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Petroleum and liquid petroleum products — Direct static measurements — Contents of vertical storage tanks —

Part 1:
Mass measurement by hydrostatic tank gauging

Pétrole et produits pétroliers liquides — Mesurage statique direct — Contenu des réservoirs verticaux de stockage —

Partie 1: Mesurage de masse par jaugeage hydrostatique des réservoirs

Reference number
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Contents

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Foreword

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

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.

International Standard ISO 11223-1 was prepared by Technical Committee ISO/TC 28, *Petroleum products and lubricants*, Subcommittee SC 3, *Static petroleum measurement*.

ISO 11223 consists of the following parts, under the general title *Petroleum and liquid petroleum products — Direct static measurements — Contents of vertical storage tanks*:

— *Part 1: Mass measurement by hydrostatic tank gauging*

— *Part 2: Volume measurement by hydrostatic tank gauging*

Annexes A and B form an integral part of this part of ISO 11223. Annexes C and D are for information only.

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 part of ISO 11228 to indicate mass in vacuum (true mass). In the petroleum industry it is not uncommon to use apparent mass (in air) for commercial transactions.

Petroleum and liquid petroleum products — Direct static measurements — Contents of vertical storage tanks —

Part 1:
Mass measurement by hydrostatic tank gauging

1 Scope

This part of ISO 11223 gives guidance on the installation, commissioning, maintenance, validation and calibration of hydrostatic tank gauging (HTG) systems for the direct measurement of static mass in petroleum storage tanks.

This part of ISO 11223 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 part of ISO 11223 is not applicable to the use of hydrostatic tank gauging on pressurized tanks.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 11223. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 11223 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

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

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

ISO 3838:1983, *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 4266:1994, *Petroleum and liquid petroleum products — Measurement of temperature and level in storage tanks — Automatic methods.*

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

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

ISO 7507-1:1993, *Petroleum and liquid petroleum products — Calibration of vertical cylindrical tanks — Part 1: Strapping method.*

IEC 79-0:1983, *Electrical apparatus for explosive gas atmospheres — Part 0: General requirements.*

API[1] Standard 2545, *Standard practice for gaging petroleum and petroleum products*, 1965; reapproved 1990 (ANSI/ASTM D 1085).

3 Definitions

For the purposes of this part of ISO 11223, the following 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 critical zone height

(1) Upper limit of the critical zone.

(2) Level at which one or more of the floating roof or floating blanket legs first touch the tank bottom.

3.4 critical zone: Level range through which the floating roof or floating blanket is partially supported by its legs.

3.5 dipped volume: Observed volume of product, sediment and water, calculated from the dip level and the tank capacity table.

3.6 floating-roof mass: Value of the floating-roof mass, inclusive of any mass load on the roof, manually entered in the data processor.

3.7 free water level: Level of any water and sediment that exist as layers separate from the product and lie beneath the product.

3.8 gauge pressure sensor: Sensor that uses the ambient air pressure as pressure reference.

3.9 head mass: Total measured mass between the HTG bottom sensor and the top of the tank.

3.10 head space: Space inside the tank, above the bottom HTG sensor, in which product and in-tank vapour are present.

1) American Petroleum Institute.

3.11 heel space: Space inside the tank, below the bottom HTG sensor.

3.12 HTG reference point: Stable reference point from which the HTG sensor positions are measured.

3.13 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.

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

3.15 pin height: Lower limit of the critical zone; the level at which the floating roof or floating blanket rests fully on its legs.

3.16 pressure sensor effective centre: Point on the sensor from which the hydrostatic pressure head is measured.

3.17 product heel mass: Mass of product below the bottom HTG sensor.

3.18 product heel volume: Observed volume of product below the bottom HTG sensor, calculated by subtracting the water volume from the total heel volume.

3.19 product mass: Sum of the head mass and the product heel mass, reduced by the floating-roof mass (if applicable) and the vapour mass.

3.20 product temperature: Temperature of the tank liquid in the region where the HTG measurements are performed.

3.21 reference density: Density at the reference temperature.

3.22 reference temperature: Temperature to which reference density and standard volumes are referred.

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

3.24 tank lip: Tank bottom plate on the outside of the tank shell.

