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Petroleum and liquid petroleum products — Direct static measurements — Measurement of content of vertical storage tanks by hydrostatic tank gauging

Pétrole et produits pétroliers liquides — Mesurage statique direct — Mesurage du contenu des réservoirs verticaux de stockage par jaugeage hydrostatique des réservoirs

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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 11223 was prepared by Technical Committee ISO/TC 28, *Petroleum products and lubricants*, Subcommittee SC 3, *Static petroleum measurement*.

This first edition of ISO 11223 cancels and replaces ISO 11223-1:1995, which has been technically revised.

Introduction

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

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

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

The term “mass” is used in this International Standard to indicate mass in vacuum (true mass). In the petroleum industry, it is not uncommon to use apparent mass (in air) for commercial transactions.

INTERNATIONAL STANDARD **ISO 11223:2004(E)**

Petroleum and liquid petroleum products — Direct static measurements — Measurement of content of vertical storage tanks by hydrostatic tank gauging

1 Scope

This International Standard gives guidance on the selection, installation, commissioning, maintenance, validation and calibration of hydrostatic tank-gauging (HTG) systems for the direct measurement of static mass in petroleum storage tanks. It is intended to cover custody transfer applications, although details of other, less accurate, measurements are included for information. It also gives guidance on calculations of standard volume from measured mass and independently measured reference density. Information is also included on measurements of observed and standard volume using density measured by the HTG system itself.

This International Standard is applicable to hydrostatic tank-gauging systems which use pressure sensors with one port open to the atmosphere. It is applicable to the use of hydrostatic tank gauging on vertical, cylindrical, atmospheric storage tanks with either fixed or floating roofs.

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

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 degrees C and 60 degrees F*

ISO 91-2:1991, *Petroleum measurement tables — Part 2: Tables based on a reference temperature of 20 degrees C*

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

ISO 3170:2004, *Petroleum liquids — Manual sampling*

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

ISO 3838:2004, *Crude petroleum and liquid or solid petroleum products — Determination of density or relative density — Capillary-stoppered pyknometer and graduated bicapillary pyknometer methods*

ISO 3993:1984, *Liquefied petroleum gas and light hydrocarbons — Determination of density or relative density — Pressure hydrometer method*

ISO 4266-4:2002, *Petroleum and liquid petroleum products — Measurement of level and temperature in storage tanks by automatic methods — Part 4: Measurement of temperature in atmospheric tanks*

ISO 4267-2:1988, *Petroleum and liquid petroleum products — Calculation of oil quantities — Part 2: Dynamic measurement*

ISO 4268:2000, *Petroleum and liquid petroleum products — Temperature measurements — Manual methods*

ISO 4512:2000, *Petroleum and liquid petroleum products — Equipment for measurement of liquid levels in storage tanks — Manual methods*

ISO 7078:1985, *Building construction — Procedures for setting out, measurement and surveying — Vocabulary and guidance notes*

ISO 7507-1:2003, *Petroleum and liquid petroleum products — Calibration of vertical cylindrical tanks — Part 1: Strapping method*

ISO 9857:—[1] *Petroleum and liquid petroleum products — Continuous density measurement*

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

IEC 60079-0:2004, *Electrical apparatus for explosive gas atmospheres — Part 0: General requirements*

API, *Manual of Petroleum Measurement Standards Chapter 3 — Tank Gauging Section 1A — Standard Practice for the Manual Gauging of Petroleum and Petroleum Products*, First Edition

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
ambient air density
density of ambient air at the tank side on which the pressure sensors are mounted

3.2
ambient air temperature
representative temperature of the ambient air at the tank side on which the HTG pressure sensors are mounted

3.3
apparent mass in air
value obtained by weighing in air against standard masses without making correction for the effect of air buoyancy on either the standard masses or the object weighed

[ISO 3838]

3.4
capacity table
table, often referred to as a tank table or a tank calibration table, showing the capacities of, or volumes in a tank corresponding to various liquid levels measured from a stable reference point

[ISO 7507-1]

3.5
critical zone height
upper limit of the critical zone; the level at which one or more of the floating-roof or floating-blanket legs first touch the tank bottom

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[1] To be published.

3.6
critical zone
level range through which the floating roof or floating blanket is partially supported by its legs

3.7
density
mass of the substance divided by its volume

[ISO 3838]

NOTE When reporting the density, it is necessary to explicitly state the unit of density used, together with the temperature. The standard reference temperature for international trade in petroleum and its products is 15 °C (see ISO 5024). Other reference temperatures might be required for legal metrology or other special purposes (see ISO 3993).

3.8
dip
innage
depth of a liquid in a tank

[adapted from ISO 7507-1]

3.9
dipped volume
observed volume of product, sediment and water, calculated from the dip level and the tank capacity table

3.10
fixed-roof tank
vertical cylindrical storage vessel with either a cone- or domed-shaped roof of either the non-pressurized (freely vented) type or the low-pressure type

[ISO 1998]

3.11
floating blanket
cover
screen
light-weight cover of either metal or plastic material designed to float on the surface of the liquid in a fixed-roof tank

NOTE The blanket is used to retard the evaporation of volatile products in a tank.

[adapted from ISO 7507-1]

3.12
floating-roof mass
value of the floating-roof mass, inclusive of any mass load on the roof, manually entered in the data processor

3.13
floating-roof tank
tank in which the roof floats freely on the surface of the liquid contents except at low levels when the weight of the roof is taken, through its supports, by the tank bottom

[ISO 7507-1]

3.14
free-water level
level of any water and sediment that exist as a separate layer underneath the product

3.15
gross standard volume
volume of oil, including dissolved water, suspended water and suspended sediment, but excluding free water and bottom sediment, calculated at standard conditions

3.16
head mass
total measured mass between the HTG bottom sensor and the top of the tank

3.17
heel space
space inside the tank, below the bottom HTG sensor

3.18
HTG reference point
stable reference point from which the HTG sensor positions are measured

3.19
hydrostatic tank gauging
HTG
method of direct measurement of liquid mass in a storage tank based on measuring static pressures caused by the liquid head above the pressure sensor

3.20
in-tank vapour density
density of the gas or vapour (mixture) in the ullage space at the observed conditions of product temperature and pressure

3.21
observed density
value obtained at a test temperature which differs from the calibration temperature of the apparatus

[adapted from ISO 3838]

3.22
pin height
lower limit of the critical zone, i.e. the level at which the floating roof or floating blanket rests fully on its legs

3.23
product heel mass
mass of product below the bottom HTG sensor

3.24
product heel volume
observed volume of product below the bottom HTG sensor, calculated by subtracting the water volume from the total heel volume

3.25
product mass
sum of the head mass and the product heel mass, reduced by the floating-roof mass (if applicable) and the vapour mass

3.26
product temperature
temperature of the tank liquid in the region where the HTG measurements are performed

3.27
reference density
density at the reference temperature

3.28
reference temperature
temperature to which reference density and standard volumes are referred

3.29
tank average cross-sectional area
average cross-sectional area between the level of the bottom HTG sensor and the dip level, over which the hydrostatic pressures are integrated in order to obtain the head mass

3.30
tank lip
tank bottom plate on the outside of the tank shell

3.31
tank shell
outer casing of a storage tank that on land is secured to the ground and includes the roof, if it is a **fixed-roof tank** (3.10)

3.32
total heel volume
observed volume below the bottom HTG sensor, calculated from the level of the bottom sensor and the tank capacity table, corrected for observed temperature

3.33
total volume
indicated volume, including all water and sediment without correction for temperature and pressure.

[adapted from ISO 4267-2]

3.34
ullage pressure
absolute pressure of the atmosphere (air or vapour) inside the tank, above the product

3.35
vapour relative density
ratio of molecular mass of vapour (mixture) to that of air (mixture)

3.36
water volume
observed volume of free sediment and water, calculated from the free water level and the tank capacity tables

3.37
ullage
outage
capacity of the tank not occupied by the liquid

[ISO 7507-1]

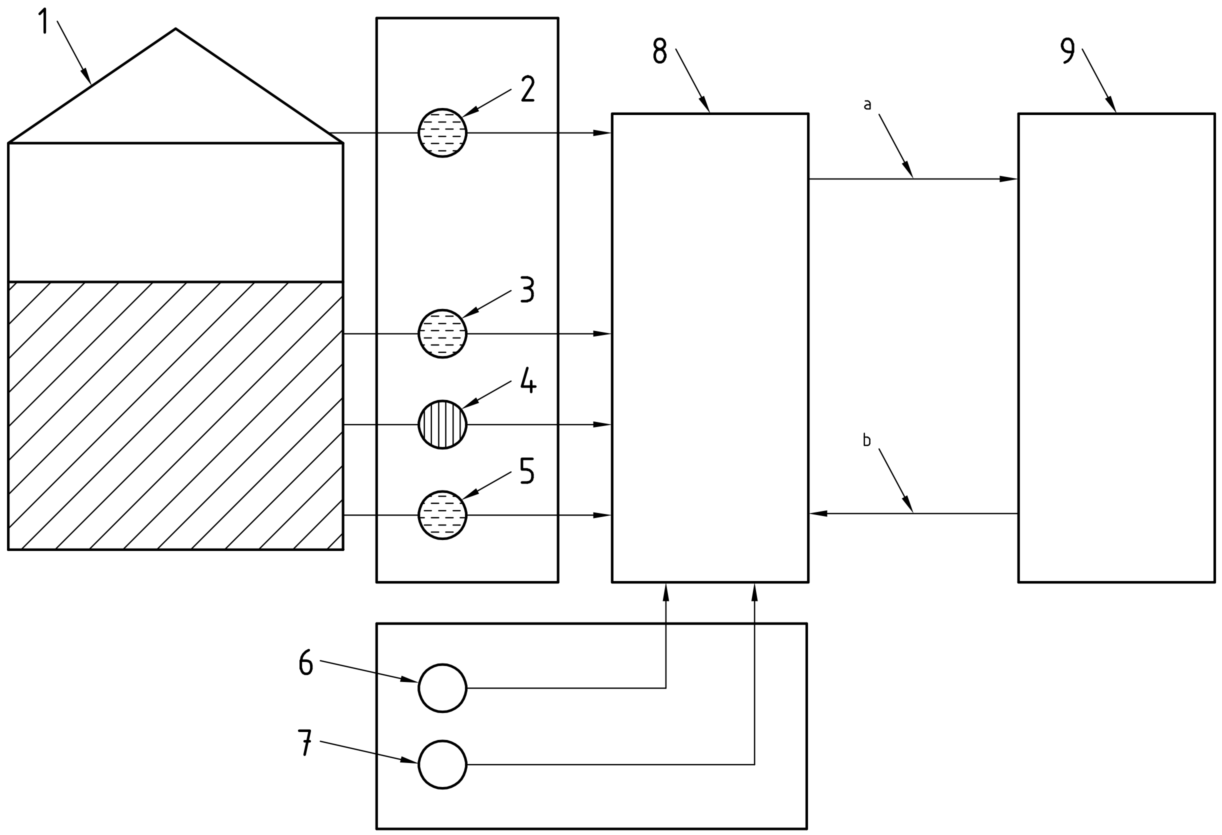
3.38
uncertainties
unless stated otherwise, all uncertainties, including maximum permissible errors, are assumed to be extended uncertainties with coverage factor $k = 2$

4 System description

4.1 General

A hydrostatic tank gauging (HTG) system is a static mass-measuring system. It uses pressure and temperature inputs, the parameters of the tank and of the stored liquid to compute the mass of the tank contents and other variables as described in Table 1 and Annex A (see Figure 1).

Determination of the other variables shown in brackets in Figure 1 is not included in the scope of this International Standard. However, information on them is given in Annexes B and C.



Key

1 storage tank

2 sensor P3 (ullage pressure)

3 sensor P2 (density measurements)

4 liquid temperature sensor

5 sensor P1 (liquid head measurements)

6 ambient pressure sensor

7 ambient temperature sensor

8 HTG processor (calculations)

9 HTG interface (display, printing, configuration, control)

[a] Calculated outputs: mass (volume, density, level).

[b] Input parameters: tank, ambient, sensor, liquid.

Figure 1 — HTG system — Functional diagram

4.2 Sensors

4.2.1 Pressure sensors

The hydrostatic tank gauging (HTG) system consists of up to three pressure sensors mounted on the tank shell. An ambient air pressure sensor (Pa) may be installed for measurements requiring high accuracy.

Sensor P1 is installed at or near the tank bottom.

