsequent verification given in ISO 4266-1 (for upright cylindrical tanks).

b) The ATT should be verified in accordance with the procedures and tolerances for subsequent verification given in ISO 4266-4 (for upright cylindrical tanks).

c) The stability of the pressure sensor/transmitter should be verified as follows.

    1) 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 given in Table 2. If the zero reading is greater than the maximum recommended values given in Table 2, and does not exceed 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.

    2) The transmitter linearity should be verified *in situ* using a high-precision pressure calibrator traceable to national standards. The linearity-error should not exceed the manufacturer's specification, or the maximum recommended values given in Table 2. If the manufacturer's specifications are exceeded, the manufacturer should be consulted. The linearity reading “as-found” and “as-left” values should be documented.

NOTE For high-precision pressure transmitters, it may be difficult or impractical to adjust the transmitter linearity under field conditions.

9.4.1.2 The product density measured by an HTMS should also be compared with the product density determined by representative tank sample and laboratory analysis. Sampling should be performed in accordance with ISO 3170. The density should be determined in accordance with either ISO 3675 or ISO 12185.

The density comparison should be performed at a level of approximately (4 ± 0,5) m, and when HTMS provides on-line measurement of density, i.e. with a level above h_{min}. The tolerance between the product density by the HTMS and by tank sample should be within ± 0,5 % of reading. 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) should be used. This tolerance can be established using statistical quality control methods.

9.4.2 Frequency of subsequent verification

9.4.2.1 The frequency of subsequent verification of the major components of HTMS should be as follows.

a) The ALG should be verified in accordance with the frequency described for subsequent field verification given in ISO 4266-1.

b) The ATT should be verified in accordance with the frequency described for subsequent field verification given in ISO 4266-4. A newly installed or repaired ATT should be verified every three months. If the performance of the ATT is stable, the frequency can be reduced to once per year.

c) For 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.

9.4.2.2 The comparison of product density should be performed, using the procedure given in 9.4.1.2, at least once every 3 months following initial verification.

NOTE 1 Use of statistical quality control methods, rather than the above predetermined time, may also determine the frequency of regular verification.

NOTE 2 More frequent comparison of product density should enable early detection of any problem in ALG, ATT or pressure sensors/transmitter components, and it provides valuable statistical data on the HTMS.

9.5 Subsequent verification of HTMS in mass-based custody transfer applications

9.5.1 Procedures and tolerances

9.5.5.1 The major components of a mass-based HTMS should be verified as follows.

a) The ALG should be verified in accordance with the procedure for subsequent verification of calibration given in ISO 4266-1, and should meet the tolerance given in Table 1.

b) The ATT should be verified in accordance with the procedure for subsequent verification of calibration given in ISO 4266-4, and should meet the tolerance given in Table 3.

c) The zero and linearity stability of the pressure sensor/transmitter(s) should be verified in accordance with the method given in 9.4.1.1 c) and should meet the tolerance given in Table 2.

9.5.1.2 Comparison of product density determined by HTMS and by manual methods is optional in mass-based custody transfer applications. This comparison, if required, should be made in accordance with 9.4.1.2.

9.5.2 Frequency of subsequent verification

The frequency of regular verification of the major components/measurement performance of an HTMS used in mass-based custody transfer applications should be as follows.

a) A newly installed or repaired ALG should be verified once per quarter. If the performance of the ALG 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 that the overall system is stable.

b) A newly installed or repaired ATT should be verified at the same frequency as the ALG.