3.25 total heel volume: Observed volume below the bottom HTG sensor, calculated from the bottom sensor elevation and the tank capacity table, corrected for observed temperature.

3.26 ullage pressure: Absolute pressure of the air (air or vapour) inside the tank, above the product.

3.27 ullage volume: Observed volume of vapour/air mixture in the ullage space, calculated as the difference between the total tank volume and the dipped volume.

3.28 vapour relative density: Ratio of molecular mass of vapour (mixture) to that of air (mixture).

3.29 water volume: Observed volume of free sediment and water, calculated from the free water level and the tank capacity tables.

4 System description

4.1 General

A hydrostatic tank gauging (HTG) system is a tank-inventory 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 are not included in the scope of this part of ISO 11223.

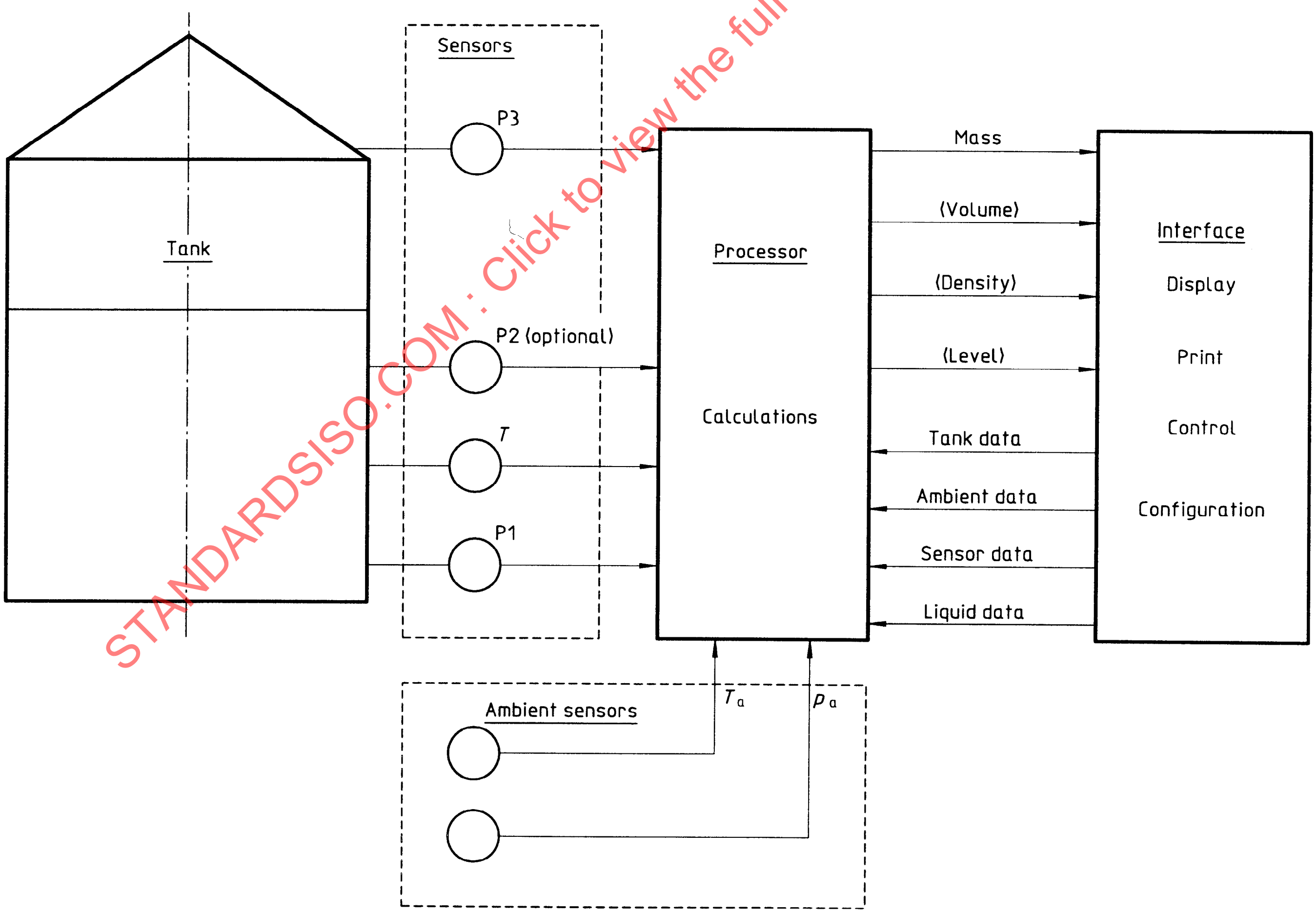

Figure 1 — HTG system — Functional diagram

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. Additionally, temperature sensors can be included to measure the temperature of the tank contents (T) and of the ambient air (T_a). An ambient air pressure sensor (p_a) 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

