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Petroleum and liquid petroleum products — Calculation of oil quantities —

Part 2: Dynamic measurement

Pétrole et produits pétroliers liquides — Calcul des quantités de pétrole —

Partie 2 : Mesurage dynamique

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 approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 4267-2 was prepared by Technical Committee ISO/TC 28, *Petroleum products and lubricants*.

Users should note that all International Standards undergo revision from time to time and that any reference made herein to any other International Standard implies its latest edition, unless otherwise stated.

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Petroleum and liquid petroleum products — Calculation of oil quantities —

Part 2: Dynamic measurement

0 Introduction

Before the compilation of this publication, words and expressions employed in dynamic measurement calculations were interpreted slightly differently by different people, and there was a lack of coherence in their use. In addition, because data were spread over so many standards, there was difficulty in readily comparing the finer points of calculations.

Rules for rounding, and the choice of how many significant figures entered each calculation, were open to a variety of interpretations. For different operators to obtain identical results from the same data, the rules for sequence, rounding and significant figures have to be defined. This International Standard aims, among other things, at defining the minimum set of rules required. Nothing in this International Standard precludes the use of more precise determinations of temperature, pressure and density or the use of more significant digits, by mutual agreement among the parties involved.

This International Standard aims at consolidating and standardizing calculations pertaining to the metering of petroleum liquids, and at clarifying terms and expressions by eliminating local variations of such terms. The purpose of standardizing calculations is to produce the same answer from the same data regardless of the computing system used.

Although ISO/TC 28 standards use 15 °C as a standard reference temperature, it is recognized that individual countries may use other reference temperatures, for example 20 °C, 12 °C or 60 °F.

This standard sets minimum levels of accuracy for industrial calculations, but, if parties consider agreeing to set tighter requirements, it is important to demonstrate whether such requirements can be met. Future technological progress in meter proving and operation may justify a tighter specification for calculation procedures.

1 Scope and field of application

This International Standard defines the various terms (be they words or symbols) employed in the calculation of metered

petroleum quantities. Where two or more terms are customarily employed in the oil industry for the same quantity, a preferred term is selected.

This International Standard also specifies the equations which allow the values of correction factors to be computed. It also gives rules for the sequence, rounding and significant figures to be employed in a calculation. It provides tables which may be used to look up specific correction factors should it not be desired to calculate them by manual as well as computer methods. The calculation of prover base volumes, meter factors and measurement tickets is also covered.

The field of application of this International Standard is the volumetric measurement of liquid hydrocarbons, including liquefied petroleum gases, by meter and prover. It does not include two-phase fluids (though it may be found useful in such situations) except in so far as sediment and water may be mixed in with crude oil.

2 References

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

ISO 2715, *Liquid hydrocarbons — Volumetric measurement by turbine meter systems.*

ISO 5024, *Petroleum liquids and gases — Measurement — Standard reference conditions.*

ISO 7278-2, *Liquid hydrocarbons — Dynamic measurement — Proving systems for volumetric meters — Part 2: Pipe provers.*¹⁾

ISO 8222, *Petroleum measurement systems — Calibration — Temperature corrections for use with volumetric reference measuring systems.*

ISO 9770, *Petroleum products — Compressibility factors for hydrocarbons in the range 638 kg/m³ to 1 074 kg/m³.*¹⁾

1) At the stage of draft.

3 Definitions

For the purposes of this International Standard, the following definitions apply to the terms used herein:

3.1 base volume: The volume of a prover under standard conditions.

3.2 indicated volume: The change in meter reading that occurs during a transfer through the meter.

3.3 K-factor: The number of pulses generated by a meter for a unit of volume delivered.

$$K\text{-factor} = \frac{\text{pulses generated by meter}}{\text{volume delivered by meter}}$$

3.4 measurement ticket: A generalized term for the written acknowledgment of the receipt or delivery of a quantity of crude oil or petroleum product, including a record of the measurement data (see clause 9). It may be a form to be completed, a data print-out or a data display depending on the degree of automation, remote control, or computerization. Previously described as "run ticket" and "receipt and delivery ticket".