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

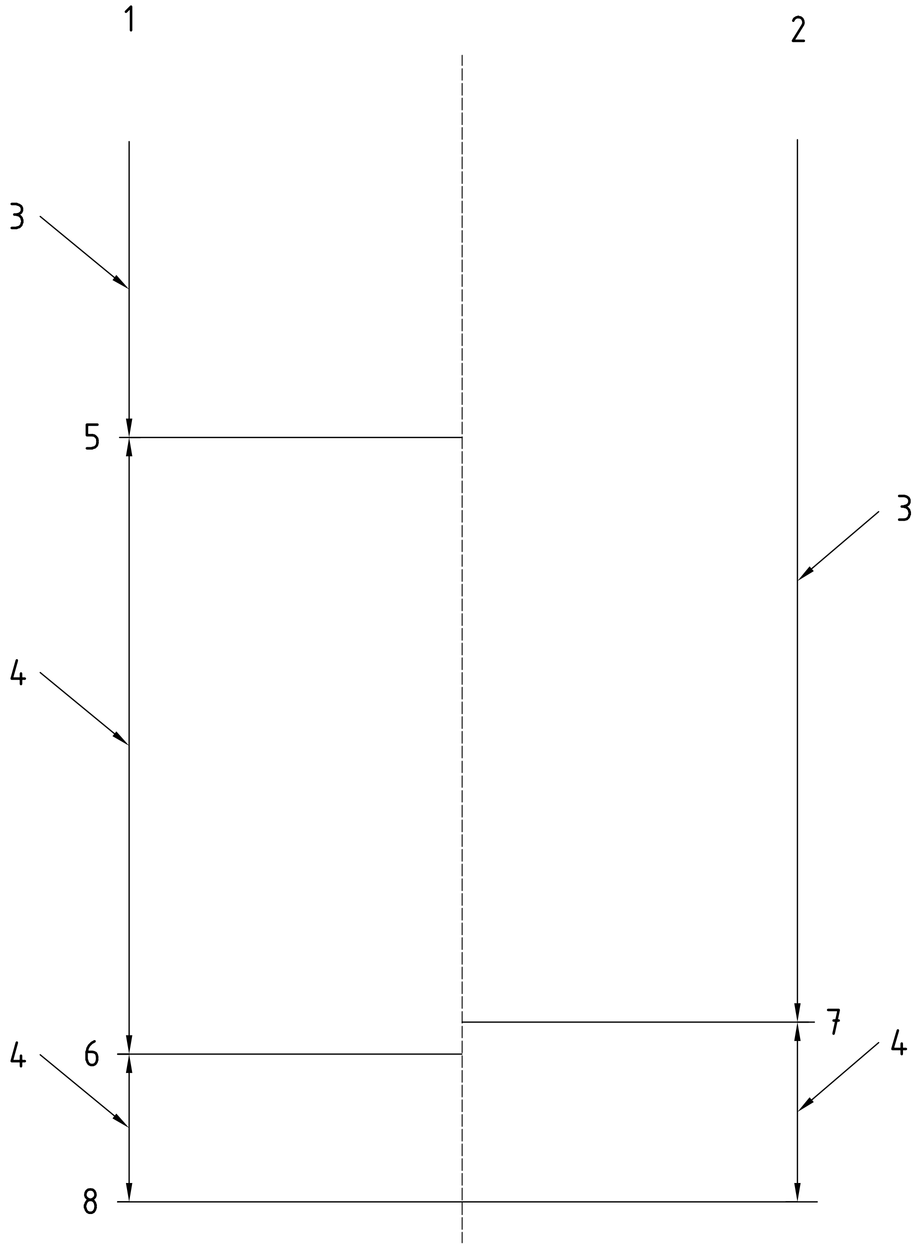
d) The comparison of product density by an HTMS with density determined by manual methods is optional, except that, if the density comparison is to be used as a basis for reducing the frequency of the subsequent ALG, verification [9.5.2 a)], the density comparison should be carried out at least quarterly.

NOTE More frequent comparison of product density will ensure early detection of problems in the ALG, ATT, or pressure sensor/transmitter(s), and will provide valuable statistical data.

9.6 Handling out-of-tolerance situations during regular verification of HTMS in custody transfer application

9.6.1 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 reset, or repaired.

9.6.2 After adjustment or repair, the component should be reverified using the procedure given in 8.5.



Key

1	HTMS Mode 1	5	Level h_{min}
2	HTMS Mode 2	6	P_1 position
3	Method A	7	P_1 cut off
4	Method B	8	Datum plate

Figure 1 — Summary of HTMS calculation methods as they relate to level for Modes 1 and 2

Table 4 — Typical HTMS 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
	Level h_{min}	All tanks (see 6.2)
	Level h_{o}	Distance between hybrid reference point and datum plate
ALG component data	Measurement	Innage, ullage
	Reference height	Vertical distance from datum plate to ALG mounting
Pressure sensor data	Sensor configuration	Tank with one or more sensors
	Sensor location(s)	At applicable reference point(s) (see Figure A.1)
	P_3 sensor elevation	
ATT component data	Type of ATT	May be programmed in the ALG
	Element type	Resistance or other, may be programmed in ALG
	Number of elements	
	Vertical location of elements	
Product data	Coefficients related to liquid expansion	See for further information ISO 91-1
	Vapour parameters	
	Free water level	
Ambient data	Local acceleration due to gravity	Obtained from a recognized source
	Ambient temperature	Optional
	Ambient pressure	Optional