The 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:

c) calculation of ambient air density;

d) calculation of volumetric expansion of the tank shell;

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

4.2.3 System configuration

The sensor configurations vary depending on the application and data required. Some of the more common variations are as follows.

4.2.3.1 Known liquid density

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

4.2.3.2 Known ullage pressure

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

NOTE 1 Tank ullage pressure on atmospheric fixed-roof tanks may 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 P3 can be entered into the data processor as a constant and sensor P3 omitted on nonvented tanks.

4.2.3.3 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 (ISO 4266).

4.2.3.4 Varying atmospheric conditions

Ambient temperature and pressure sensors can 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 which are required by the application should be programmed into the HTG system.

NOTE 2 The data processor can also calculate level, observed and standard volumes, and observed and reference densities. However, such calculations are not included in the scope of this part of ISO 11223.

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	Temperature to which the tank capacity table was corrected
HTG sensor data	Sensor configuration	Tank with 1, 2 or 3 sensors
	P1 sensor elevation	To HTG reference point
	P2 sensor elevation	Referenced to P1
	P3 sensor elevation	Referenced to P1
Liquid data	Liquid density	If no P2 sensor
	Liquid expansion coefficients	See ISO 91
	Free water level	
Ambient data	Local acceleration due to gravity	Obtained from a recognized source
	Ambient temperature	Optional
	Ambient pressure	Optional

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.

5 Installation

5.1 Pressure sensors

5.1.1 Tank preparation

Prior to installation of the HTG pressure sensors, it is necessary to perform the following activities.

5.1.1.1 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 can 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.

5.1.1.2 Process taps

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

5.1.1.3 HTG reference point

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

5.1.1.4 Tie bars

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

5.1.2 Pressure sensor installation

5.1.2.1 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.

5.1.2.2 Protection against overpressurizing

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

Pressure snubbers between the block valves and the sensors may be required to avoid overpressurizing the sensors. Alternatively, the bleed vent may be opened to relieve pressure buildup as the block valve is closed.

5.1.3 Determination of pressure sensor position

Sensor positions should be measured to the effective centres of the pressure sensors. Since the sensor diaphgrams 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 be also provided.

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

a) P1 sensor elevation H_b above the HTG reference point is used to calculate the tank bottom mass. The error in P1 elevation measurement should not exceed $\pm$ 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 error in the vertical distance P1-to-P2 should not exceed $\pm$ 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 error in the vertical height H_t should not exceed $\pm$ 50 mm.

5.1.4 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 elevation 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 elevation 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). Sensor P1 elevation above the HTG reference point should be measured with the tank full and again with the tank empty. If the elevation 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 only affect 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 B.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 overstressing the sensors.

5.1.5 Wind effect

Wind impacting on 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 respectively. 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 the P1 and P3 sensors should be connected together by a pressure-equalization pipe. The 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 condensed water.

If the P3 sensor is not used, variations in 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 P1 sensor 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 of 0,5 m away from the tank at the ground level is recommended.

5.1.6 Thermal effect

For measurements requiring high accuracy, the HTG performance can 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.

5.2 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 (ISO 4266) and may also include an ambient air temperature-measuring device.

NOTE 3 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 as near to the tank as the pressure sensors, with the same environmental protection.

5.3 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 can be a mark on the tank shell.

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 distance between the HTG and the manual level gauge reference points should be measured using a standard survey technique (for example ISO 7078).

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 HTG parameter entry

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

NOTE 4 The tank parameters will normally remain unchanged. HTG sensor parameters may change if any item of HTG hardware is replaced. Liquid parameters may 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.