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

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

4.2.2 Temperature sensors

Temperature sensors may be included to measure the temperature of the tank contents (T) and of the ambient air (T_a).

The tank content (product) temperature is needed for

a) calculation of volumetric expansion of the tank shell;

b) calculation of reference density from observed density (used in HTG systems which calculate level and density as well as mass).

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

The ambient air temperature is needed for

a) calculation of ambient air density;

b) calculation of volumetric expansion of the tank shell;

c) corrections for thermal expansion of the tie bars to sensor P1 and between sensors P1 and P2.

4.2.3 System configuration

4.2.3.1 General

The sensor configurations vary depending on the application and data required. Some of the more common variations are as described in 4.2.3.2 to 4.2.3.5.

4.2.3.2 Known liquid density

Sensor P2 is normally used for the automatic measurement of the tank liquid density. It is not required if the average liquid density is known.

4.2.3.3 Known ullage pressure

Sensor P3 is not required for those tanks which are vented to atmosphere (the ullage gauge pressure equals 0). This includes all floating-roof tanks and all fixed-roof tanks that are freely vented or that have gauging hatches that are not sealed.

NOTE 1 Tanks with pressure/vacuum (PV) relief valves are not considered as vented to atmosphere for the purposes of hydrostatic gauging. Their ullage pressures normally vary more than the expected uncertainties of pressure measurements.

NOTE 2 Tank ullage pressure on atmospheric fixed-roof tanks might differ slightly from atmospheric pressure during transfers to and from the tank. Since inventory measurements are not taken during a transfer, errors due to this effect are not significant.

If the ullage pressure is known, pressure p_3 may be entered into the data processor as a constant and sensor P3 omitted on non-vented tanks.

4.2.3.4 Known tank liquid temperature

Tank liquid and ambient temperatures are used to correct for shell thermal expansion. The tank liquid temperature sensor is not required for mass measurement if the temperature of the liquid in the tank is known (see ISO 4266-4 or ISO 4268).

4.2.3.5 Varying atmospheric conditions

Ambient temperature and pressure sensors may be used to remove secondary errors for measurements requiring high accuracy. Single measurements of ambient air temperature and pressure may be used for all tanks at the same location.

4.3 HTG data processor

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

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

NOTE The data processor can also calculate level, observed and standard volumes, and observed and reference densities. These calculations are given for information in Annex A.

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

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

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

Computations normally performed by the data processor are described in Annex A

Table 1 — Stored parameters for HTG data processing

Parameter group	Parameter	Remarks
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	Two thermal expansion constants (see ISO 7507-1)
	Tank capacity table	Volumes at given levels
	Tank calibration temperature	Temperatures to which the tank capacity table was corrected
HTG sensor data	Sensor configuration	Tank with 1, 2 or 3 sensors
	HTG reference point height	To tank calibration datum point
	P1 sensor height	To HTG reference point
	P2 sensor height	Referenced to P1
	P3 sensor height	Referenced to P1
Liquid data	Liquid density	If no P2 sensor
	Liquid expansion coefficients	See ISO 91-1 and ISO 91-2
	Free water level	—
Ambient data	Local acceleration due to gravity	Obtained from a recognized source
	Ambient temperature	Optional
	Ambient pressure	Optional

5 Installation and initial commissioning

5.1 Pressure sensors

5.1.1 Selection of pressure sensors

The pressure sensors should be selected in accordance with the uncertainty calculation. The maximum permissible errors for custody transfer applications are given in Table 2. These figures are considered to be extended uncertainties with a coverage factor $k = 2$.

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

Maximum permissible error of pressure sensors			
P1		**P3** [a]	
Zero error Pa	**Linearity error** % of reading	**Zero error** Pa	**Linearity error** % of reading
± 50	± 0,07	± 24	± 0,2

[a] If P3 is used.

The range of pressure sensor P3 may be much smaller than that chosen for pressure sensor P1 because the gauge vapour pressure is typically limited to a maximum of approximately 5 kPa.

Zero and linearity errors should be assessed independently of one another. The requirements for linearity errors also apply to differences in readings for a single pressure sensor.

The combination of zero and linearity errors influences the uncertainties of inventory measurements.

For transfers, uncertainties are those of pressure differences between the start and the end of transfers. Zero errors (partly) cancel out and transfer uncertainties are primarily those of linearity.

Analogue or digital sensor output should be selected as appropriate in order to meet the accuracy requirements.

5.1.2 Tank preparation

5.1.2.1 General

Prior to installation of the HTG pressure sensors, it is necessary to perform the activities given in 5.1.2.2 to 5.1.2.5.

5.1.2.2 Selection of sensor positions

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

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

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

Pressure sensor P2, if used, is located a vertical distance H above sensor P1. The maximum P2-to-P1 vertical distance is not specified, the restricting factor being that when the liquid level drops below sensor P2, the observed density can no longer be measured. The minimum P2-to-P1 vertical distance depends on the requirements for density measurement accuracy and on the sensor performance. Usually, sensor P2 is installed approximately 2 m to 3 m above sensor P1.

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

5.1.2.3 Process taps

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

5.1.2.4 HTG reference point

The location of the HTG reference point for each tank should be established. If necessary, the height of the HTG reference point for each tank may be referred to the tank calibration datum point using optical-surveying techniques (see ISO 7078).

5.1.2.5 Tie bars

Tie bars are used to prevent excessive movement of the HTG pressure sensors relative to the HTG reference point due to bulging of the tank as the tank is filled (see 5.1.4 and Annex D). The need for tie bars may be assessed by direct measurement on the tanks or from an assessment of the tank construction parameters. If they are necessary, a detailed technical evaluation should be undertaken as to the number and the design of the tie bars.

5.1.3 Pressure sensor installation

5.1.3.1 Process connections

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

5.1.3.2 Protection against overpressure

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

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

5.1.4 Determination of pressure sensor position

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

The uncertainties of the sensor positions and those of the distances between sensors are important for achieving a high accuracy of HTG measurement. Guidelines for distance measurement uncertainties are as follows.

a) P1 sensor height, H_b, above the HTG reference point is used to calculate the tank bottom mass. The uncertainty of the P1 height measurement should not exceed 1 mm.

b) P1-to-P2 vertical distance, H, is used to calculate the observed density, which in turn is used to calculate the heel mass. The uncertainty of the vertical distance P1-to-P2 should not exceed 1 mm.

c) P1-to-P3 vertical distance, H_t, is used to calculate the magnitude of vapour mass and the effects of ambient air. Both the vapour mass and the ambient air are secondary correction factors which are subject to a number of approximations. The uncertainty of the vertical height, H_t, should not exceed 50 mm.

5.1.5 Limitation of pressure sensor movement

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

Changes in sensor P1 height will have a direct effect on measured mass and should therefore be minimized. Sensor P1 is normally mounted on the lower part of the tank where the movements of the tank shell are small (tank datum plates fixed to the tank shell may incur similar movements). The height of sensor P1 above the HTG reference point should be measured with the tank full and again with the tank empty. If the height changes by more than 1 mm, a tie bar should be fitted which holds the P1 pressure sensor a constant vertical distance above the HTG reference point.

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

HTG sensor movement is described in D.1. If any tie bars are used, the pressure-sensor connections to the tank should be made flexible enough to satisfy the mechanical safety requirements. The tie bar should be fitted to the process end of the pressure sensors to avoid over-stressing the sensors.

5.1.6 Wind effect

Wind impacting the tank causes variations in the static ambient air pressure. Depending on local circumstances, the ambient air pressure may be different at P1, P2 and P3. Since the sensors measure gauge pressures (referenced to atmosphere), wind-induced differences in ambient pressures at each of the sensors will cause additional measurement errors.

Wind effects will be minimal when all three pressure sensors are mounted on one side of the tank, in a vertical straight line.

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

If sensor P3 is not used, variations in the P1 ambient pressure reading will have a direct impact on the HTG mass measurement accuracy (note that atmospheric tanks do not require P3). If the HTG installation is exposed to strong winds, the outside port of the sensor P1 should be connected to a pipe which slopes down and away from the tank and is open at a point where the ambient pressure variations due to wind are minimal. A minimum distance of 0,5 m away from the tank at ground level is recommended.

5.1.7 Thermal effect

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

a) elimination of temperature gradients through the sensor bodies;

b) maintaining the sensors at constant temperatures.

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

5.1.8 Uncertainties of pressure measurements

Outputs of pressure sensors are subject to measurement uncertainties whose magnitude may vary with operating conditions (e.g. the hydrostatic head, liquid temperature as well as ambient conditions, such as ambient air temperature).

The uncertainty of a pressure sensor will normally exhibit zero and linearity components. The zero component is absolute in character, normally expressed in the units of measurement (pascal in SI units). It remains unchanged through the measuring range. The linearity component will vary with measured pressure and is typically expressed as a relative figure, e.g. as a percentage of the pressure reading. The manufacturer should unambiguously state both the zero and linearity uncertainties and their variations over the anticipated operating ranges, in particular over the ranges of the temperature sensors. This is to enable the user to verify that the contribution of the pressure sensor will result in an acceptable overall uncertainty of HTG measurement(s) (see Table 2 for maximum permissible zero and linearity errors).

The total absolute uncertainty of a pressure sensor may be calculated from Equation (1):

$$up_{\text{total}} = up_{\text{zero}} + \left(\frac{p_{\text{applied}} \times up_{\text{linearity}}}{100} \right) \tag{1}$$

where

up_{total} is the total absolute uncertainty, expressed, for example, in pascals, of the pressure sensor;

up_{zero} is the absolute zero component, expressed, for example, in pascals, of pressure sensor uncertainty;

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

$up_{\text{linearity}}$ is the relative linearity component, expressed in percent of p_{applied}, of pressure sensor uncertainty.

NOTE 1 The applied pressure $p_{\text{1-applied}}$ is approximately the sum of the liquid head above the P1 level, the vapour head and the pressure p_3.

NOTE 2 The applied pressure $p_{\text{2-applied}}$ is approximately the sum of the liquid head above the P2 level, the vapour head and the pressure p_3.

NOTE 3 The applied pressure $p_{\text{3-applied}}$ is approximately equal to the vapour pressure, independent of the liquid level.

5.2 Temperature sensors

5.2.1 General

The temperature input to the data processor may be either automatic or manual. HTG systems are generally installed with a tank-temperature-measuring device (see ISO 4266-4) and may also include an ambient air temperature-measuring device.

If product or air temperature is determined by other means, the value(s) may be input manually to the HTG data processor.

5.2.2 Sensor positions

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

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

5.2.3 Uncertainty of temperature measurement

The accuracy of the measured temperature directly affects the reference density and standard volume accuracy. The accuracy of the temperature measurement has only a secondary effect on the accuracy of the mass, through thermal expansion of the tank shell, which has impact on the tank capacity table. In most cases, a single-point or spot temperature sensor (e.g. RTD) should be considered adequate.

Average tank shell temperature is required for calculation of the thermal expansion of the tank shell. It may be calculated as a weighted average of the temperature of the liquid on the inside and the ambient air on the outside of the shell.

The uncertainty of the measurement of the liquid temperature has two components:

- uncertainty $u_{\text{equipment}}$ of the total temperature measurement (sensor; transmitter and converter), normally available from the sensor manufacturer;
- uncertainty u_{grad} due to thermal gradients that are influenced by position of the sensor, thermal stratification in the process liquid, quality of the thermal contact with the liquid, etc. This is normally estimated between 1 °C for liquids stored at ambient conditions (with no or minimal thermal gradients) and 5 °C for tanks that contain heated liquids.

Overall uncertainty may be obtained from Equation (2):

$$u_{\text{total}} = (u_{\text{equipment}}{}^2 + u_{\text{grad}}{}^2)^{1/2} \qquad (2)$$

5.3 Reference points for the HTG system

5.3.1 HTG and level gauge references

The HTG reference point should be on the outside of the tank, directly under the sensor P1. The preferred reference point is the tank lip; if the tank lip is not accessible, the reference point may be a mark on the tank shell.

The HTG reference point allows installation of the pressure sensor(s) without having to measure their height(s) above the datum point inside the tank.

The HTG reference point differs from the level gauge reference. The level gauge reference is either a manual gauging datum point or the mark on the tank gauge hatch at a fixed distance above the manual-gauging datum point.

The vertical height between the HTG and level reference points should be used whenever comparisons are made between HTG measurements and manual measurement of level.

5.3.2 HTG and tank calibration reference

Tank calibration uses a reference point that does not coincide either with the level gauge reference or with the HTG reference point.