Table 5 — HTMS measurements and overview of calculations – Calculation Method A
(see notes 1, 2)

Parameter	Method of measurement or calculation
Product level (L)	Measured by ALG
Average product temperature (t)	Measured by ATT
Observed product density (D_{obs})	Calculated using equation in A.3
Reference density (D_{ref})	Calculated from D_{obs} and t, by iteration (see note 4)
Volume correction factor (VCF)	Calculated as VCF = D_{obs} / D_{ref}
Gross observed volume (GOV)	Calculated from L by ALG and tank capacity table (see note 3)
Gross standard volume (GSV)	Calculated as GSV = GOV × VCF
Mass (in vacuo)	Calculated as m = GOV × D_{obs}

NOTE 1 This table is applicable to Mode 1 at levels at and above h_{min}, only.

NOTE 2 This table is applicable to Mode 2 at all levels above P_1 “cut 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.

Table 6 — HTMS Measurements and overview of calculations – Calculation Method B
(see note 1)

Parameter	Method of measurement or calculation
Product level (L)	Measured by ALG
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 P_1 in Mode 2 (see note 3)
Volume correction factor (VCF)	Calculated from t measured by ATT, and from D_{ref} which is stored when $L = h_{min}$ in Mode 1, or when L is below P_1 in Mode 2.
Gross observed volume (GOV)	Calculated from L by ALG and tank capacity table (see note 2)
Gross standard volume (GSV)	Calculated as GSV = GOV × VCF
Mass (in vacuo)	Calculated as m_{vacuo} = GSV × D_{ref}

NOTE 1 This table is applicable to Mode 1 at levels below h_{min}, only.

NOTE 2 After deducting for free water (FW), if any, from the total observed volume (TOV) of the liquid in the tank. GOV = TOV − FW

NOTE 3 Manual density may be used if the HTMS measured density is not reliable or not available.

Annex A
(informative)

Calculation overview

A.1 General

This Annex 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).

Table A.1 — Units table for HTMS equations

Constant	**Units used in the equations**						
	Inputs			Calculated results			
N	Gauge pressure	Capacity table volume	Local acceleration due to gravity	Level	Observed and standard volume	Observed and reference density	Mass
1,000	Pa	m^3	m/s^2	m	m^3	kg/m^3	kg
1 000,0	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

For atmospheric tanks, in-tank vapour density and ambient air densities have only second order effects on the calculated variables. They can be considered constant, or can be calculated for high accuracy. In-tank vapour density can be calculated using the gas equation of state from absolute vapour pressure and absolute vapour temperature together with the vapour 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.

A.2 Gross observed volume (GOV)

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

where

GOV	is the gross observed volume;
TOV	is the total observed volume as calculated from ALG and tank capacity table;
FW	is the free water quantity (volume);
FRA	is the floating roof adjustment, if applicable;
CTSh	is tank shell thermal expansion correction.

$$\text{CTSh} = 1 + 2\,\alpha\,(\Delta t) + \alpha^2(\Delta t)^2$$

where

α is the linear thermal expansion factor given in Table A.2.

$$\Delta t = t_{\text{sh}} - t_{\text{B}}$$

where

t_{sh} is the temperature of shell;

t_{B} is the base shell temperature (the shell temperature at which the tank capacity was computed);

L is the liquid level by the ALG, referenced to the tank capacity table reference point. Effect of linear thermal expansion, if any, has been compensated in L.

Table A.2 — Linear thermal expansion factor

Shell material	α (per °C)
Mild carbon steel	0,000 011 2
304 Stainless steel	0,000 017 3
316 Stainless steel	0,000 015 9
17-4PH Stainless steel	0,000 010 8

A.3 Observed product density (in vacuo) (D_{obs})

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:

$p_1 - p_3$ = (total liquid product head + in-tank vapour head) – ambient air head between P_1 and P_3.