3.5 meter factor: The ratio of the actual volume of liquid passed through a meter to the volume indicated by the meter.

$$\text{Meter factor} = \frac{\text{volume passed through a meter}}{\text{volume indicated by the meter}}$$

3.6 net standard volume: The total standard volume (see 3.9) minus the volume of water and sediment transferred through the meter.

NOTE — For clean, refined products, the total standard volume and net standard volume are usually equal.

3.7 reading; meter reading: The instantaneous display of meter volume (see *indicated volume*).

3.8 standard (reference) conditions: For the measurement of petroleum and its products, these are a pressure of 101,325 kPa (1,013 25 bar) and a temperature 15 °C, with the exception of liquids having a vapour pressure greater than atmospheric pressure at 15 °C, in which case the standard pressure is the equilibrium vapour pressure at 15 °C (see ISO 5024).

3.9 total standard volume: The total volume at standard temperature, also corrected to standard pressure.

3.10 total volume: The indicated volume multiplied by the appropriate meter factor for the liquid and flow rate concerned, without correction for temperature and pressure. It includes all water and sediment transferred through the meter.

4 Hierarchy of accuracies

4.1 Purpose and implications

4.1.1 There is an inevitable, or natural, hierarchy of accuracies in petroleum measurement. At the top are volume standard measures which are certified by a government agency or laboratory traceable to the appropriate national standard. From this level downwards, any uncertainty at a higher level must be reflected in all the lower levels as a systematic error. Whether such systematic error will be positive or negative is unknown; either is possible.

4.1.2 To expect equal or less uncertainty at a lower level of the hierarchy than exists in a higher level is unrealistic. The only way to decrease the random component of uncertainty in a given measurement system or method is to increase the number of determinations, and calculate the mean value. The number of significant digits in intermediate calculations of a value can be larger in the upper levels of the hierarchy than in the lower levels.

4.2 Hierarchy

4.2.1 The hierarchy of accuracies in this standard is structured, in general, as shown in table 1.

4.2.2 This standard gives rules for rounding, truncating and reporting final values for each level of the hierarchy.

5 Principal correction factors

5.1 Purpose and implications

5.1.1 Designation of correction factors by symbol rather than by words is recommended because, first, it abbreviates their expression; second, it allows algebraic manipulations; third, it indicates their similarity subject only to the particular liquid or metal involved; and fourth, it can more readily eliminate confusion, as for example the difference between the compressibility factor F of a liquid and the correction factor C_{pl} , which is a function of F .

There are six principal correction factors employed in calculations of liquid quantities.

5.1.2 The first of these six correction factors is the meter factor MF, a non-dimensional value which corrects the volume indicated on a meter or meter accessory to the actual volume, be that volume a raw or corrected volume (see clause 7). In some instances, the K -factor is used in place of or along with the meter factor (see clause 8).

Table 1 — Hierarchy of accuracies

Clause	Hierarchy level	Correction factors and intermediate calculations to	Number of significant digits in volume	Temperature and pressure determination, for entering calculations, to
6	Prover calibration	6 decimal places ¹⁾	5	0,05 °C 50 kPa ²⁾
7	Meter factor	4 decimal places	5	0,25 °C ³⁾ 50 kPa ²⁾
8	K-factor	4 decimal places	5	0,25 °C ³⁾ 50 kPa ²⁾
9	Measurement tickets	4 decimal places	5	0,50 °C ³⁾ 50 kPa ²⁾

1) When water is used as the calibration liquid, correction factors for the effect of temperature and pressure on the calibrating liquid to 6 decimal places are used.

When a hydrocarbon is used as the calibrating liquid, correction factors for the effect of temperature and pressure on the calibrating liquid shall be calculated using the procedures referred to in ISO 91-1. Factors calculated using ISO 91-1 will be limited to 5 significant figures (4 or 5 decimal places). Cases may arise where calibration personnel do not have the capability to calculate ISO 91-1 values but do have access to the printed tables referred to in ISO 91-1. Under these conditions, linear interpolation of the tables over a limited span is acceptable for use in correcting for the temperature difference between master meter and prover during calibration.