5.4 Commissioning

5.4.1 General

Commissioning is performed following HTG system installation. Some or all parts of the commissioning procedure may also be repeated if some or all of the HTG system is replaced after a hardware failure or a system update. Records should be kept of all data for future use during maintenance (Clause 6).

5.4.2 Establishment of HTG reference points

The vertical distances should be measured between the HTG reference point and

- tank calibration reference (datum) point, height H_0;
- level gauge reference (datum) point, height H_g.

The vertical distances should also be established between

- effective centre of pressure sensor P1 and the HTG reference point (height H_b);
- effective centres of sensors P1 and P2 (height H);
- effective centres of sensors P1 and P3 (height H_t).

All heights should be measured using a standard survey technique (for example ISO 7078).

5.4.3 HTG parameter entry

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

The height of the pressure sensor P1 above the tank calibration datum plate ($Z = H_0 + H_b$) as well as the heights of sensors P2 and P3 above sensor P1 (H and H_t, respectively) should then be entered into the HTG processor.

The height of the HTG reference point above the gauging reference point does not normally form part of calculations performed by the HTG processor.

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

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

5.4.4 Pressure-sensor zero adjustment

In order to check and adjust the pressure-sensor zero, the following procedure should be followed.

a) If the outside ports of the sensors are connected together to prevent wind effects, remove the connections when adjusting the sensor zeros.

b) Isolate the sensor from the tank by shutting the block valve; their bleed valve may need to be released at the same time in order to avoid over-ranging the sensor.

c) Remove all liquid from the process connection to the sensor by draining.

d) Vent to the atmosphere the process connection to the sensor.

e) Adjust the sensor zero following the manufacturer’s instructions.

f) After the adjustment, wait for 15 min and then monitor the zero reading of the sensor for approximately 2 min and make further adjustments, if necessary.

5.4.5 Tank-capacity table validation

Some tanks currently in service have been calibrated using out-of-date, non-standard methods. Highly accurate mass measurements assume a minimal error in the tank-capacity table. It is recommended that the tank-capacity table be verified for conformance with ISO 7507-1 and a new tank calibration performed, if necessary.

Capacity tables are normally derived from calibration reports that give break points in the volume/level table (see ISO 7507-1 for development of the tank calibration report).

The capacity table is subject to second-order influences (see D.2 and D.3).

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

5.4.6 Verification of HTG processor calculations

As part of the approval performed either by the manufacturer or by another qualified authority, the HTG processor calculations should be checked against manual calculations in order to verify the calculation algorithms and proper parameter entry.

The equipment user should verify that the calculations yield expected results with a given set of calculation parameters.

5.4.7 Checking against manual measurement

The values computed by the HTG system should be compared with those provided by manual measurements. As the uncertainties of HTG and manual measurements are comparable, the acceptable comparison is an interim action, for information only, and its results should be interpreted as follows.

If HTG and manual mass measurements agree, within the limits of the root of the mean squares (RMS) of the two uncertainties of the HTG and the manual measurements, then the HTG system may be assumed to be operating properly. If HTG and manual mass measurements do not agree, further investigation is required.

In any mass comparison between HTG and another mass measurement, it is important to ensure that due account is taken of the differences between mass in air (e.g. as measured by a weighbridge), and true mass. The user should ensure that the comparisons are made between masses of the same type, either mass in air (weight) or real mass (in vacuum).

5.4.8 Temperature-sensor checks

The readings of the temperature sensors (if used) should be compared to the temperature readings obtained via an alternative temperature-measurement device calibrated to the required accuracy (see ISO 4268) and traceable to relevant standards.

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

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

If the HTG and the reference temperatures do not agree within the limits of the root of the mean squares (RMS) of the two uncertainties, the HTG parameters (if any) should be adjusted or the sensor(s) replaced.

To estimate the uncertainty of temperature measurement used to correct for thermal expansion of the tank shell, the reading of the HTG temperature sensor read-out should be compared against temperature of the process liquid near the inside of the shell.

6 Maintenance

6.1 General

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

6.2 Validation

The objective of HTG validation is to show that the HTG system still works within the required accuracy and to allow use of statistical quality control to establish the frequency of recalibration, provided this is acceptable to parties involved in the custody transfer. Validation is usually performed on a regular basis, following the local code of practice, to monitor performance and to establish frequency of system calibration.

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

6.2.1 HTG sensor heights

HTG sensor heights should be compared with those obtained in 5.4.2 and any deviations recorded.

6.2.2 Pressure sensors

6.2.2.1 Zeros for the pressure sensors

Pressure sensor zeros should be verified *in situ* using the procedure described in 5.4.4, without any adjustments. The zero reading should not exceed the manufacturer’s specifications, nor the maximum recommended values of 50 Pa for p_1 and p_2, and 24 Pa for p_3. If the zero reading is greater than the maximum recommended values given above, and does not exceed the manufacturer’s specifications, the transmitter should be calibrated (see below). If the manufacturer’s specifications are exceeded, the manufacturer should be consulted. The “as-found” and “as-left” values of the zero reading should be documented.

6.2.2.2 Linearity

A single point on the transmitter measuring range should be verified *in situ* using a high-precision pressure calibrator traceable to a national standard. The linearity error should be judged from this single-point reading at maximum pressure and should not exceed the manufacturer’s specification, nor the maximum recommended values of 0,07 % of reading for p_1 and p_2, and 0,2 % of reading for p_3. If the manufacturer’s specifications are exceeded, the manufacturer should be consulted. The “as-found” and “as-left” values of the span reading should be documented.

For high-precision pressure transmitters, it might be difficult or impractical to span the transmitter under field conditions. In these circumstances, this procedure cannot be performed and the transmitter should be taken for verification to a certified laboratory.

6.2.3 On-tank measurements

If the comparison is to be carried out against a manual method, the procedure described in 5.4.7 should be followed.

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

Any of these comparisons should take into account the inventory uncertainties of the HTG, as well as those of the alternative measurement(s).

6.2.4 Off-tank measurements

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

a) volumetric flowmeter with online densitometer;

b) volumetric flowmeter with sampled line density;

c) mass flowmeter;

d) weighbridge.

Any of these comparisons should take into account the transfer uncertainties of the HTG as well as those of the off-tank measurements. Care should also be taken that the transfers involve transferred quantities that would normally be expected to be measured by static methods. The transfer uncertainties, expressed in percent of the transferred quantity, get bigger for smaller quantities. As a first approximation, the transfer should be equivalent to a change in level in excess of 2 m for a liquid with a density of 800 kg/m^3, or an equivalent that yields the same difference in hydrostatic pressures.

6.2.5 Temperature sensors

Temperature sensors should be checked using the procedure described in 5.4.8, without any adjustments.

6.2.6 Frequency of verification

The frequency of verification of major component of HTG should follow local practice. This International Standard recommends that the frequencies should be as follows.

a) The pressure sensor/transmitter(s) zero stability should be verified every three months following initial verification. The pressure sensor/transmitter(s) range stability should be verified every six months following initial verification.

b) The temperature sensor/transmitter should be verified every six months. If its performance is stable, the frequency may be reduced to once per year.

6.3 Calibration

6.3.1 General

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

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

Except for pressure-sensor zero, no sensor adjustments are normally possible. If the pressure sensors are found to be outside specification, they should be replaced.

6.3.2 HTG system parameters

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

6.3.3 Adjustment of pressure-sensor zero

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

If the sensor is found to be within the manufacturer's specification, the validation records should be used to determine the optimal magnitude of the pressure-sensor zero adjustment. The zero adjustment should be carried out using the procedure described in 5.4.4.

6.3.4 Temperature sensor calibration

The validation records should be examined and, if needed, further checks should be made as described in 5.4.6. The temperature sensors should be adjusted or replaced if found to be operating outside the limits established at commissioning (see 5.4.8).

6.3.5 Pressure-sensor calibration

6.3.5.1 General

Pressure-sensor calibration of the HTG mass measurement system is the only method for which calibration equipment may be obtained whose accuracy is sufficiently better than the accuracy of the HTG system itself.

If such equipment is not available, the HTG system may be calibrated to a lower accuracy using the method described in 6.3.6.

The accuracy of the mass measurement obtained by the HTG will correspond to the accuracy of its pressure sensors, providing that the pressure-sensor positions are known and stable and that the calculations are performed with the correct parameters (see 6.3.2).

Depending on which calibration equipment is available, one or the other of the methods described in 6.3.5.2 and 6.3.5.3 should be used.

6.3.5.2 Reference pressure source method

The reference device for calibration is a calibrated traceable dead-weight tester with a zero uncertainty of 20 Pa and a linearity uncertainty of 0,02 % of the reading, which is suitable for use in the field.

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

The pressure measurements from the HTG system are compared with those from the dead-weight tester. If the two readings differ by less than the values in Table 2, the contribution to mass error from the HTG sensors will be within the equipment specification. When carrying out the comparisons, due account should be taken of additional hydrostatic pressure heads in the connections between the dead-weight tester and the pressure sensor.

6.3.5.3 Reference pressure sensor method

The reference device for calibration is a calibrated traceable pressure sensor with a zero uncertainty of 20 Pa and a linearity uncertainty of 0,02 % of the reading, which is suitable for use in the field.

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

The pressure measurements from the HTG system are compared with those from the reference pressure sensor. If the two readings differ by less than the values in Table 2, then the contribution to mass error from the HTG sensors will be within the equipment specification. When carrying out the comparisons, due account should be taken of additional hydrostatic pressure heads in the connections between the reference pressure sensor and the pressure sensor under test.

6.3.6 Calibration by manual measurements on the tank

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

Standard procedures should be used to obtain manual measurements of level and temperature (API MPMS Chapter 3.1A), and density (ISO 3838 or ISO 3993), to calculate standard volume (ISO 4267-2) and reference density (ISO 91-1 and ISO 91-2). Mass should be calculated as the product of standard volume and reference density.

Calibration based on manual measurements can only be adequately performed by a transfer measurement where initial and final levels in a tank differ by at least 4 m, so that the uncertainty of the manual reference is much smaller than the expected uncertainty of HTG.

If the difference between the transferred mass measured by the HTG system and the transferred mass calculated from manual measurements, expressed as a percentage of the transferred mass calculated from the manual measurements, is less than 0,25 %, the HTG system should be assumed to be operating correctly.

NOTE 1 The limit of 0,25 % is based on the following uncertainties:

Manual method total uncertainty of 0,2 %, consisting of contributions:

Level error, opening and closing dip: 3 mm

Temperature: 1 °C

Sampled density: 0,1 %

Other: 0,05 %

HTG mass transfer: 0,1 %

NOTE 2 Errors in level measurements due to movement of the level gauge reference caused by tank bulging will add to the manual measurement uncertainty.

7 Safety

7.1 Mechanical safety

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

7.2 Electrical safety

All electrical systems should comply with the local safety regulations. Additionally, account should be taken of the requirements given in IEC 60079-0.