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

Liquid head pressure $= g \times (L - Z) \times D_{\text{obs}}$ (at P_1 elevation)

In tank vapour head $= g \times [h_{\text{t}} - (L - Z)] \times D_{\text{v}}$ (at liquid surface)

Ambient air head $= g \times h_{\text{t}} \times D_{\text{a}}$ (at P_1 elevation)

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

$$D_{\text{obs}} = D_{\text{v}} + \frac{\text{N} \times (p_1 - p_3) - g \times (D_{\text{v}} - D_{\text{a}}) \times h_{\text{t}}}{g \times (L - Z)}$$

where

D_{obs} is the observed liquid density in vacuo;

N is the unit constant (see Table A.1);

L is the ALG (innage) level reading;

Z is $h_b + h_o$ (the heel under P_1 transmitter to tank datum plate (see Figure A.1);

h_b is the vertical distance of the centre of force on sensor P_1 from the hybrid reference point;

h_o is the vertical distance from the tank datum plate to the hybrid reference point;

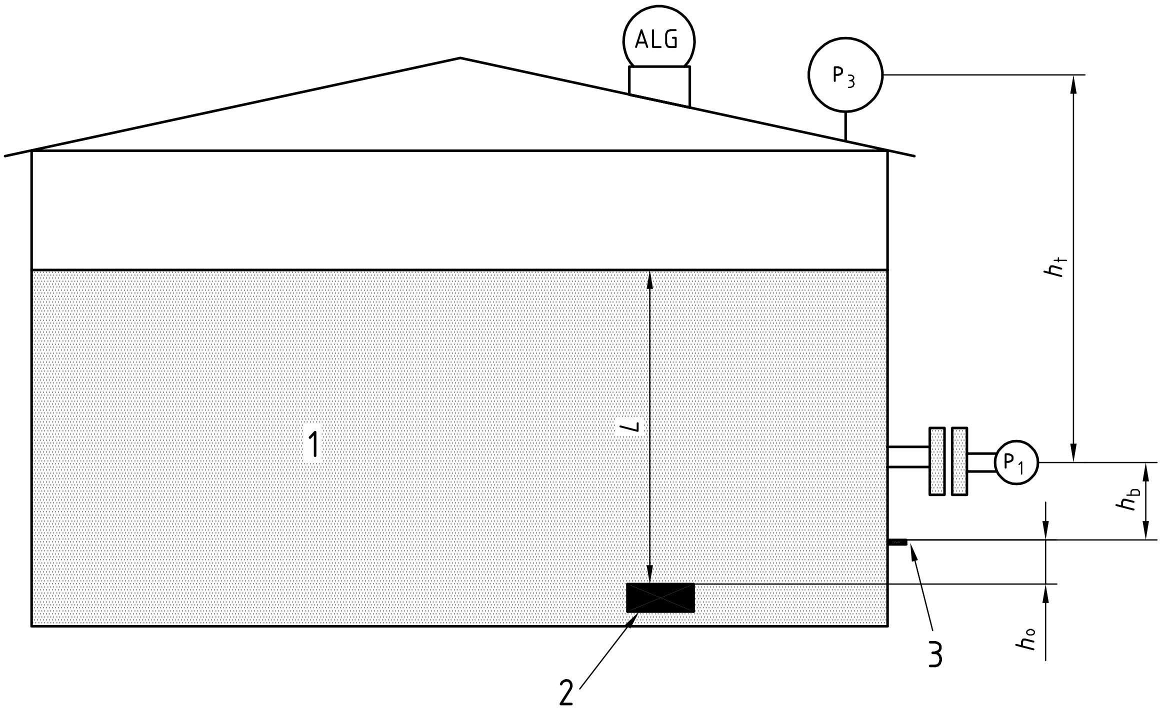
g is the local acceleration due to gravity;

h_t is the vertical distance of the centres of force on the diaphragms of sensors P_1 and P_3;

D_v is the in-tank vapour density;

D_a is the ambient air density.

NOTE h_o is zero if the hybrid reference point is at the same altitude as the tank datum plate.



Key

1 Liquid
2 Datum plate
3 Hybrid reference point

NOTE 1 $Z = h_b + h_o$.

NOTE 2 ATT is not shown.

Figure A.1 — Measurement parameters and variables – Fixed roof tank

A.4 Product mass calculation (in vacuo) (m)

$$m = \text{GOV} \times D_{\text{obs}}$$

where

GOV is the gross observed volume as calculated in A.2;

D_{obs} is the observed product density (in vacuo) as calculated in A.3.

NOTE For atmospheric storage tanks, m_{vapour} may be assumed to be zero.