5.4.3 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;

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, monitor the zero reading of the sensor for approximately 1 h and make further adjustments if necessary.

5.4.4 Tank capacity table validation

Some tanks currently in service have been calibrated using out-of-date, nonstandard 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 calibration performed if needed.

Capacity tables are normally derived from calibration reports which 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 B.2 and B.3).

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

5.4.5 Checking against manual measurement

The values computed by the HTG system should be compared with those provided by manual measurements. 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 uncertainties of the HTG and the manual measurements, then the HTG system can 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 as measured by HTG. Since weighbridges normally indicate apparent mass in air, it is recommended that apparent mass in air be used when comparing HTG and weighbridges.

5.4.6 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.

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 reference temperatures do not agree within their uncertainties, the HTG parameters (if any) should be adjusted or the sensor(s) replaced.

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 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. Validation is usually performed on a regular basis, following the local code of practice, in order 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 elevations

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

6.2.2 Pressure sensor zeros

Pressure sensor zeros should be checked using the procedure given in 5.4.3, without any adjustments.

6.2.3 On-tank measurements

If the comparison is to be carried out against a manual method, the procedure described in 5.4.5 should be followed.

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

6.2.4 Off-tank measurements

Comparisons on mass 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.

6.2.5 Temperature sensors

Temperature sensors should be checked using the procedure given in 5.4.6, without any adjustments.

6.3 Calibration

6.3.1 General

The objective of HTG system calibration is to verify performance of the HTG system to specified accuracy and to undertake appropriate corrective actions when warranted. HTG system calibration should be performed following a 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.

Apart from 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 the 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. Zero adjustment should be done using the procedure given in 5.4.3.

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 operate outside the limits established at commissioning (see 5.4.6).

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 can be obtained whose accuracy is sufficiently better than the accuracy of the HTG system itself. If such equipment is not available, the HTG system can be calibrated to less 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, either of the two following methods should be used.

6.3.5.2 Reference pressure source method

The reference device for calibration is a traceable deadweight tester accurate to within 25 Pa and 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 deadweight tester. The deadweight tester is used to generate pressures to span 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 mass ranges are covered.

The pressure measurements from the HTG system are compared with those from the deadweight tester. If the two are equal within combined measurement uncertainties, 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 deadweight tester and the pressure sensor.

6.3.5.3 Reference pressure sensor method

The reference device for calibration is a traceable pressure sensor accurate to within $\pm$ 25 Pa and 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 span corresponding to the full height of the tank should be covered either by changing the liquid level in the tank 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 are equal within combined measurement uncertainties, 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 only be used 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 (API Standard 2545), temperature (API Standard 2545) and density (ISO 3838 or ISO 3993), to calculate standard volume (ISO 4267-2) and reference density (ISO 91). Mass should be calculated as the product of standard volume and reference density.

Since manual and HTG measurements are performed using different reference points, two mass readings should be taken 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 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 < 0,2 %, then the HTG system should be assumed to be operating correctly.

NOTE 5 The limit of 0,2 % 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 %

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 withstand a product impact such as corrosion or erosion.

7.2 Electrical safety

All electrical systems should comply with the local safety regulations. Additionally, account should also be taken of the requirements given in IEC 79-0.

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 clause 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:

Parameter	Unit
pressure	pascal
level	metre
area	square metre
volume	cubic metre
mass	kilogram
density	kilogram per cubic metre
acceleration	metre per second squared