Annex A
(normative)

Calculation overview

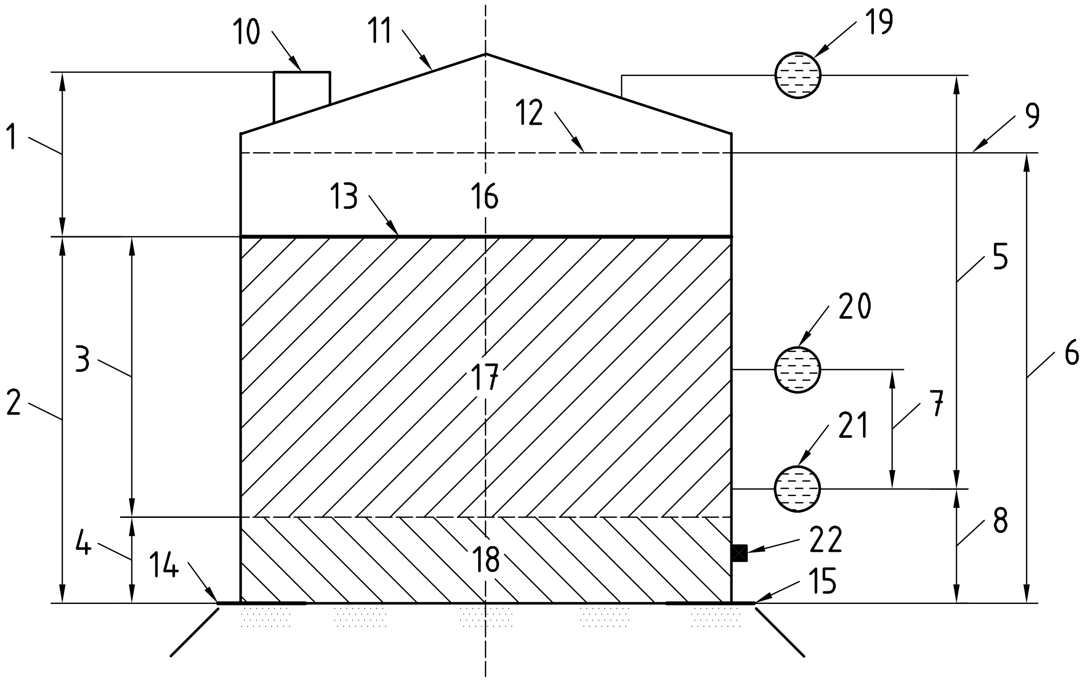
A.1 General

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

The symbols used in this annex are listed in A.2 and illustrated in Figures A.1 and A.2. All values to be substituted in the equations in this annex should be in SI units. If values are obtained in other units, they should be converted into values in the following SI units:

Pressure	Pa
Level	m
Area	m^2
Volume	m^3
Mass	kg
Density	kg/m^3
Acceleration	m/s^2

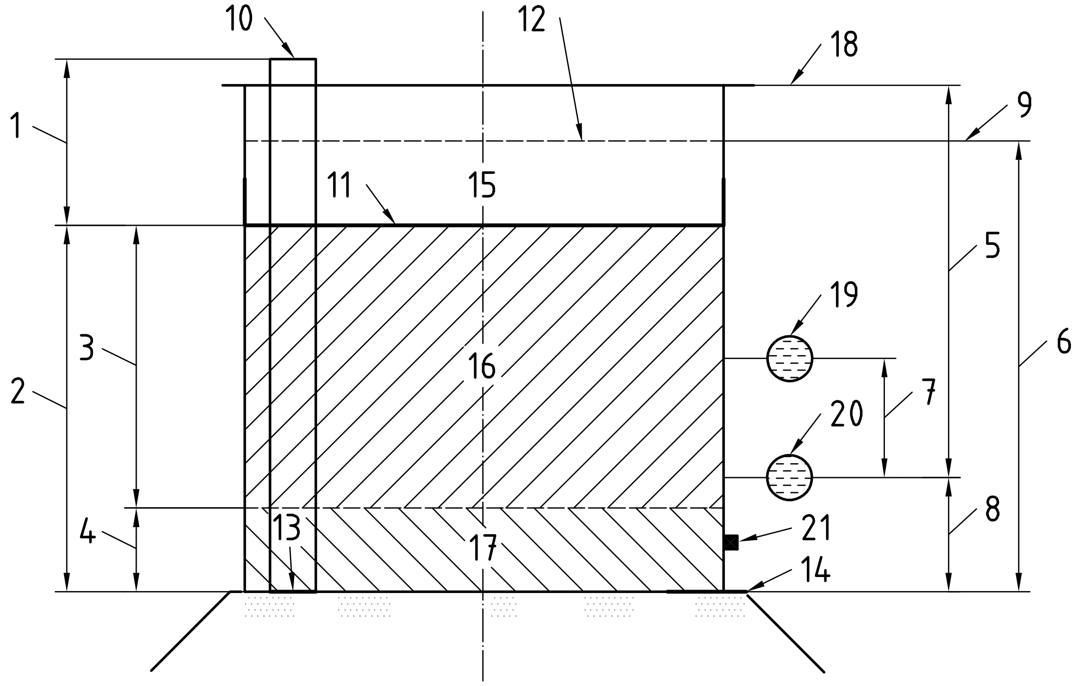
Calculation procedures are the same for both fixed- and floating-roof tanks.



Key

1	ullage	12	max. fill height	L	variable level(s)
2	dip (L, V)	13	floating blanket (W_R)	V	variable volume(s)
3	product (M)	14	datum plate	M	variable mass(es)
4	bottom (L_w, V_w)	15	tank lip	H	fixed height(s)
5	head (H_t, Y_t, M_t)	16	vapours/air mixture	Y	fixed volume(s)
6	total	17	product	W	fixed mass(es)
7	height of sensor P2 above P1 (H)	18	free water and sediments		
8	heel ($H_b + H_0$, Y_z)	19	sensor P3 (present or implied)		
9	capacity table top	20	sensor P2 (density measurements)		
10	gauge hatch	21	sensor P1 (liquid head measurements)		
11	tank roof	22	HTG reference point		

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



Key

1	ullage	12	max. fill height	L	variable level(s)
2	dip (L, V)	13	datum plate	V	variable volume(s)
3	product (M)	14	tank lip	M	variable mass(es)
4	bottom (L_w, V_w)	15	vapours/air mixture	H	fixed height(s)
5	head (H_t, Y_t, M_t)	16	product	Y	fixed volume(s)
6	total	17	free water and sediments	W	fixed mass(es)
7	height of sensor P2 above P1 (H)	18	implied sensor P3		
8	heel ($H_b + H_0$, Y_z)	19	sensor P2 (density measurements)		
9	capacity table top	20	sensor P1 (liquid head measurements)		
10	gauge hatch	21	HTG reference point		
11	floating tank roof (W_R)				

Figure A.2 — Measurement parameters and variables — Floating-roof tank

In-tank vapour and ambient air densities have only second-order effects on the calculated variables. They may be considered constant or, for high accuracy, may be calculated.

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

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

All sensor input data presented to the HTG processor should refer to the same time frame.

A.2 List of symbols

The following symbols and their meanings have been used in this annex:

A_E	tank average cross-sectional area
D	liquid density (observed product density)
D_a	ambient air density
D_ref	density at reference (base) conditions
D_v	in-tank vapour density
g	local acceleration due to gravity
H	vertical distance between sensors P1 and P2
H_0	vertical distance between the tank calibration reference point (datum plate) and the HTG reference point
H_b	vertical distance between the HTG reference point and sensor P1
H_t	vertical distance between sensors P3 and P1
L	dip level
L_w	free water level
M	product mass
M_a	product apparent mass in air
M_b	product heel mass
M_t	product head mass
M_x	mass of the product transferred
p_1	pressure given by pressure sensor P1
p_2	pressure given by pressure sensor P2
p_3	pressure given by pressure sensor P3
V	dipped volume (at dip level)
V_b	product heel volume
V_ref	reference volume of the product
V_refx	reference volume of the product transferred
V_w	free water volume
W_R	mass of floating roof (or floating blanket)
Y_z	total heel volume
Y_t	product head volume

A.3 Pressure balance

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

Therefore:

$p_1 - p_3$ is the total liquid product pressure head plus in-tank vapour pressure head minus ambient air pressure head between sensors P1 and P3;

$p_1 - p_2$ is the liquid product pressure head between sensors P1 and P2 minus ambient air pressure head between sensors P1 and P2.

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

The floating-roof load has both constant (roof mass) and variable (roof-load mass) components. For the purposes of this International Standard, both components are user-entered constants. This applies also to the floating blanket optionally used in fixed-roof tanks.

A.4 Density calculations

The observed product density, D, is calculated from the pressures in accordance with Equation (A.1):

$$D = \frac{p_1 - p_2}{g \times H} + D_\text{a} \tag{A.1}$$

where

$(p_1 - p_2)$ is the difference between the pressure sensor readings from sensors P1 and P2;

g is the local acceleration due to gravity;

H is the vertical distance between the centres of force on the sensor P1 and P2 diaphragms respectively (see Figure A.1 or Figure A.2);

D_a is the ambient air density.

Observed density may be calculated from manually entered reference density. The calculations should follow existing standards such as ISO 91-1 and ISO 91-2.

Observed density may also be manually entered into the data processor.

A.5 Dip-level calculations

The dip level, L, is calculated in accordance with Equation (A.2):

$$L = H_0 + H_b + \frac{\left[(p_1 - p_3)/g - H_t \times (D_v - D_a)\right]}{(D - D_v)} \tag{A.2}$$

where

H_0	is the vertical distance from the tank calibration reference point to the HTG reference point;
H_b	is the vertical distance of the centre of force on sensor P1 from the HTG reference point (see Figure A.1 or Figure A.2);
$(p_1 - p_3)$	is the difference between the pressure sensor readings from sensors P1 and P3;
g	is the local acceleration due to gravity;
H_t	is the vertical distance between the centres of force on the sensor P1 and P3 diaphragms respectively (see Figure A.1 or Figure A.2);
D_v	is the in-tank vapour density;
D_a	is the ambient air density;
D	is the liquid density calculated in A.4.

NOTE If D_v is not available, it can be assumed to be equal to D_a.

A.6 Average tank cross-sectional area calculations

The average tank cross-sectional area is calculated in accordance with Equation (A.3):

$$A_E = \frac{V - Y_z}{L - H_b - H_0} \tag{A.3}$$

where

V	is the dipped volume (at dip level);
Y_z	is the total heel volume;
L	is the dip level calculated in A.5;
H_b	is the vertical distance of the centre of force on sensor P1 from the HTG reference point (see Figure A.1 or Figure A.2);
H_0	is the vertical distance from the tank calibration reference point (datum plate) to the HTG reference point.

Dipped volume and total heel volume should be calculated from the dip level and the sensor P1 height ($H_b + H_0$), respectively, as described in ISO 7507-1.

A.7 Head mass calculations

The product head mass, M_t, is calculated in accordance with Equation (A.4):

$$M_t = \left[\frac{p_1 - p_3}{g} - H_t \times (D_v - D_a) \right] \times \frac{D}{D - D_v} \times A_E \tag{A.4}$$

where

A_E is the tank average cross-sectional area calculated in A.6;

g is the local acceleration due to gravity;

D_v is the in-tank vapour density;

D is the liquid density;

H_t is the vertical distance between the centres of force on the sensor P1 and P3 diaphragms (see Figure A.1 or Figure A.2);

D_a is the ambient air density.

NOTE If D_v is not available it can be assumed equal to D_a.

A.8 Product-heel volume and mass calculations

The product-heel volume is calculated in accordance with Equation (A.5):

$$V_b = Y_z - V_w \tag{A.5}$$

where

Y_z is the total heel volume calculated from the P1 sensor height ($H_b + H_0$) and the tank capacity table;

V_w is the free water volume calculated from the free water level, L_w, and the tank capacity table.

Assuming that A_E is approximately constant through the tank, V_b may also be calculated in accordance with Equation (A.6):

$$V_b = (H_b + H_0 - L_w) \times A_E \tag{A.6}$$

The product-heel mass is calculated in accordance with Equation (A.7):

$$M_b = V_b \times D \tag{A.7}$$

where

V_b is the product heel volume calculated above;

D is the observed product density calculated in A.4.

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

A.9 Product mass calculation

The product mass, M, is calculated in accordance with Equation (A.8):

$$M = M_t + M_b - W_R \tag{A.8}$$

where

M_t is the product head mass calculated in A.7;

M_b is the product heel mass calculated in A.8;

W_R is the mass of the floating-roof (or floating blanket).

Substitution of the respective formulae for M_t and M_b yields Equation (A.9):

$$M = \left[\frac{p_1 - p_3}{g} - H_t \times (D_v - D_a)\right] \times A_E \times \frac{D}{D - D_v} + (H_b + H_0 - L_w) \times A_E \times D - W_R \tag{A.9}$$

The liquid density D is measured either independently or by HTG (see A.4).

The calculations for product mass are identical for fixed- and floating-roof tanks providing that the floating-roof mass is set equal to zero for the fixed-roof tanks with no floating blanket.

When the floating roof enters the critical zone, the floating-roof mass and the floating-roof load mass will be gradually taken up by the floating-roof legs. See ISO 7507-1 for calculations within and below the critical zone.

A.10 Calculation of product apparent mass in air

The product apparent mass in air, M_a, is calculated in accordance with Equation (A.10):

$$M_a = M \times \left(1 - \frac{D_a}{D}\right) \tag{A.10}$$

where

M is the product mass calculated in A.9;

D_a is the ambient air density;

D is the observed product density calculated in A.4.

A.11 Calculation of reference volume from mass

The product reference (standard) volume is calculated in accordance with Equation (A.11):

$$V_{ref} = \frac{M}{D_{ref}} \tag{A.11}$$

where

M is the product mass calculated in A.9;

D_{ref} is the product reference density measured by external means.

A.12 Inventory uncertainties

A.12.1 Product mass in tank

Providing that the pressure sensor installation parameters are correct, the uncertainty of calculated mass depends primarily on the uncertainties of the pressure sensors, including their positions, the water level and the tank capacity table. Secondary contributions from uncertainties of the local acceleration due to gravity, temperature, densities of in-tank vapour and ambient air, etc., can normally be neglected. For HTG systems, typical calculations of uncertainty of inventory measurements are given below.