2) In all hierarchies above, pressures shall be read, recorded and rounded to the nearest 50 kPa (0,5 bar). Where the gauge scale permits a closer tolerance, readings should be read, recorded and rounded to the nearest gauge scale division.

3) The use of a temperature determination device that can perform to a more stringent determination level than outlined in table 1 is acceptable provided that the installation, maintenance, operation and calibration practices are adequate to ensure performance to the level chosen.

5.1.3 The next four correction factors employed in calculations of liquid quantities are needed because of changes in volume from the effects of temperature and pressure upon both the containing vessel (usually made of mild steel) and upon the liquid involved. These four correction factors are:

C_{ts} (or CTS) ... the correction factor for the effect of temperature on steel (see 5.2)

C_{ps} (or CPS) ... the correction factor for the effect of pressure on steel (see 5.3)

C_{pl} (or CPL) ... the correction factor for the effect of pressure on liquid (see 5.4)

C_{tl} (or CTL) ... the correction factor for the effect of temperature on liquid (see 5.5)

5.1.4 Finally, there is a correction factor C_{sw} (or CSW) for accounting for the presence of sediment and water in crude oil (see 9.3.1).

5.1.5 Additional subscripts may be added to the symbolic notations above to make it clear to what part of the measuring apparatus they apply, namely p for prover, m for meter and M for a volume standard measure.

While the customary subscript notation is used in this standard, the allowed upper case notation is needed for computer pro-

gramming and is convenient in typing. In such cases, M for measure shall be SM while m for meter shall be M.

5.1.6 The method for correcting volumes by 2 or more factors is to first obtain a CCF (combined correction factor) by multiplying the individual correction factors together in a set sequence, rounding at each step. Only then multiply the volume by the CCF. The set sequence is MF, C_{ts} , C_{ps} , C_{pl} , C_{tl} and C_{sw} , omitting any factors that may not be required in the calculation.

NOTE — This is considered the theoretically correct sequence for applying the six correction factors. However, it is acknowledged that, in some cases where mechanical or electronic devices are used to apply one or more of these factors, the order may be changed. This is especially true of temperature-compensated meters. However, if the correction factors are determined using the correct basis of temperature, pressure and density, the numerical value of the combined correction factor (CCF) will not be significantly different from the theoretical value.

5.1.7 All multiplication within a single operation shall be completed before the division is started.

5.2 C_{ts}

5.2.1 The volume of a metal container, such as a pipe prover, tank prover or volume standard measure, will change when subjected to a change in temperature. The volume change, regardless of shape, is directly proportional to the temperature

change of the material of which the container is made. The correction factor for the effect of temperature on steel (C_{ts}) shall be calculated from the equation

$$C_{ts} = 1 + (t - 15) \gamma \qquad \dots (1)$$

where

- t is the temperature, in degrees Celsius, of the container walls;
- γ is the coefficient of cubical expansion per degree Celsius of the material of which the container is made.

Thus, C_{ts} will be greater than 1 when the temperature t is greater than 15 °C, and less than 1 when the temperature t is less than 15 °C.

5.2.2 The value of γ is $3,3 \times 10^{-5}$ (or 0,000 033) per degree Celsius for mild or low-carbon steels, and has a range of $4,30 \times 10^{-5}$ to $5,40 \times 10^{-5}$ per degree Celsius for Series 300 stainless steels. The value used in the calculations shall be that given on the certificate from the calibrating agency for a volume standard measure or from the manufacturer of a prover. Tables of C_{ts} values against observed temperature will be found in annex A of this standard, the table for stainless steels being based upon a typical value of γ of $5,10 \times 10^{-5}$ for Series 300 stainless steels.

5.2.3 When the volume of the container at standard temperature (15 °C) is known, the volume at any other temperature t can be calculated from the equation

$$V_t = V_{15} \times C_{ts} \qquad \dots (2)$$

5.2.4 Conversely, when the volume of the container at any temperature t is known, the volume at standard temperature (15 °C) can be calculated from the equation

$$V_{15} = V_t / C_{ts} \qquad \dots (3)$$

5.3 C_{ps}

5.3.1 If a metal container such as a tank prover, pipe prover or volume standard measure is subjected to an internal pressure, the walls of the container will stretch elastically and the volume of the container will change accordingly.