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

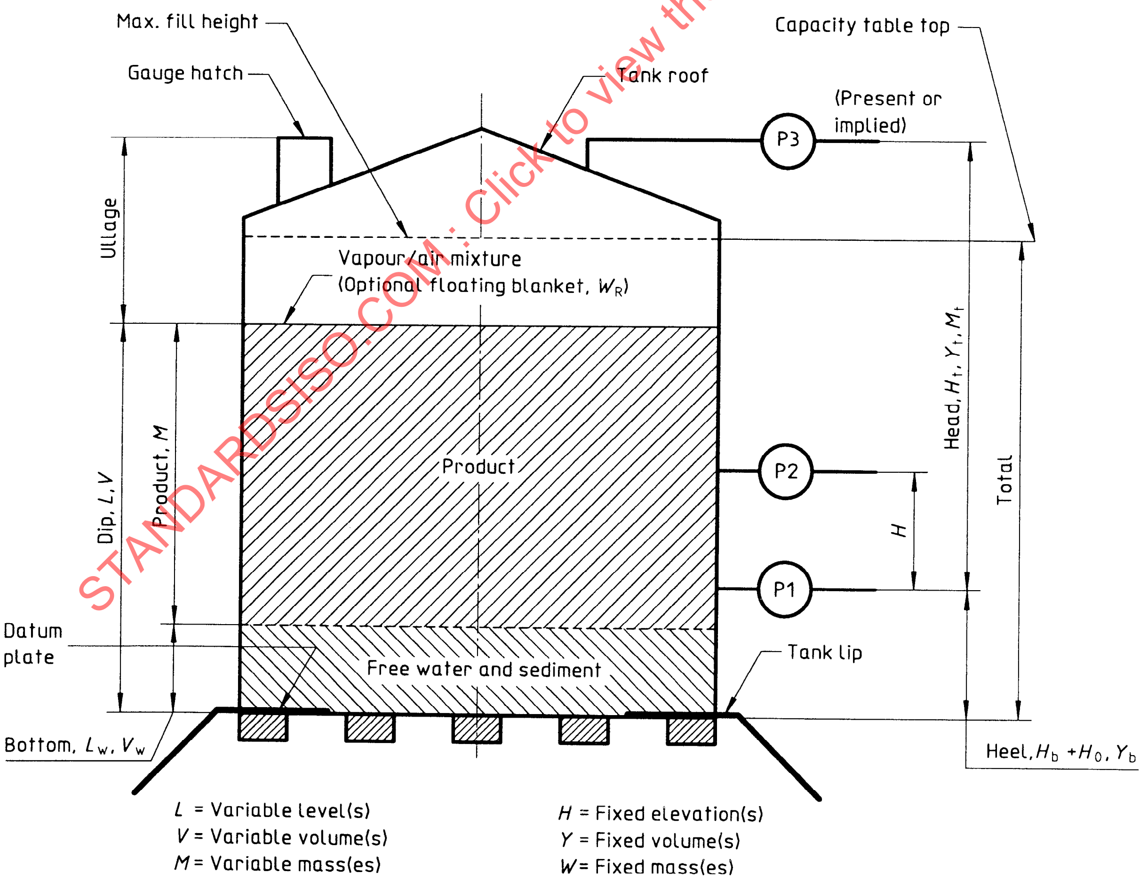

Figure A.1 — Measurement parameters and variables — Fixed-roof tank

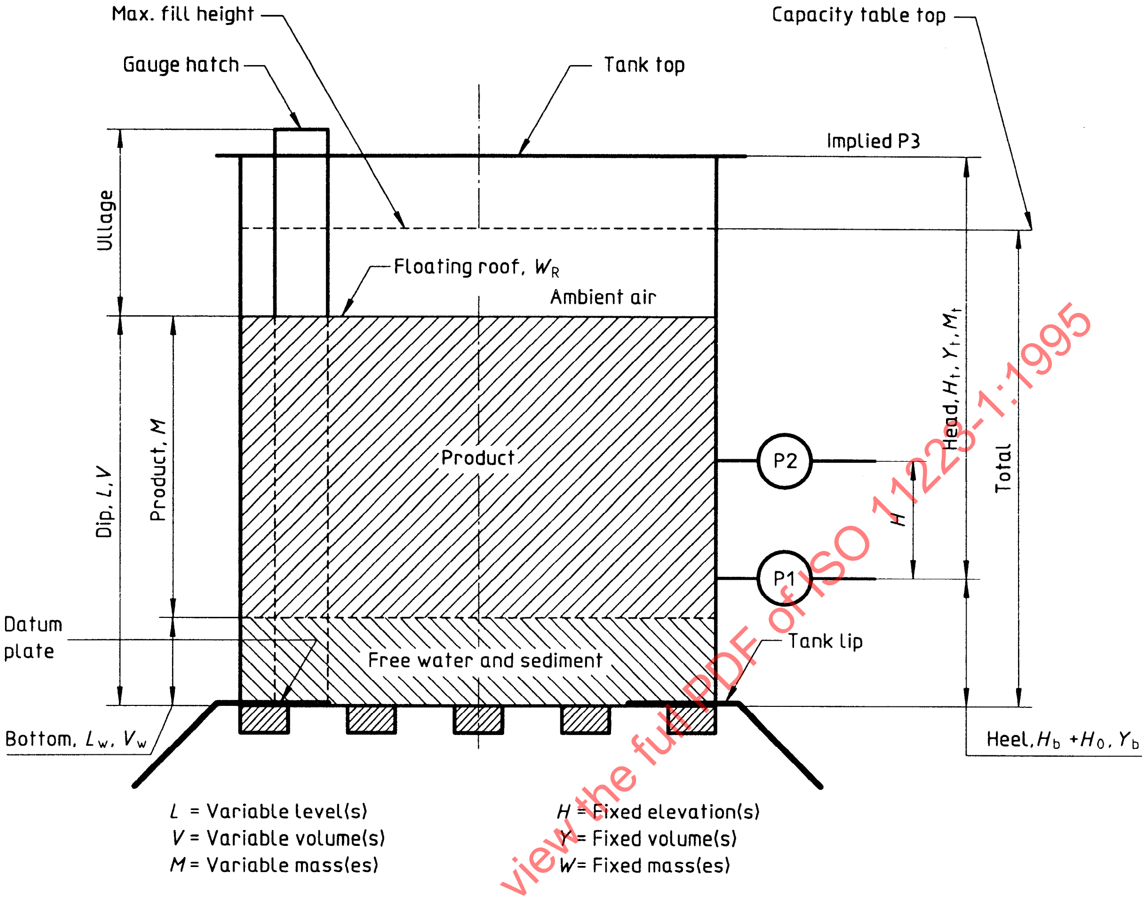

Figure A.2 — Measurement parameters and variables — Floating-roof tank

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

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

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

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

A.2 List of symbols

Symbol	Meaning
A_E	tank average cross-sectional area
D	liquid density (observed product density)
D_a	ambient air density
D_V	in-tank vapour density
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 nass
M_t	product head mass
V	dipped volume (at dip level)
V_b	product heel volume
V_w	free water volume
W_R	mass of floating roof (or floating blanket)
Y_b	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:

Thus:

P1 – P3 = total liquid product pressure head + in-tank vapour pressure head – ambient air pressure head between sensors P1 and P3;

P1 – P2 = liquid product pressure head between sensors P1 and P2 – 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 which 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 standard, both components are user-entered constants. This applies also to the floating blanket optionally used in fixed-roof tanks.

A.4 Density calculations

Observed density D (calculated from pressures):

$$D = [(\mathrm{P1} - \mathrm{P2}) / (gH)] + D_a$$

where

(P1 – P2)	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 diaphgrams respectively (see figure A.1 or A.2);