A.12.1.1 Density measured independently

For purposes of uncertainty calculations, the simplified equation for product mass, M, is given by Equation (A.12):

$$M = \left[\frac{p_1 - p_3}{g} + (H_b + H_0 - L_w) \times D \right] \times A_E - W_R = (L - L_w) \times D \times A_E - W_R \tag{A.12}$$

The relative uncertainty of product mass for tanks without floating roofs is calculated in accordance with Equation (A.13):

$$\left(\frac{uM}{M} \right) = \sqrt{\frac{{up_1}^2 + {up_3}^2}{\left[g \times (L - L_w) \times D \right]^2} + \left(\frac{H_b + H_0 - L_w}{L - L_w} \times \frac{uD}{D} \right)^2 + \frac{{uH_b}^2 + {uH_0}^2 + {uL_w}^2}{\left(L - L_w \right)^2} + \left(\frac{uA_E}{A_E} \right)^2} \tag{A.13}$$

where

up_1, up_3	are the total uncertainties, in pascals, of pressure p_1 and p_3, respectively;
uA_E	is the uncertainty, in square metres, of the effective cross-sectional area of the tank derived from tank calibration;
uD	is the uncertainty, in kilograms per square metre, of the density of the liquid in the heel space of the tank;
uH_b	is the uncertainty, in metres, of the height of sensor P1 above HTG reference point;
uH_0	is the uncertainty, in metres, of the height of the HTG reference point above the tank calibration reference point;
uL_w	is the uncertainty, in metres, of the level of free water.

All uncertainties are absolute, expressed in their SI engineering units.

NOTE Uncertainties of typical pressure sensors are influenced most of all by variations in sensor temperature. Low inventory uncertainties can be achieved by holding the sensors near the temperature at which they were zeroed.

The uncertainty uA_E of the average cross-sectional area of the tank is the same as the uncertainty of the tank capacity table. Depending on the chosen calibration method, uA_E might vary with level of the liquid in the tank. As an approximation, the relative value of uA_E may be taken as a constant in the region of 0,05 % to 0,1 % of reading.

Table A.1 shows uncertainties of the mass inventory measurements on a typical vertical tank.

Table A.1 — Example of measurement uncertainty of inventory mass — Freely vented tank, density measured independently

Product: Gasoline in freely vented tank [a]							
Case	Sensor or measurement uncertainty				Mass measurement uncertainty		
	$u_{p1\text{–zero}}$ Pa	$u_{p1\text{–linearity}}$ fraction of reading	$u(H_b + H_o)$ m	uA_E fraction	$L = 4$ m % of reading	$L = 8$ m % of reading	$L = 12$ m % of reading
1	50	0,000 7	0,003	0,000 5	0,255	0,166	0,138
2	50	0,000 7	0,003	0,001 0	0,269	0,188	0,163
3	50	0,000 7	0,005	0,001 0	0,287	0,194	0,166
4	100	0,001 0	0,003	0,001 0	0,456	0,290	0,237
5	100	0,001 0	0,005	0,001 0	0,467	0,294	0,239

[a] Values for the variables used in the calculations are as follows:

$D = 741{,}0$ kg/m^3
$D_v = 1{,}2$ kg/m^3
$D_a = 1{,}1$ kg/m^3
$H_b + H_o = 0{,}2$ m
$g = 9{,}81$ m/s^2
Density uncertainty = 0,3 %.

A.12.1.2 Density measured by HTG

For purposes of uncertainty calculations, the simplified equation for mass:

$$M = \left[\frac{p_1 - p_3}{g} + (H_b + H_0 - L_w) \times \frac{p_1 - p_2}{g \times H}\right] \times A_E - W_R \qquad \text{(A.14)}$$

Relative uncertainty of product mass for tanks without floating roofs:

$$\frac{uM}{M} = \sqrt{\frac{\left[uP_1 \times (1 + H_R)\right]^2 + (up_2 \times H_R)^2 + up_3{}^2}{\left[g \times (L - L_w) \times D\right]^2} + \left(\frac{uH \times H_R}{L - L_w}\right)^2 + \frac{uH_b{}^2 + uH_0{}^2 + uL_w{}^2}{\left(L - L_w\right)^2} + \left(\frac{uA_E}{A_E}\right)^2} \qquad \text{(A.15)}$$

where the level ratio H_R is defined as

$$H_R = \frac{H_b + H_0 - L_w}{H} \qquad \text{(A.16)}$$

Table A.2 shows the uncertainties of the mass inventory measurements on a typical vertical tank.

Table A.2 — Example of measurement uncertainty of inventory mass — Freely vented tank, density measured by HTG

Product: Gasoline in freely vented tank [a]							
Case	Sensor or measurement uncertainty				Mass measurement uncertainty		
	$u_{p1\text{-zero}}$ and $u_{p2\text{-zero}}$ Pa	$u_{p1\text{-linearity}}$ and $u_{p2\text{-linearity}}$ fraction of reading	$u(H_\text{b} + H_\text{o})$ m	uA_E fraction	$L = 4$ m % of reading	$L = 8$ m % of reading	$L = 12$ m % of reading
1	50	0,000 7	0,003	0,000 5	0,273	0,178	0,147
2	50	0,000 7	0,003	0,001 0	0,287	0,198	0,171
3	50	0,000 7	0,005	0,001 0	0,304	0,204	0,174
4	100	0,001 0	0,003	0,001 0	0,491	0,310	0,252
5	100	0,001 0	0,005	0,001 0	0,501	0,314	0,255

[a] Values for the variables used in the calculations are as follows:
$D = 741{,}0$ kg/m^3
$D_\text{v} = 1{,}2$ kg/m^3
$H_\text{b} + H_\text{o} = 0{,}2$ m
$g = 9{,}81$ m/s^2
$H = 2{,}5$ m
$uH = 0{,}005$ m

A.12.2 Reference volume with independent density

The reference density, D_ref, enters directly into Equation (A.11) for the reference volume:

$$V_\text{ref} = \frac{M}{D_\text{ref}}$$

Assuming that all uncertainties are statistically independent:

$$\left(\frac{uV_\text{ref}}{V_\text{ref}}\right)^2 = \left(\frac{uM}{M}\right)^2 + \left(\frac{uD_\text{ref}}{D_\text{ref}}\right)^2 \tag{A.17}$$

where

uV_ref is the absolute uncertainty of the reference volume, expressed in cubic metres;

uM is the absolute uncertainty of the mass, expressed in kilograms;

uD_ref is the absolute uncertainty of the reference density, expressed in kilograms per cubic metre.

Table A.3 shows an example of the calculation uncertainties of reference-volume inventory from the uncertainties of measured mass and manually entered reference density.

Table A.3 — Example of calculations of uncertainties for manually entered reference density

Source uncertainties		Inventory uncertainties
Mass % of reading	**Reference density** % of reading	**Reference volume** % of reading
0,1	0	0,1
0,1	0,1	0,14
0,2	0,1	0,22
0,2	0,2	0,28

A.13 Transfer uncertainties

A.13.1 Mass with independent density

Transfer uncertainties differ from inventory uncertainties due to the fact that some calculation parameters do not change during transfer and do not appear in the difference between the masses before and after the transfer. Their uncertainties therefore do not figure in the uncertainties of the transferred mass. Typical calculations for the uncertainty of transfer measurements are given below.

The simplified equation for the mass transferred, assuming that density below P1 and the free-water level is the same at the start and at the end of the transfer ($D_o = D_c$, $L_{wo} = L_{wc}$) is given by Equation (A.18):

$$M_x = A_E \times \frac{(p_{1o} - p_{1c}) - (p_{3o} - p_{3c})}{g} \tag{A.18}$$

If he uncertainty of the gravity acceleration factor is neglected, the relative uncertainty of transferred mass is given by Equation (A.19):

$$\left(\frac{uM_x}{M_x}\right) = \sqrt{\frac{u(p_{1o} - p_{1c})^2 + u(p_{3o} - p_{3c})^2}{\left[D \times g \times (L_o - L_c)\right]^2} + \left(\frac{uA_E}{A_E}\right)^2} \tag{A.19}$$

where

$u(p_{1o} - p_{1c})$ is the absolute transfer uncertainty, in pascals, of the difference between pressures p_1 at start (opening) and end (closing) of the transfer;

$u(p_{3o} - p_{3c})$ is the absolute transfer uncertainty, in pascals, of the difference between pressures p_3 at start (opening) and end (closing) of the transfer;

L_o, and L_c are opening and closing levels, respectively;

uA_E is the absolute uncertainty, in cubic metres, of the effective cross-sectional area of the tank derived from tank calibration.

The uncertainties of pressure differences are usually assumed to be, at practically constant sensor temperature, smaller than the pressure uncertainties for inventory measurements. Normally, the zero offset will (partly) cancel out and the only remaining element of the uncertainties is the non-linearity of the sensors.

NOTE Uncertainties of typical pressure sensors are influenced most of all by variations in sensor temperature. It may be expected that for transfers that take only a short amount of time, the sensor temperature would remain nearly constant. Consequently, the zero error of the sensor will be approximately constant during the transfer. Thus, the zero component of the sensor uncertainty will be significantly reduced. Sensor manufacturers are expected to supply figures for zero uncertainties of sensors at constant temperature.

Expressing the uncertainties of pressures in terms of their components:

$$\left(\frac{uM_{\mathrm{x}}}{M_{\mathrm{x}}}\right)=\sqrt{\frac{\left\{up_{\text{1-linearity}}\times\left[D\times g\times(L_{\mathrm{o}}-L_{\mathrm{c}})\ +\ p_{\text{3range}}\right]\right\}^{2}+\left(up_{\text{3-linearity}}\times p_{\text{3range}}\right)^{2}}{\left[D\times g\times(L_{\mathrm{o}}-L_{\mathrm{c}})\right]^{2}}+\left(\frac{uA_{\mathrm{E}}}{A_{\mathrm{E}}}\right)^{2}} \qquad \text{(A.20)}$$

where p_{3range} is difference in vapour pressure between maximum (e.g. greater than the ambient pressure for a PV valve) and minimum (e.g. less than the ambient for a PV valve) vapour pressure.

Table A.4 shows uncertainties of the mass transfer measurements for a typical vertical tank.

Table A.4 — Example of the measurement uncertainty of the transferred mass — Density measured independently — Tank with a PV valve

Product: Gasoline in a fixed-roof tank [a]							
Case	Sensor or measurement uncertainty				Mass-measurement uncertainty for any start level		
	$u_{p1\text{−zero}}$	$u_{p1\text{−linearity}}$	Transfer out by (difference of levels)	uA_{E}	Variation in p_3 = 500 Pa	Variation in p_3 = 1 000 Pa	Variation in p_3 = 2 000 Pa
	Pa	fraction of reading	m	fraction	% transferred mass	% transferred mass	% transferred mass
1	50	0,000 7	2	0,000 5	0,088	0,091	0,097
2	50	0,000 7	3	0,001 0	0,123	0,124	0,127
3	50	0,000 7	4	0,001 0	0,123	0,124	0,125
4	100	0,001 0	2	0,001 0	0,144	0,147	0,153
5	100	0,001 0	4	0,001 0	0,143	0,144	0,147

[a] Values for the variables used in the calculations are as follows:

g = 9,81 m/s^2

p_3 zero error = 24 Pa

p_3 linearity error = 0,002 of reading

Product density = 741 kg/m^3

A.13.2 Mass with density measured by HTG

If the uncertainty of the gravity acceleration factor is neglected, the relative uncertainty of transferred mass is given by Equation (A.21):

$$\left(\frac{uM_{\mathrm{x}}}{M_{\mathrm{x}}}\right)=\sqrt{\frac{(1+H_{\mathrm{R}})^{2}\times u(p_{1\mathrm{o}}-p_{1\mathrm{c}})^{2}+H_{\mathrm{R}}{}^{2}\times u(p_{2\mathrm{o}}-p_{2\mathrm{c}})^{2}\ +u(p_{3\mathrm{o}}-p_{3\mathrm{c}})^{2}}{\left[D\times g\times(L_{\mathrm{o}}-L_{\mathrm{c}})\right]^{2}}+\left(\frac{uA_{\mathrm{E}}}{A_{\mathrm{E}}}\right)^{2}} \qquad \text{(A.21)}$$

where

$u(p_{1\mathrm{o}}-p_{1\mathrm{c}})$ is the absolute transfer uncertainty, in pascals, of the difference between pressures, p_1, at the start (opening) and the end (closing) of the transfer and may be calculated as:

$$u(p_{1\mathrm{o}}-p_{1\mathrm{c}})=up_{1\text{–linearity}}\times(p_{1\mathrm{o}}-p_{1\mathrm{c}})$$

$u(p_{2\mathrm{o}}-p_{2\mathrm{c}})$ is the absolute transfer uncertainty, in pascals, of the difference between pressures, p_2, at the start (opening) and the end (closing) of the transfer and may be calculated as:

$$u(p_{2\mathrm{o}}-p_{2\mathrm{c}})=up_{2\text{–linearity}}\times(p_{2\mathrm{o}}-p_{2\mathrm{c}})$$

$p(p_{3\text{o}} - p_{3\text{c}})$ is the absolute transfer uncertainty, in pascals, of the difference between pressures, p_3, at start (opening) and end (closing) of the transfer and may be calculated as:

$$u(p_{3\text{o}} - p_{3\text{c}}) = up_{3\text{–linearity}} \times (p_{3\text{o}} - p_{3\text{c}})$$

L_o and L_c are the opening and the closing level, respectively

uA_E is the absolute uncertainty, in square metres, of the effective cross-sectional area of the tank derived from tank calibration

Level ratio H_R is defined as:

$$H_\text{R} = \frac{H_\text{b} + H_0 - L_\text{w}}{H}$$

Table A.5 shows uncertainties of the mass transfer measurements for a typical vertical tank.