A.5 Product apparent mass in air (m_{a})

$$m_{\text{a}} = m \times (1 - D_{\text{a}} / D_{\text{obs}})$$

where

m is the total product mass (in vacuo) as calculated in A.4;

D_{a} is the ambient air density;

D_{obs} is the observed liquid density (in vacuo) as calculated in A.3.

A.6 Gross standard volume (GSV)

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

where

GOV is the gross observed volume as calculated in A.2;

VCF is the volume correction factor, typically obtained from ISO 91-1.

Annex B
(informative)

Measurement accuracy and uncertainty analysis

B.1 General

Provided that the ALG and the pressure sensor installations are correct, the calculated density, mass, and standard volume accuracy depend upon the combined accuracy of the pressure sensor(s), the ALG sensor, the ATT sensor, the measurement of the hybrid reference point, the tank capacity table and the local acceleration due to gravity.

Local acceleration due to gravity can be estimated with an uncertainty of 0,005 %. The uncertainty in the gravitational term is neglected in the accuracy equations in B.2 to B.4.

The symbols, terms and units used in the inventory accuracy equations below are as follows:

Symbol	Term	Units
L	ALG innage reading	m
p_1	Reading of pressure sensor P_1	Pa
p_3	Reading of pressure sensor P_3	Pa
t	Reading of ATT temperature sensor	°C
Z	Offset of P_1 from tank datum plate ($= h_o + h_b$)	m
D_v	Vapour 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 is a hypothetical actual density, which is the same as observed density if there are 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 ALG level measurement	m
$U_{P1\text{-zero}}$	Uncertainty of P_1 when no pressure is applied	Pa
$U_{P1\text{-linearity}}$	Uncertainty of P_1 related to applied pressure	(fraction of reading)
$U_{P1\text{-total}}$	Total uncertainty of P_1 (combination of zero error and linearity)	Pa
$U_{P3\text{-zero}}$	Uncertainty of P_3 when no pressure is applied	Pa
$U_{P3\text{-linearity}}$	Uncertainty of P_3, related to applied pressure	(fraction of reading)
$U_{P3\text{-total}}$	Total uncertainty of P_3 (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	Constants of thermal expansion factor defined by ISO 91-1	
F_{Q}	Tank geometry factor. (F_{Q} = 1,0 for vertical cylindrical tanks) (see B.5 for equations)	

The uncertainty examples, as given in this Annex, neglect the four following uncertainty sources because of their minor effect: gravity (g); ambient air density D_{a}; vapour density D_{v} and distance h_{t}.

The uncertainty examples given in B.2 to B.6 each consist of several cases, which are intended to represent examples of configurations of HTMS. In each case, the maximum allowable uncertainty of measurement for each parameter, which contributes uncertainty to the final measurement, is used. The cases are 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.

B.2 Accuracy equation for observed density

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

$$U_D = \sqrt{\frac{U_{\text{P1-total}}{}^2 + U_{\text{P3-total}}{}^2}{g^2 D^2 \left(L - Z\right)^2} + \frac{U_L{}^2 + U_Z{}^2}{\left(L - Z\right)^2} \times \frac{\left(D - D_{\text{v}}\right)^2}{D^2}} \times 100 \text{ with}$$

$$U_{\text{P1-total}} = U_{\text{P1-zero}} + p_{\text{1applied}} \times U_{\text{P1-linearity}}$$

$$p_{\text{1applied}} = g\left(L - Z\right) D + g\left[h_{\text{t}} - \left(L - Z\right)\right] D_{\text{v}} + p_{\text{3max}} - g\, h_{\text{t}}\, D_{\text{v}} \approx g\left(L - Z\right)\left(D - D_{\text{v}}\right) + p_{\text{3max}}$$

$$U_{\text{P1-total}} = U_{\text{P1-zero}} + \left[g\left(L - Z\right)\left(D - D_{\text{v}}\right) + p_{\text{3max}}\right] \times U_{\text{P1-linearity}}$$

$$U_{\text{P3-total}} = U_{\text{P3-zero}} + p_{\text{3max}} \times U_{\text{P3-linearity}}$$

Examples of calculations are given in Tables B.1 and B.2.