D_a	is the ambient air density.

NOTE 6 Observed density can be calculated from manually entered reference density. The calculations should follow existing standards such as ISO 91.

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

A.5 Dip level calculations

Dip level, L:

$$L = H_0 + H_b + \frac{\{[(\mathrm{P1} - \mathrm{P3}) / g] - [H_t(D_V - D_a)]\}}{(D - D_V)}$$

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 A.2);
(P1 – P3)	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 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 7 If D_V is not available, it may be assumed equal to D_a.

A.6 Tank average cross-sectional area calculations

Tank average cross-sectional area:

$$A_E = (V - Y_b) / (L - H_b - H_0)$$

where

V is the dipped volume (at dip level);

Y_b 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 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 dip level and the sensor P1 elevation $(H_b + H_0)$ respectively, as described in ISO 7507-1.

A.7 Head mass calculations

Product head mass:

$$M_t = A_E \{[(P1 - P3) / g] - [D_V(H_t + H_b - L)] + [D_a H_t]\}$$

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;

H_b is the vertical distance of the centre of force on sensor P1 from the HTG reference point (see figure A.1 or A.2);

H_t is the vertical distance of the centres of force on the sensor P1 and P3 diaphgrams respectively (see figure A.1 or A.2);

L is the dip level calculated in A.5;

D_a is the ambient air density.

NOTE 8 If D_V is not available it may be assumed equal to D_a.