Table A.5 — Example of measurement uncertainty of transferred mass; density measured by HTG — Tank with PV valve

Gasoline in fixed-roof tank [a]									
Case	**Sensor or measurement uncertainty**						**Mass measurement uncertainty for any start level**		
	$u_{p1\text{–zero}}$	$u_{p1\text{–linearity}}$	$u_{p2\text{–zero}}$	$u_{p2\text{–linearity}}$	Transfer out by (difference of levels)	uA_E	Variation in $p_3 = 500$ Pa	Variation in $p_3 = 1\,000$ Pa	Variation in $p_3 = 2\,000$ Pa
	Pa	fraction of reading	Pa	fraction of reading	m	fraction	% transferred mass	% transferred mass	% transferred mass
1	50	0,000 7	50	0,000 5	2	0,000 5	0,093	0,096	0,103
2	50	0,000 7	50	0,001 0	3	0,001 0	0,127	0,128	0,131
3	50	0,000 7	50	0,001 0	4	0,001 0	0,126	0,127	0,129
4	100	0,001 0	100	0,001 0	2	0,001 0	0,150	0,154	0,161
5	100	0,001 0	100	0,001 0	4	0,001 0	0,149	0,150	0,154

[a] Values for the variables used in the calculations are as follows:

$g = 9{,}81$ m/s^2

p_3 zero error = 24 Pa

p_3 linearity error = 0,002 of reading

Product density = 741 kg/m^3

A.13.3 Reference volume with independent density

If it is assumed that only one sample of reference density is taken, either at beginning or at end, and that the density remains the same during the transfer, the uncertainty of the transferred reference volume is given by Equation (A.22):

$$\left(\frac{uV_\text{refx}}{V_\text{refx}}\right)^2 = \left(\frac{uM_\text{x}}{M_\text{x}}\right)^2 + \left(\frac{uD_\text{ref}}{D_\text{ref}}\right)^2 \tag{A.22}$$

where

uV_{refx}	is the absolute uncertainty of the transferred reference volume, expressed in cubic metres;
uM_{x}	is the absolute uncertainty of the transferred mass, expressed in kilograms;
uD_{ref}	is the absolute uncertainty of the reference density, expressed in kilograms per cubic metre.

Annex B
(normative)

Volume measurement using independent density

B.1 General

HTG measures mass, reference density is measured independently, using separate densitometers. These may be

a) mounted on the tank;

b) mounted on the connecting pipes (in-line densitometers, ISO 9857);

c) based in laboratory and used with manually-obtained samples (ISO 3170) of the measured liquid.

The reference density is entered into HTG calculations of reference volume (see C.7).

B.2 Uncertainties

As a direct analogy with the systems where mass is calculated from measured volume, the reference density is agreed between the parties involved in the transaction. For the purposes of the transaction, either the reference density may be assumed to be error-free or its uncertainty is that of the separate densitometer.

If the (assumed) uncertainty of the reference density is zero, the uncertainty of the calculated reference volume is the same as that of the measured mass.

If the measured density cannot be assumed to be error-free, the uncertainty of the reference volume may be calculated using the equations given in C.8.

B.3 Liquid stratification

Measured mass is not affected by liquid stratification.

Liquid stratification will add to the errors in the measured density and therefore to the errors in the calculated reference volume. These additional errors will depend on how the density measurement is performed.

Correct average density should be measured

a) for the total liquid in the tank for inventory measurements, the recommended methods being

   1) taking “running samples” of the liquid throughout the tank (see ISO 3170) and measuring the average density in the laboratory,

   2) taking multi-point density measurements throughout the tank and establishing the required average by calculations;

b) for the liquid transferred into or out of the tank for transfer measurements. The recommended methods use an in-line densitometer (and temperature sensor) that measures the density (and the temperature) of the transferred liquid and calculates an average reference density throughout the transfer. The densitometer (and the temperature sensor) should be mounted

   1) on the tank near the pipe entry,

   2) on the pipe itself, near its entry into the tank.

Significant errors could occur if other than an in-line densitometer (or an in-line temperature sensor) is used, i.e. if the density and temperature other than that of the transferred liquid is used for the calculation of the liquid volume. This could occur if

a) the density or temperature is averaged over the whole height of the liquid and the density of the transferred liquid differs from the average;

b) the density or temperature is averaged over a section at the bottom of the tank and the liquid being pumped into the tank is lighter than the liquid already in the tank or its temperature is different.

Thermal stratification could amount to as much as 5 °C. Significant errors could result in the conventional measurement if the temperature averaged through the entire tank contents (e.g. measured by multi-point resistive elements) is used to calculate the corrections of the transferred volume.

Annex C
(informative)

Volume measurement with density measured by hydrostatic tank gauge

C.1 Introduction

This annex gives guidance on the installation, commissioning, maintenance, validation and calibration of hydrostatic tank gauging systems for the direct measurement of the static reference volume and volume transfers in petroleum storage tanks, additional to the measurements of mass.

The important part of this annex is the analysis of uncertainties of the measured volume, for both inventories and transfers.

NOTE Due to large uncertainties in systems with density measured by the HTG system, the measurement of reference volume would normally be applicable to custody transfer only if the reference volume is calculated from measured mass and the reference density obtained by separate measurements (see ISO 3675, ISO 3838, ISO 3993, ISO 9857, ISO 12185).

C.2 Description

C.2.1 Introduction

The ultimate objective of the measurement described in this annex is to obtain reference volume of the liquid in the tank for the purposes of ascertaining

a) quantity of the stored liquid (inventory quantity);

b) quantity of the liquid transferred into or out of the tank (transfer quantity).

Reference (base) volume may be provided by HTG in several different ways, depending on how the user obtains the reference (base) density of the measured liquid. Independently measured density is covered in Annex B.

C.2.2 HTG-measured density

C.2.2.1 General

With an additional pressure sensor P2 mounted a fixed distance above the sensor P1, HTG can measure the observed density as well as mass. HTG usually also measures a single-point or average temperature of the liquid between the sensors P1 and P2 using a single-point temperature sensor or an averaging temperature bulb mounted between the two sensors.

From the measured observed density and temperature, HTG can calculate an average reference density between the sensors P1 and P2.

For the calculations of the reference volume, it is assumed that the reference density below the sensor P1 and above the sensor P2 are the same as the calculated average reference density between the sensors P1 and P2.

C.2.2.2 Uncertainties

The uncertainty of the observed density is proportional

- directly to the combined uncertainties of the pressure measurements p_1 and p_2;
- indirectly to the vertical distance between the pressure sensors P1 and P2;
- directly to the uncertainty of the vertical distance between the sensors P1 and P2.

Significant improvements in performance can be obtained if the vertical distance of the two pressure sensors P1 and P2 is increased. This has to be traded off against the fact that no density measurement is available from HTG with the liquid level below the pressure sensor P2.

For typical temperature sensors, given the fact that the liquid temperature is usually within narrow limits, the uncertainty of temperature measurement is expected to be less than 1 °C.

The uncertainty of the reference density is a combination of the uncertainties of the measured observed density and the measured temperature. The uncertainty equations depend on the equations used for the calculations, which in turn depend on the type of liquid (see C.8).

The uncertainty of the calculated reference volume is less than the combination of the uncertainties of mass and reference density, due to the fact that both measurements share the same sensor P1 and their uncertainties are therefore correlated (see C.8).

C.2.2.3 Liquid stratification

Additional uncertainty in the measurement of the reference volume is possible due to the fact that, owing to liquid stratification, the average reference density between sensors P1 and P2 may not be representative of the required average reference density.

As HTG measures density at the bottom of the tank, its density is likely to be

- not representative of the average inventory density if the liquid level is significantly above the sensor P2, with the strata boundary(ies), with the dividing plane(s) between liquid strata above P2;
- representative of the average inventory density with the liquid level at or near the sensor P2 or with no strata above the sensor P2 or below the sensor P1;
- representative of the transferred density for transfers out of the tank (if averaged over the transfer);
- representative of the transferred density for transfers into the tank, when the observed density of the transferred liquid is greater than that of the liquid already in the tank (if averaged over the transfer);
- not representative of the transferred density for transfers into the tank, when the observed density of the transferred liquid is less than that of the liquid already in the tank.

The magnitude of the additional error depends on the severity of the stratification, i.e. on

a) differences of reference densities in the individual strata;

b) sizes of the strata above the pressure sensor P2.

Stratification by temperature when the reference density is constant throughout the liquid causes no additional errors in the measurement of reference volume.

C.2.3 Applications

HTG is primarily intended to measure mass of the stored liquid. The uncertainty of the HTG measurement of the reference volume is likely to be greater than that of the systems based on level and temperature measurements (see C.8 for uncertainty analysis and examples of HTG performance).

For liquids where there can be no assurance of chemical uniformity, the user should be aware that the reference volume measurements by HTG could be subject to significant additional errors due to liquid stratification.

C.3 System description

C.3.1 General

HTG is a measuring system for tank inventory static mass and reference volume. It uses pressure and temperature inputs, the parameters of the tank and of the stored liquid to compute the mass and the reference volume of the tank contents and other variables (see Figure 1).

C.3.2 Sensors

C.3.2.1 Pressure sensors

The same sensor configuration is used for both mass and volume measurements. To measure volume, HTG may operate with or without the sensor P2. If no sensor P2 is used, the liquid density or reference density has to be entered manually into the HTG data processor.

C.3.2.2 Temperature sensors

The reasons for measuring the product temperature for mass measurements apply also to volume measurements. The additional reason for measuring the temperature of the liquid is the conversion between the observed density and the reference density.

C.3.3 Processor

The HTG processor receives data from the sensors and uses the data together with the tank and liquid parameters to compute the mass and reference volume inventories in the storage tank (see Figure 1).

When the product level drops below the level of P2, observed density can no longer be measured by HTG. Below P2, the last measured value of the reference density may be used to calculate the reference volume.

Additional calculations normally performed by the processor to obtain the reference volume are described in C.7.

C.4 Installation

C.4.1 Height of the pressure sensor P2

The position of pressure sensor P2 on the tank should be determined bearing in mind

a) requirements for measurement accuracy of density, level and volumes;

b) filling cycles of the tank and requirements for measurement availability;

c) ease of installation.

To improve the measurement performance, the height of P2 above P1 should be as large as possible, provided that

a) the installation cost is still acceptable;

b) direct density measurements are not normally required with the liquid level below the sensor P2.

To achieve a typical uncertainty of the density measurement, P2 should be at least 2 m above P1.

C.4.2 Determination of position of pressure sensor P2

The distance between sensors P1 and P2 is critical for the measurements of density. It should be noted that errors could be made in determining the positions of

- the external markings on the sensors P1 and P2 relative to each other and to the tank reference point;
- the effective centres of force within the sensors relative to the external markings on the sensors.

If the measurement of the height of P2 above P1 using the external markings on the sensors does not yield satisfactory results, the method of using multiple measurements of level should be considered (see C.5.1).

