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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

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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*

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.