Table B.1 — Example of observed density accuracy – Floating roof tank

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**
P_1 zero error ($U_{\text{P1-zero}}$)	[Pa]	50	100	50
linearity error ($U_{\text{P1-linearity}}$)	[fraction of reading]	0,000 7	0,001 0	0,000 7
U_L	[m]	0,004	0,004	0,012
U_Z	[m]	0,003	0,003	0,003
Observed density accuracy [± % of reading]				
Vertical cylindrical tank				
L = 4 m		0,283	0,480	0,411
L = 10 m		0,149	0,246	0,188
L = 16 m		0,118	0,190	0,138

Table B.2 — Example of observed density accuracy – Fixed roof tank

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					
p_{3max} = 5 000 Pa					
Sensor or measurement uncertainty					
			Case 1	**Case 2**	**Case 3**
P_1 zero error	($U_{P1\text{-zero}}$)	[Pa]	50	100	50
linearity error	($U_{P1\text{-linearity}}$)	[fraction of reading]	0,000 7	0,001 0	0,000 7
P_3 zero error	($U_{P3\text{-zero}}$)	[Pa]	24	40	24
linearity error	($U_{P3\text{-linearity}}$)	[fraction of reading]	0,002	0,005	0,002
U_L		[m]	0,004	0,004	0,012
U_Z		[m]	0,003	0,003	0,003
Observed density accuracy [± % of reading]					
Vertical cylindrical tank					
L = 4 m			0,294	0,498	0,418
L = 10 m			0,151	0,248	0,190
L = 16 m			0,118	0,190	0,138
Spherical tank, diameter = 20 m					
L = 4 m			0,294	0,498	0,418
L = 10 m			0,151	0,248	0,190
L = 16 m			0,118	0,190	0,138
Horizontal cylindrical tank, diameter = 4 m					
L = 1 m			1,194	2,050	1,849
L = 2 m			0,560	0,957	0,841
L = 3,5 m			0,330	0,561	0,476

B.3 Accuracy equation for mass

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

$$U_m = \sqrt{\left[\frac{U_L}{L}\left(F_\mathrm{Q} - \frac{L}{L-Z} \times \frac{D-D_\mathrm{v}}{D}\right)\right]^2 + \frac{{U_\text{P1-total}}^2 + {U_\text{P3-total}}^2}{g^2 D^2 (L-Z)^2} + \frac{{U_Z}^2}{(L-Z)^2} \times \frac{(D-D_\mathrm{v})^2}{D^2} + {U_\mathrm{AE}}^2} \times 100$$

$$U_\text{P1-total} = U_\text{P1-zero} + p_\text{1applied} \times U_\text{P1-linearity}$$

$$p_\text{1applied} = g\,(L-Z)\,D + g\,\{h_\mathrm{t} - (L-Z)\}\,D_\mathrm{v} + p_\text{3max} - g\,h_\mathrm{t}\,D_\mathrm{a} \approx g\,(L-Z)\,(D-D_\mathrm{v}) + p_\text{3max}$$

$$U_\text{P1-total} = U_\text{P1-zero} + \{g\,(L-Z)\,(D-D_\mathrm{v}) + p_\text{3max}\} \times U_\text{P1-linearity}$$

$$U_\text{P3-total} = U_\text{P3-zero} + p_\text{3max} \times U_\text{P3-linearity}$$

Examples of calculations are given in Tables B.3 and B.4. These examples apply to static conditions (i.e. product level and temperature are constant) and are not to be confused with transfer accuracy.

Table B.3 — Example of mass measurement accuracy – Floating roof tank

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**
P$_1$ zero error linearity error	($U_\text{P1-zero}$) ($U_\text{P1-linearity}$)	[Pa] [fraction of reading]	50 0,000 7	100 0,001 0	50 0,000 7
U_L		[m]	0,004	0,004	0,012
U_Z		[m]	0,003	0,003	0,003
U_AE		(fractional uncertainty)	0,001	0,001	0,001
Mass measurement accuracy [± % of reading]					
Vertical cylindrical tank					
L = 4 m			0,281	0,479	0,282
L = 10 m			0,175	0,262	0,175
L = 16 m			0,153	0,213	0,152