C.4.3 Limitation of movement of pressure sensor P2

The use of a tie bar between P1 and P2 to maintain a constant vertical distance between P1 and P2 should be considered. To ascertain the need for the tie bar, the vertical distance between the external markings on sensors P1 and P2 should be measured with the tank empty and again with the tank full. If the difference of the two measurements of the vertical distance is more than 1 mm, a tie bar should be fitted on those systems requiring highly accurate measurements of reference volume.

Thermal expansion and contraction of the tie bar will affect the density measurements. In measurements requiring a high accuracy, the temperature of ambient air should be measured and the actual length of the tie bar corrected for its fluctuations (see C.7).

The pressure sensor connections to the tank should be made flexible enough to satisfy the user's mechanical safety requirements. The tie bar should be fitted to the process end of the pressure sensors to avoid overstressing the sensors.

C.4.4 Wind effect

The differences between the ambient pressures of sensors P1 and P2 will have a direct impact on the HTG measurement of density. If exposed to strong winds, the outside ports of the P1 and P2 sensors should be connected together by a pressure-equalizing pipe. This pipe should be essentially vertical, with no seals or traps, closed at the top and open at the bottom to eliminate risks of becoming filled with condensation.

C.5 Commissioning

C.5.1 Commissioning of basic HTG system

For commissioning of the basic HTG system, see 5.4.

C.5.2 Checking against manual measurements

The values of reference volume measured by the HTG should be compared with those obtained from manual measurements of level, temperature and density.

Standard procedures should be used to obtain measurements of level (ISO 4512), temperature (ISO 4268) and density (ISO 3675, ISO 3838, ISO 3993 or ISO 12185), to calculate standard volume (ISO 4267-2) and reference density (ISO 91-1 and ISO 91-2).

The comparison will yield valid results only if the reference density of the liquid in the tank is essentially uniform throughout the tank, i.e. there are no significant strata above the sensor P2 whose reference density would differ from the average by more than the specified uncertainty of the HTG density measurements.

If HTG and manual measurements of reference volume agree within the uncertainties of the HTG and the manual measurement, the HTG may be assumed to be operating correctly. If HTG and manual methods do not agree, the following should be rechecked:

- pressure sensor positions;

- pressure sensor zeros;

- HTG calculation parameters, including the capacity table entries;

- stratification of the reference density of the liquid in the tank, in particular any strata above the sensor P2.

C.6 Maintenance

C.6.1 General

The operations described in 6.2 and 6.3 cover the system validation and system calibration. Validation differs from calibration in that it does not involve any adjustments of the HTG installation or any corrections of the calculation parameters in the HTG data processor.

C.6.2 Validation

C.6.2.1 On-tank measurements

If the comparison is to be carried out against a manual method, the procedure described in 6.2.3 should be followed.

C.6.2.2 Off-tank measurements

Comparisons on measured a reference volume should be carried out if either of the following are available:

- volumetric flowmeter with on-line densitometer;

- volumetric flowmeter with sampled line density.

C.6.3 Calibration by traceable tank measurements

This calibration method compares the reference volume measured by HTG with reference volume calculated from manual measurements of level, density and temperature. Comparisons between the two measurement methods are also possible on level, density, reference density and/or observed volume. It should be noted that:

a) the reference volume is the ultimate objective of the measurement and therefore the most important measurement to be compared;

b) additional errors in the level in HTG with a manually entered reference density may be caused by the errors in temperature measurements, in which case the errors in reference volume will be less than those in level.

It is important that a part of the manual measurement method should be to examine whether or not the measured liquid is stratified and whether the stratification is by reference density (varying product composition) or only by temperature. If the liquid is stratified by reference density, both HTG and the manual method may exhibit errors outside their normal performance specification. In this case, the HTG calibration should be abandoned.

Standard procedures should be used to obtain measurements of level (ISO 4512), temperature (ISO 4268) and density (ISO 3838 or ISO 3993), to calculate standard volume (ISO 4267-2) and reference density (ISO 91-1 and ISO 91-2).

The calibration should be done on reference volume inventory or transfer. If the inventory quantities are seen as the prime aim of the measurements, the following should be taken into account.

If the manual and the HTG measurements are performed using different measurement reference points, two readings should be taken in order to remove the effects of any offset. The calibration should be carried out at levels which are approximately 4 m apart, preferably with the same liquid.

If

$$\left| \frac{\Delta V_{\text{refH}} - \Delta V_{\text{refM}}}{\Delta V_{\text{refM}}} \right| < 0{,}012 \ \ (1{,}2\ \%),$$

where

ΔV_{refH} is the difference in HTG reference volumes;

ΔV_{refM} is the difference in manual reference volumes;

then the HTG should be assumed to be operating correctly.

NOTE 1 The limit of 1,2 % is based on the following uncertainties:

Level error, opening and closing dip: ± 3 mm

Temperature error: ± 1 °C

Tank capacity table error: ± 0,08 %

Other errors: ± 0,05 %

Expected error in HTG ref. volume: ± 1,15 %

NOTE 2 Errors in level measurement due to movement of the datum plate caused by tank bulging may add to the manual measurement uncertainty.

C.7 Calculations overview

C.7.1 General

This clause describes the additional calculations performed by the HTG processor in order to compute the reference volume of the tank contents.

All values to be substituted in the equations should be in SI units.

C.7.2 Symbols and abbreviated terms

A_D	is a thermal expansion multiplier
M	is the product mass
g	is the local acceleration due to gravity
D	is the observed density (density at operating conditions)
D_{ref}	is the density at reference (base) conditions
C_0, C_1 and C_2	are the expansion constants, dependent on the properties of the stored liquid
C_{exp}	is the coefficient of volumetric expansion of the measured liquid that fits the linear or quadratic expansion
C_{expt}	is the linear coefficient of expansion of the material of the tie bar
exp	is an exponential function
H	is the height of the sensor P2 above P1 at operating conditions
H_{ref}	is the height of P2 above P1 measured at the temperature T_{ambref}
H_{b}	is the height of the sensor P1 above the HTG tank datum point at operating conditions
H_0	is the height of the HTG datum point above the tank datum point at operating conditions
L_{w}	is the level of free water at operating conditions
T	is the measured temperature of the liquid
T_{ref}	is the reference (base) temperature
T_{amb}	is the observed ambient temperature
T_{ambref}	is the ambient temperature at which the height, H_{ref}, of P2 was established
p_1	is the pressure registered by sensor P1
p_2	is the pressure registered by sensor P2
p_3	is the pressure registered by sensor P3
L_{P1}	is the liquid level above P1
L_{P2}	is the liquid level above P2
V	is the observed volume of the product
V_{ref}	is the reference volume
F_{VC}	is the volume-correction factor

C.7.3 Reference density

If density is measured by HTG, the appropriate formula is given in A.4.

In systems where density is measured by HTG or by other densitometers that measure the observed density (and temperature), the reference density of petroleum products is calculated from observed density using conversion tables given in ISO 91-1 and ISO 91-2. These tables are based on the following equations:

$$D_{\text{ref}} = \frac{D}{F_{VC}} \tag{C.1}$$

where

$$F_{VC} = \exp\{-A_D \times (T - T_{\text{ref}}) \times [1 + 0{,}8 \times A_D \times (T - T_{\text{ref}})]\} \tag{C.2}$$

where

exp is an exponential function;

T is measured temperature of the liquid;

T_{ref} is reference (base) temperature;

A_D is calculated from Equation (C.3):

$$A_D = \left(\frac{C_0}{{D_{\text{ref}}}^2}\right) + \left(\frac{C_1}{D_{\text{ref}}}\right) + C_2 \tag{C.3}$$

where

C_0, C_1 and C_2 are constants, dependent on the properties of the stored liquid.

Refer to Table C.1 for values of the density coefficients C_0, C_1 and C_2.

Table C.1 — Values of the density conversion coefficients

Group	Reference density range kg/m^3	C_0	C_1	C_2
A (products)	653 – 769,5	346,422 8	0,438 8	0
	770 – 787,5	2 680,320 6	0	– 0,003 363 12
	788 – 838,5	594,541 8	0	0
	839 – 1 075	186,969 6	0,486 2	0
B (lubricating oils)	800 – 1 164	0	0,627 8	0
C (special products): A_D factor entered manually	—	not used	not used	not used
D (crude oils)	610 – 1 075	613,972 3	0	0

Reference density can be calculated only by iterations.

Simplified equations may be used for non-petroleum liquids.

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$$D_{\text{ref}} = \frac{D}{\left[1 - C_{\text{exp}} \times \left(T - T_{\text{ref}}\right)\right]} \text{ for linear expansion} \tag{C.4}$$

$$D_{\text{ref}} = \frac{D}{\left[1 - C_{\text{exp}} \times \left(T - T_{\text{ref}}\right)\right]^2} \text{ for quadratic expansion} \tag{C.5}$$

where C_{exp} is the appropriate coefficient of volumetric expansion of the measured liquid that fits the linear or quadratic expansion.

C.7.4 Observed volume

The observed volume, V, is given by Equation (C.6):

$$V = \frac{M}{D} \tag{C.6}$$

where

M is product mass (refer to A.9);

D is observed density (refer to A.4 for D calculated by HTG).

C.7.5 Reference volume

The reference volume, V_{ref}, is given by Equation (C.7):

$$V_{\text{ref}} = \frac{M}{D_{\text{ref}}} \tag{C.7}$$

where

M is the product mass (refer to A.9);

D_{ref} is the reference density (refer to C.7.3).

C.7.6 Thermal expansion of the P1-P2 tie bar

The length of tie bar, H, is equal to the height of P2 above P1:

$$H = H_{\text{ref}} \times [1 + C_{\text{expt}} \times (T_{\text{amb}} - T_{\text{ambref}})] \tag{C.8}$$

where

H_{ref} is the height of P2 above P1 measured at temperature T_{ambref};

C_{expt} is the coefficient of linear expansion of the material of the tie bar;

T_{amb} is the observed ambient temperature;

T_{ambref} is the ambient temperature at which the height, H_{ref}, of P2 was established.

C.8 Measurement uncertainties

C.8.1 Manually entered reference density

Refer to Annex B.

C.8.2 Measured observed density

If the ambient air density is neglected, the observed density is calculated from the measured pressures p_1 and p_2 and the vertical height, H, of P2 above P1 using the simplified Equation (C.9):

$$D = \frac{p_1 - p_2}{g \times H} \tag{C.9}$$

Its uncertainty is given by Equation (C.10):

$$\frac{uD}{D} = \sqrt{\frac{{up_1}^2 + {up_2}^2}{\left(g \times D \times H\right)^2} + \left(\frac{uH}{H}\right)^2} \tag{C.10}$$

where

up_1 is absolute uncertainty, in pascals, of p_1;

up_2 is absolute uncertainty, in pascals, of p_2;

g is local acceleration, in metres per square second, due to gravity;

D is measured observed density, in kilograms per cubic metre;

H is the height, in metres, of the sensor P2 above P1;

uH is the absolute uncertainty, expressed in metres, of the height of the sensor P2 above P1.

C.8.3 Observed inventory volume of product

If the densities of the ambient air and the in-tank vapour are neglected, the product head mass is calculated from the pressures p_1 and p_3 , from the tank average cross sectional area, A_E, and the local acceleration due to gravity, g, using the simplified Equation (C.11):

$$M_\mathrm{head} = \frac{p_1 - p_3}{g} \times A_\mathrm{E} \tag{C.11}$$

The observed volume, V, is calculated from Equation (C.12):

$$V = \left(L_\mathrm{P1} + H_0 + H_\mathrm{b} - L_\mathrm{w}\right) \times A_\mathrm{E} - \frac{W_\mathrm{R}}{D} = \left(\frac{p_1 - p_3}{p_1 - p_2} \times H + H_0 + H_\mathrm{b} - L_\mathrm{w}\right) \times A_\mathrm{E} - \frac{W_\mathrm{R} \times g \times H}{p_1 - p_2} \tag{C.12}$$

The relative uncertainty of the observed volume of tank without a floating roof is given by Equation (C.13):

$$\frac{uV}{V} = \sqrt{\frac{\left(L_\mathrm{P2} \times u\mathrm{P1}\right)^2 + \left(L_\mathrm{P1} \times u\mathrm{P2}\right)^2 + (H \times u\mathrm{P3})^2}{\left[\left(p_1 - p_2\right) \times \left(L - L_\mathrm{w}\right)\right]^2} + \left(\frac{L_\mathrm{P1}}{L - L_\mathrm{w}} \times \frac{uH}{H}\right)^2 + \frac{{uH_0}^2 + {uH_\mathrm{b}}^2 + {uL_\mathrm{w}}^2}{\left(L - L_\mathrm{w}\right)^2} + \left(\frac{uA_\mathrm{E}}{A_\mathrm{E}}\right)^2} \tag{C.13}$$

where

$uP1$	is the absolute uncertainty, in metres, of pressure sensor P1;
$uP2$	is the absolute uncertainty, in metres, of pressure sensor P2;
$uP3$	is the absolute uncertainty, in metres, of pressure sensor P3;
uH	is the absolute uncertainty of the height, in metres, of P2 above P1;
uH_b	is the absolute uncertainty of the height, in metres, of P1 above the HTG reference point;
uH_0	is the absolute uncertainty of the height, in metres, of the HTG reference point above the tank calibration reference point;
uL_w	is the absolute uncertainty of the level, in metres, of free water;
H	is the height, in metres, of P2 above P1;
L	is the product level, in metres;
L_w	is the level, in metres, of free water;
L_{P1}	is the product level, in metres, above sensor P1;
L_{P2}	is the product level, in metres, above sensor P2;
uA_E	is the absolute uncertainty, expressed in square metres, of the tank cross-sectional area.