A.8 Heel mass calculations

Product heel volume:

$$V_b = Y_b - V_w$$

where

Y_b is the total heel volume calculated from the P1 sensor elevation $(H_b + H_0)$ 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.

Product heel mass:

$$M_b = V_b D$$

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 can be affected by liquid stratification (see B.4).

A.9 Product mass calculation

Product mass:

$$M = M_t + M_b - W_R$$

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).

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

Product apparent mass in air:

$$M_a = M[1 - (D_a/D)]$$

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 Inventory accuracy

Providing that the pressure sensor installation parameters are correct, the calculated mass accuracy depends only on the accuracies of the pressure sensors, the tank capacity table and the local acceleration due to gravity. For HTG systems, typical accuracy calculations are given below:

Neglecting P3 and considering that:

$$M_t = \mathrm{P1} \times \frac{A_E}{g}$$

Assuming that all errors are statistically independent, then:

$$E_{M_t}^{\ 2} = E_{P1}^{\ 2} + E_g^{\ 2} + E_{A_E}^{\ 2}$$

where

E_{M_t} is the error of reading of product head mass (absolute mass error/absolute mass);

E_{P1} is the error of reading of pressure P1;

E_g is the error of reading of the local acceleration due to gravity;

E_{A_E} is the error of reading of the tank average cross-sectional area.

The error of reading of the tank average cross-sectional area is the same as the error in the tank capacity table. This is normally in the region of ± 0,05 % to ± 0,1 %.

Table A.1 shows that the error in the average area (based on the tank capacity table) has a dominant influence on inventory accuracy.

Table A.1 — Example of inventory accuracies

Sensor	Accuracy (± % reading)			
Pressure P1	0,01	0,02	0,05	0,1
Local g	0	0	0	0
Average tank area	0,1	0,1	0,1	0,1
Inventory mass	0,10	0,10	0,11	0,14

Annex B
(normative)

Second-order influences

The following effects 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.

B.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 can 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, 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 5.1.1.4).

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

B.2 Hydrostatic expansion

The tank capacity tables are corrected for hydrostatic pressure variations. The corrections assume a liquid with density typical for the tank contents according to ISO 7507-1. If the stored liquid density is significantly different from that used for the tank calibration, then the tank capacity table should be corrected and the HTG data processor should be updated with the new parameters. 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.

B.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 required correction of all measured volumes. Corrections as given in ISO 7505-1 should be performed by the HTG data processor.

B.4 Liquid stratification

Liquid stratification affects the product mass only by bringing uncertainty into the product heel mass (below sensor P1) which 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. The effect is normally insignificant.

Annex C
(informative)

Terminology

The following terms are included in this annex for information only. The terms are defined in previous ISO standards.

C.1 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]

C.2 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]

C.3 density: Mass of the substance divided by its volume. [ISO 3838].

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

C.4 dip; innage: Depth of a liquid in a tank. [ISO 7507-1]

C.5 fixed-roof tank: Vertical cylindrical storage vessel with either a cone- or domed-shaped roof. The tank may be of the nonpressurized or freely vented type or it may be of the low pressure type. [ISO 4266]

C.6 floating blanket [cover] [screen]: Lightweight cover of either metal or plastic material designed to float on the surface of the liquid in a fixed-roof tank. The blanket is used to retard the evaporation of volatile products in a tank. [ISO 7507-1]

C.7 floating-roof tank: Tank in which the roof floats freely on the surface of the liquid, except at low levels when the weight of the roof is taken, through its supports, by the tank bottom. [ISO 7507-1]

C.8 gauge reference point: Point from which the liquid depths are measured. [ISO 8311]

C.9 net standard volume: Total standard volume minus the volume of water and sediment.

NOTE 9 For clean, refined product, the total standard volume and the net standard volume are usually equal. [ISO 4267-2]

C.10 observed density: Value obtained at a test temperature which differs from the calibration temperature of the apparatus. [ISO 3838]

C.11 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. [ISO 7507-1]

C.12 total standard volume: Total volume at standard conditions, also corrected to standard pressure. [ISO 4267-2]

C.13 total volume: Indicated volume without correction for temperature and pressure. It includes all water and sediment. [ISO 4267-2]

C.14 ullage; outage: Capacity of the tank not occupied by the liquid. [ISO 7507-1]