Table B.4 — Example of mass measurement 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

p_{3max} = 5 000 Pa

				Case 1	Case 2	Case 3
Sensor or measurement uncertainty						
P_1	zero error	($U_{P1\text{-zero}}$)	[Pa]	50	100	50
	linearity error	($U_{P1\text{-linearity}}$)	[fraction of reading]	0,000 7	0,001 0	0,000 7
P_3	zero error	($U_{P3\text{-zero}}$)	[Pa]	24	40	24
	linearity error	($U_{P3\text{-linearity}}$)	[fraction of reading]	0,002	0,005	0,002
U_L			[m]	0,004	0,004	0,012
U_Z			[m]	0,003	0,003	0,003
U_{AE}			(fractional uncertainty)	0,001	0,001	0,001
Mass measurement accuracy [± % of reading]						
Vertical cylindrical tank						
L = 4 m				0,293	0,497	0,293
L = 10 m				0,177	0,265	0,177
L = 16 m				0,153	0,213	0,153
Spherical tank, diameter = 20 m						
L = 4 m				0,303	0,501	0,377
L = 10 m				0,178	0,265	0,186
L = 16 m				0,153	0,213	0,153
Horizontal cylindrical tank, diameter = 4 m						
L = 1 m				1,091	1,992	1,106
L = 2 m				0,524	0,937	0,533
L = 3,5 m				0,325	0,557	0,336

B.4 Accuracy equation for standard volume

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

$$U_{V\mathrm{s}} = \sqrt{\left[\left(F_{\mathrm{Q}} \times \frac{U_L}{L}\right)^2 + \left(U_{\mathrm{AE}}\right)^2 + \left(\frac{K_1}{D_{15}} + 2\,\frac{K_0}{D_{15}^2}\right)^2 \times \left(t - t_{\mathrm{ref}}\right)^2 \times \left(U_{D15}\right)^2 + \alpha^2 U_t{}^2\right]} \times 100$$

Examples of calculations are given in Tables B.5 and B.6. These examples apply to static conditions (i.e. product level and temperature are constant) and are not to be confused with transfer accuracy.

Table B.5 — Example of standard volume measurement accuracy – Floating roof tank

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**
U_L	[m]	0,004	0,004	0,012
U_t	[°C]	0,5	0,5	1,0
U_{AE}	(fractional uncertainty)	0,001	0,001	0,001
U_{D15}	(fractional uncertainty)	0,005	0,005	0,005
	Standard volume measurement accuracy [± % of reading]			
Vertical cylindrical tank				
L = 4 m		0,154	0,154	0,338
L = 10 m		0,126	0,124	0,197
L = 16 m		0,120	0,120	0,174

Table B.6 — Example of standard volume measurement accuracy – Fixed roof tank

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**
U_L	[m]	0,004	0,004	0,012
U_t	[°C]	0,5	0,5	1,000
U_{AE}	(fractional uncertainty)	0,001	0,001	0,001
U_{D15}	(fractional uncertainty)	0,005	0,005	0,005
Standard volume measurement accuracy [± % of reading]				
Vertical cylindrical tank				
$L = 4$ m		0,147	0,147	0,327
$L = 10$ m		0,116	0,116	0,177
$L = 16$ m		0,111	0,111	0,150
Spherical tank, diameter = 20 m				
$L = 4$ m		0,214	0,214	0,569
$L = 10$ m		0,124	0,124	0,222
$L = 16$ m		0,111	0,111	0,145
Horizontal cylindrical tank, diameter = 4 m				
$L = 1$ m		0,574	0,574	1,697
$L = 2$ m		0,277	0,277	0,775
$L = 3{,}5$ m		0,141	0,141	0,302

B.5 Tank geometry factor, F_{Q}

The factor F_{Q} is used to adjust accuracy equations given in B.3 (mass) and B.4 (standard volume) for difference in tank geometry.

B.5.1 Upright vertical cylindrical tanks

$$F_{\text{Q}} = 1{,}0$$

B.5.2 Spherical tanks (of internal diameter d_{i})

$$F_{\text{Q}} = \frac{6 - 6\left(\dfrac{L}{d_{\text{i}}}\right)}{3 - 2\left(\dfrac{L}{d_{\text{i}}}\right)}$$

B.5.3 Horizontal cylindrical tanks (of internal diameter d_i)

$$F_\text{Q} = \frac{2\left(\frac{L}{d_\text{i}}\right)^2 \sqrt{\frac{d_\text{i}}{L} - 1}}{0{,}25 \text{ arccos}\left[1 - 2\left(\frac{L}{d_\text{i}}\right)\right] + \left(\frac{L}{d_\text{i}} - 0{,}5\right) \times \sqrt{\frac{L}{d_\text{i}} - \left(\frac{L}{d_\text{i}}\right)^2}}$$

B.6 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 as follows.