All absolute uncertainties are expressed in their respective SI engineering units.

C.8.4 Reference inventory volume of product

The total reference volume is obtained by correcting the total observed volume for temperature. As there is a variety of different expansion models, each used for a particular liquid, the reference volume is best expressed as general function of the observed volume, V, the difference between the measured liquid temperature, T, and the reference temperature, T_{ref}, and the expansion coefficient(s), C_{exp}:

$$V_{ref} = f\,(V, T - T_{ref}, C_{exp}) \tag{C.14}$$

For oil products, the equation and tables of its coefficients C_0, C_1 and C_2 for given product is given in C.7.3.

In practice, it can be assumed that the uncertainties of expansion coefficients C_0 and C_1 are zero, and:

$$\frac{uV_{ref}}{V_{ref}} = \sqrt{\left(\frac{uV}{V}\right)^2 + \left(\frac{uF_{VC}}{F_{VC}}\right)^2} \tag{C.15}$$

where

$$\frac{uF_{VC}}{F_{VC}} = \sqrt{\left(\frac{2 \times C_0}{{D_{ref}}^2} + \frac{C_1}{D_{ref}}\right)^2 \times (T - T_{ref})^2 \times \left(\frac{uD}{D}\right)^2 + (A_D \times uT)^2} \tag{C.16}$$

where uT is absolute uncertainty, in degrees Celsius, of the measurement of the liquid temperature.

C.8.5 Reference density of product

The same principle may also be applied to the calculation of the reference density from the measured observed density. As applied to the uncertainty of the reference (base) density for oil products, the uncertainty of this reference density is given by Equation (C.17):

$$\frac{uD_{\mathrm{ref}}}{D_{\mathrm{ref}}} = \sqrt{\left(\frac{uD}{D}\right)^2 + \left(\frac{2 \times C_0}{{D_{\mathrm{ref}}}^2} + \frac{C_1}{D_{\mathrm{ref}}}\right)^2 \times (T_{\mathrm{ref}} - T)^2 \times \left(\frac{uD}{D}\right)^2 + (A_{\mathrm{D}} \times uT)^2} \qquad \text{(C.17)}$$

It is necessary to note that

a) if the liquid level is above sensor P2, the uncertainty of level and therefore also of the observed and the reference volumes varies with level above sensor P2;

b) if the liquid level is below sensor P2, the observed density is no longer measured.

In this case

— with the liquid level falling, the last valid reading of the reference density is usually frozen, its uncertainty is the last one calculated just before the level fell below P2;

— with the liquid level rising, the manually entered reference density is used for the calculations;

— the uncertainty of the reference volume is calculated in accordance with C.7.5.

C.8.6 Examples of uncertainties of inventory measurements

Table C.2 shows an example of calculation uncertainties of reference volume inventory from uncertainties of mass and observed density measured by HTG.

Table C.2 — Example of calculations of uncertainties for inventory measurements — Freely vented tank[a]

Measurement parameters	P1 height, in metres	0,3	0,3	0,3	0,3	0,3
	P2 height, in metres, above P1	2,5	2,5	2,5	5,0	5,0
	Level, in metres, above P2	0,5	5,5	10,0	0,5	8,0
	Level, in metres, above P1	3,0	8,0	12,5	5,5	13,0
	Level, in metres	3,3	8,3	12,8	5,8	13,3
	Density, in kilograms per cubic metre	741	741	741	741	741
	Gravity acceleration, in metres per square second	9,81	9,81	9,81	9,81	9,81
	Expansion coefficients $C_0 = 346{,}422\ 8$ (from table) $C_1 = 0{,}438\ 8$ (from table)	—	—	—	—	—
	Temperature difference, in degrees Celsius	10	10	10	10	10
	Reference density, in kilograms per cubic metre	750	750	750	750	750
Uncertainties of reference values	Pressure zero p_1, p_2, in pascals	50	50	50	100	100
	Pressure linearity p_1, in % of reading	0,07	0,07	0,07	0,1	0,1
	Pressure linearity p_2, in % of reading	0,07	0,07	0,07	0,1	0,1
	P1 height, in metres	0,005	0,005	0,005	0,01	0,010
	P2 height, in metres, above P1	0,005	0,005	0,005	0,01	0,010
	Tank capacity table, in % of reading	0,05	0,1	0,1	0,1	0,1
	Temperature, in degrees Celsius	1	1	1	1	1
Uncertainties of the inventory measurements	Level above P1, in metres,	0,011	0,047	0,097	0,019	0,076
	Level, in metres,	0,012	0,047	0,097	0,022	0,076
	Density, in % of reading	0,503	0,688	0,860	0,519	0,718
	Volume correction factor, in % of reading	0,120	0,121	0,121	0,120	0,121
	Reference density, in % of reading	0,517	0,698	0,868	0,533	0,728
	Volume, in % of reading	0,361	0,576	0,763	0,387	0,582
	Reference volume, in % of reading	0,381	0,588	0,772	0,405	0,594

[a] Note that the uncertainties of volumes are less than those of the densities.

C.8.7 Transferred observed and reference volumes

The transferred observed volume is calculated as the difference between the opening and closing inventories of observed volume. If it is assumed that the transfer does not open or close with the level below the sensor P1:

$$V_\mathrm{x} = (L_\mathrm{open} - L_\mathrm{close}) \times A_\mathrm{E} = L_\mathrm{x} \times A_\mathrm{E} \tag{C.18}$$

Uncertainty of the transferred observed volume is given by Equation (C.19):

$$\frac{uV_\mathrm{x}}{V_\mathrm{x}} = \sqrt{\left[\frac{up_\mathrm{1zero}}{g \times D \times H} + \left(\frac{L_\mathrm{P1o} + L_\mathrm{P1c}}{H} - 1\right) \times up_\mathrm{1lin}\right]^2 + \left[\frac{up_\mathrm{2\,zero}}{g \times D \times H} + \left(\frac{L_\mathrm{P1o} + L_\mathrm{P1c}}{H} - 1\right) \times up_\mathrm{2\,lin}\right]^2 + \left(\frac{up_\mathrm{3\,lin} \times p_\mathrm{3range}}{g \times D \times L_\mathrm{x}}\right)^2 + \left(\frac{uH}{H}\right)^2 + \left(\frac{uA_\mathrm{E}}{A_\mathrm{E}}\right)^2} \tag{C.19}$$

where

up_1zero and up_2zero	are the zero components of the uncertainties, in pascals, of the P1 and P2 sensors, respectively;
up_1lin and up_2lin	are linearity components of the uncertainties, in relative values, of the P1 and P2 sensors, respectively;
uH/H	is the relative uncertainty of the height, in metres, of sensor P2 above sensor P1;
$uA_\mathrm{E}/A_\mathrm{E}$	is the relative uncertainty of the cross-sectional area of the tank;
p_3range	is the difference in pressure between the maximum and the minimum vapour pressure (see A.13.1);
L_P1o	is the level, in metres, of the product above sensor P1 at the opening of the transfer;
L_P1c	is the level, in metres, of the product above sensor P1 at the end of the transfer;
L_x	is the difference of levels, in metres, between start and end of the transfer, equal to $L_\mathrm{open} - L_\mathrm{close}$;
H	is the height, in metres, of sensor P2 above sensor P1;
g	is the acceleration, in metres per square second, due to gravity;
D	is the product density, in kilograms per cubic metre.

The uncertainty of the transferred reference (base) volume, if it is assumed that the temperature and its uncertainty remain constant from the start to the end of the transfer, is given by Equation (20):

$$\frac{uV_\mathrm{refx}}{V_\mathrm{refx}} = \sqrt{\left(\frac{uV_\mathrm{x}}{V_\mathrm{x}}\right)^2 + \left(\frac{uF_{VC}}{F_{VC}}\right)^2} \tag{C.20}$$

where

$$\frac{uF_{VC}}{F_{VC}} = \sqrt{\left(\frac{2 \times C_0}{{D_\mathrm{ref}}^2} + \frac{C_1}{D_\mathrm{ref}}\right)^2 \times (T - T_\mathrm{ref})^2 \times \left(\frac{uD}{D}\right)^2 + (A_\mathrm{D} \times uT)^2}$$ as is given by Equation (C.16).

Table C.3 shows an example of the calculations for volume transfers from the uncertainties of mass and observed density, both of which are measured by HTG.

Table C.3 — Examples of transferred volume uncertainties — Freely vented tank

Constants	g = 9,81 m/s^2 H = 2,5 m D = 741 kg/m^3 C_0 = 346,422 8 (from table) C_1 = 0,438 8 (from table)					
Input parameters	L_{P1}, in metres, at open	3,0	9,0	11,0	5,5	11,0
	Level rise, in metres, during transfer	4,0	4,0	2,0	4,0	3,0
	L_{P1}, in metres, at close	7,0	13,0	13,0	9,5	14,0
	T_{ref}, temperature, in degrees Celsius	10	10	10	10	10
Uncertainties of the reference values	up_{1zero}, in pascals	50	50	50	100	100
	up_{1lin}, in % of reading	0,07	0,07	0,07	0,10	0,10
	up_{2zero}, in pascals	50	50	50	100	100
	up_{2lin}, in % of reading	0,07	0,07	0,07	0,10	0,10
	uH, in metres	0,005	0,005	0,005	0,01	0,01
	uT, in degrees Celsius	1	1	1	1	1
	Tank capacity table, in [% of reading]	0,05	0,05	0,10	0,10	0,10
Uncertainties of the transferred volume	Observed volume [% of transfer]	0,716	1,179	1,260	1,541	2,092
	Volume correction factor, in [% of reading]	0,123	0,124	0,125	0,126	0,128
	Reference volume [% of transfer]	0,727	1,186	1,267	1,547	2,096

Annex D
(normative)

Second-order influences

NOTE The effects given in this Annex have second-order influences on HTG measurements. The effects cannot be calibrated out. For measurements requiring high accuracy, precautions should be taken to minimize them.

D.1 HTG sensor movement

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

a) horizontal movement of the tank wall;

b) angular rotation of (parts of) the tank wall;

c) vertical movement of the fixed roof of the tank.

The magnitude of the movements depends on the tank construction and the density and level of the product in the tank. Horizontal movements of sensors P1 and P2 have no effect on the HTG measurements. The angular rotation of the tank wall in places where sensors P1 and P2 are mounted will result in HTG measurement errors. Tie bars should be used to reduce these errors (see 5.1.2.5).

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

D.2 Hydrostatic expansion

The tank capacity tables are corrected for hydrostatic pressure variations. These corrections assume a liquid with a density typical for the tank contents in accordance with ISO 7507-1. If the stored liquid density is significantly different from that used for the tank calibration, the tank capacity table should be corrected and the HTG data processor should be updated with the new parameters. The HTG system should not make any automatic compensation to the tank capacity table due to changing product density. In most practical cases, small liquid density changes will have no significant effect on the HTG measurements.

D.3 Thermal expansion

The volume within the tank shell expands and contracts with changes in the shell temperature. This causes changes in the tank capacity tables and requires correction of all measured volumes. Corrections as given in ISO 7507-1 should be performed by the HTG data processor.

D.4 Liquid stratification

Liquid stratification affects the product mass only by bringing uncertainty into the product heel mass (that below sensor P1) that is calculated from volume and density. Heel density is assumed to be the same as the observed density measured above sensor P1.

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

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