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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

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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.

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.

1) American Petroleum Institute.

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.

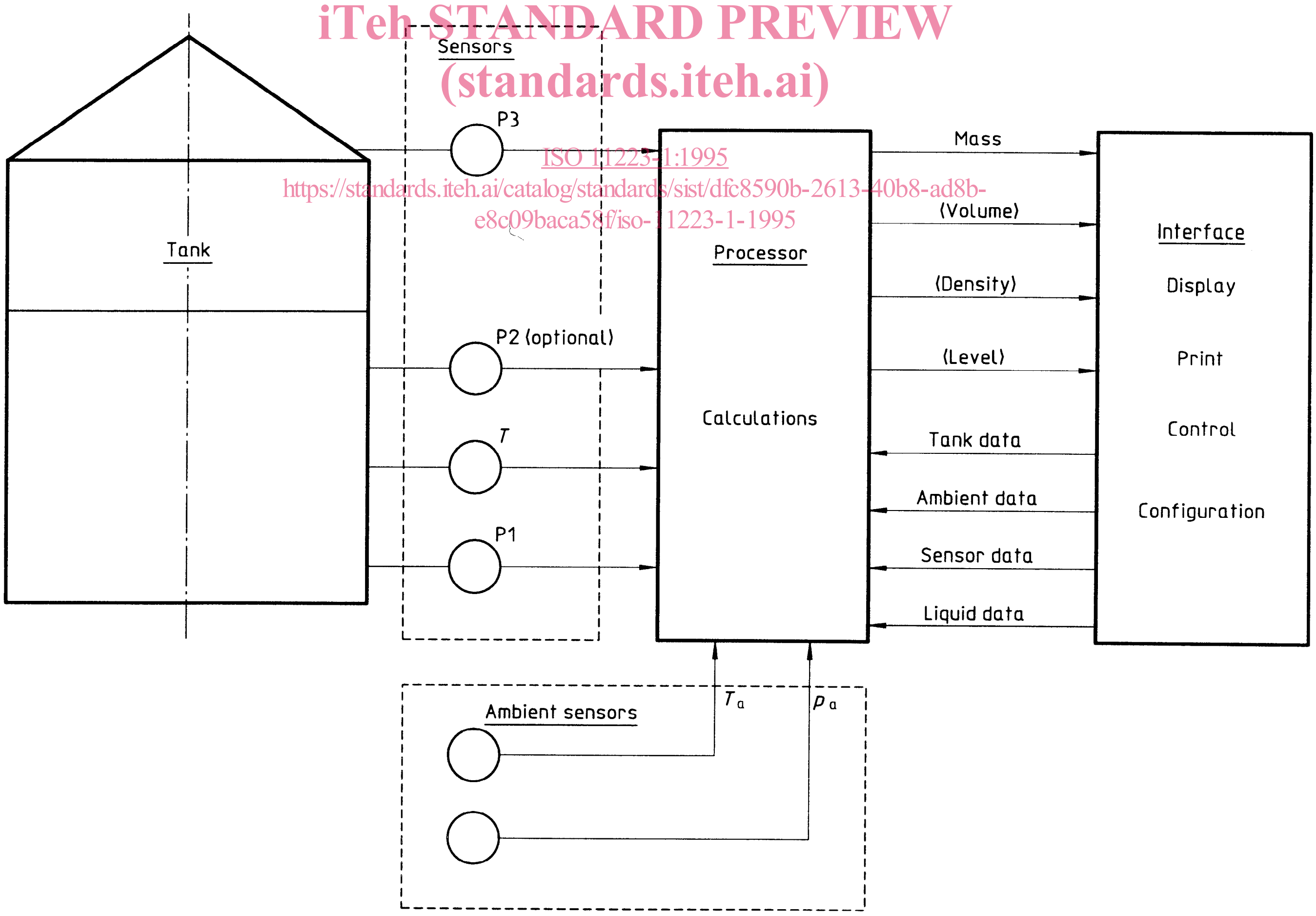

Figure 1 — HTG system — Functional diagram

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).