- Define the following two constants (A and B) to simplify the equation for h_min:

$$A = U_\text{P1-zero} + p_\text{3max} \times U_\text{P1-linearity}$$

$$B = (U_\text{P1-zero} + p_\text{3max} \times U_\text{P3-linearity})^2 + (g^2 \times U_L{}^2 + g^2 \times U_Z{}^2) \times (D - D_\text{v})^2$$

- Calculate h_min from the following equation:

$$L = Z + \frac{A \times (D - D_\text{v}) \times U_\text{P1-linearity} + \sqrt{A^2 \times U_D{}^2 \times D^2 + \left[D^2 \times U_D{}^2 - (D - D_\text{v})^2 \times U_\text{P1-linearity}{}^2\right] \times B}}{g \times \left[D^2 \times U_D{}^2 - (D - D_\text{v})^2 \times U_\text{P1-linearity}{}^2\right]}$$

Examples of h_min calculations are given in Tables B.7 and B.8.

Table B.7 — Example of h_min calculation – Floating roof tank

Product: Gasoline in floating roof 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**
P_1 zero error (U$_\text{P1-zero}$)	[Pa]	50	100	50
linearity error (U$_\text{P1-linearity}$)	[fraction of reading]	0,000 7	0,001 0	0,000 7
U_L	[m]	0,004	0,004	0,012
U_Z	[m]	0,003	0,003	0,003
		h_min (m)		
Vertical cylindrical tank				
Uncertainty density = 0,2 %		6,31	14,38	9,24
Uncertainty density = 0,3 %		3,73	7,37	5,64
Uncertainty density = 0,5 %		2,12	3,81	3,26
Uncertainty density = 1,0 %		1,10	1,82	1,67

Table B.8 — Example of h_{min} calculation – Fixed roof tank

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

$p_{3\ max}$ = 5 000 Pa

Sensor or measurement uncertainty

			Case 1	**Case 2**	**Case 3**
P$_1$ zero error	($U_{P1\text{-zero}}$)	[Pa]	50	100	50
linearity error	($U_{P1\text{-linearity}}$)	[fraction of reading]	0,0007	0,0010	0,0007
P$_3$ zero error	($U_{P3\text{-zero}}$)	[Pa]	24	40	24
linearity error	($U_{P3\text{-linearity}}$)	[fraction of reading]	0,002	0,005	0,002
U_L		[m]	0,004	0,004	0,012
U_Z		[m]	0,003	0,003	0,003
			h_{min} (m)		
(Independent of tank geometry)					
Uncertainty density = 0,2 %			6,54	14,44	9,35
Uncertainty density = 0,3 %			3,91	7,57	5,74
Uncertainty density = 0,5 %			2,24	3,99	3,33
Uncertainty density = 1,0 %			1,16	1,92	1,70

B.7 Effect on Volume Correction 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.9 and B.10.

For heavy oils such as crude oil, the change in VCF is less sensitive to the error on product density, as can be seen in Tables B.9 and B.10.

Table B.9 — Example – Effect on Volume Correction Factor (VCF) for a crude oil due to uncertainty of density

Basis: Product temperature = 20 °C "True" density is 885 kg/m^3

VCF Table: ISO 91-1:1992, Table 54A

Density at 15 °C (kg/m^3)	881,5	882,3	885,0	887,7	888,5	889,4	891,6	892,1	893,9
Uncertainty (% reading)	− 0,40	− 0,30	0,00	0,30	0,40	0,50	0,75	0,80	1,00
VCF computed	0,996 0	0,996 1	0,996 1	0,996 1	0,996 1	0,996 1	0,996 1	0,996 1	0,996 2

Table B.10 — Example – Effect on Volume Correction Factor (VCF) for a refined product due to uncertainty of density

Basis: Product temperature = 20 °C “True” density is 745,0 kg/m^3 VCF Table: ISO 91-1:1992, Table 54B										
Density at 15 °C (kg/m^3)	739,0	739,4	741,3	742,0	742,8	745,0	745,8	746,5	746,9	747,2
Uncertainty (% reading)	– 0,80	– 0,75	– 0,50	– 0,40	– 0,30	0,00	0,10	0,20	0,25	0,30
VCF computed	0,993 8	0,993 9	0,993 9	0,993 9	0,993 9	0,993 9	0,993 9	0,993 9	0,993 9	0,994 0

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