While it is recognized that simplifying assumptions enter the equations below, for practical purposes the correction factor C_{ps} for the effect of internal pressure on the volume of a cylindrical container shall be calculated from the equation

$$C_{ps} = 1 + PD/ET \qquad \dots (4)$$

where

- P is the internal gauge pressure in kilopascals;
- D is the internal diameter in millimetres;

E is the modulus of elasticity of the container material ($2,1 \times 10^8$ kPa for mild steel and $1,9 \times 10^8$ kPa to $2,0 \times 10^8$ kPa for stainless steels);

T is the wall thickness of the container in millimetres.

5.3.2 C_{ps} values for specific sizes and wall thicknesses of mild-steel pipe provers and pressures may be found in tables 6 and 7 of annex A of this International Standard. When the volume of the container at atmospheric pressure V_{atmos} (i.e. zero gauge pressure) is known, the container volume at any other pressure V_p can be calculated from the equation

$$V_p = V_{atmos} \times C_{ps} \qquad \dots (5)$$

5.3.3 When the container volume at any gauge pressure P is known, the equivalent container volume at atmospheric pressure V_{atmos} can be calculated from the equation

$$V_{atmos} = V_p / C_{ps} \qquad \dots (6)$$

5.4 C_{pl}

5.4.1 The volume of a liquid is inversely proportional to the pressure acting on that liquid. The correction factor C_{pl} for the effect of pressure on a volume of liquid can be calculated from the equation

$$C_{pl} = \frac{1}{1 - (P - P_e) F} \qquad \dots (7)$$

where

- P is the gauge pressure in kilopascals;
- P_e is the equilibrium vapour pressure of the liquid at the measurement temperature, in kilopascals gauge pressure [P_e is taken as zero gauge pressure for liquids which have an equilibrium vapour pressure less than atmospheric pressure (101,325 kPa absolute pressure) at the measurement temperature];

F is the compressibility factor for hydrocarbons from ISO 9770 (this is determined at the meter operating temperature and the oil density at 15 °C; for water, the compressibility factors at various water temperatures are listed in table 2 below).

Table 2 — Isothermal compressibility factor for water

Temperature °C	Compressibility factor kPa ⁻¹
5	$4,9 \times 10^{-7}$
10	$4,8 \times 10^{-7}$
15	$4,7 \times 10^{-7}$
20	$4,6 \times 10^{-7}$
25	$4,5 \times 10^{-7}$
30	$4,5 \times 10^{-7}$
35	$4,4 \times 10^{-7}$
40	$4,4 \times 10^{-7}$
45	$4,4 \times 10^{-7}$
50	$4,4 \times 10^{-7}$

5.4.2 When P_e is zero, equation (7) becomes:

$$C_{pl} = \frac{1}{1 - PF} \quad \dots (8)$$

5.4.3 When P_e is greater than zero gauge pressure, equation (7) shall be used.

NOTE — A convenient field method of determining P_e while proving a meter against a pipe prover is to proceed as follows:

a) On conclusion of the last proving round, stop the flow through the pipe prover and isolate it from the flowing lines by shutting the appropriate valves.

b) Reduce the pressure on the pipe prover by bleeding off liquid until the gauge pressure stops falling. This will imply that a vapour space has been created, and that the liquid has reached its equilibrium vapour pressure. Shut the bleed valve, and read P_e on the gauge, making a record of the temperature at the time. The above procedure may be used for the determination of P_e for liquid mixtures that do not conform with published charts showing P_e values plotted against temperature, or it may be used as a routine procedure.

5.4.4 When the volume of a low-vapour-pressure liquid is known at any pressure (V_p), the equivalent liquid volume at standard pressure (zero gauge pressure, or V_{atmos}) can be calculated from the equation

$$V_{atmos} = V_p \times C_{pl} \quad \dots (9)$$

5.4.5 When the volume of a low-vapour-pressure liquid is known at zero gauge pressure, the equivalent volume at any other pressure V_p can be calculated from the equation

$$V_p = V_{atmos}/C_{pl} \quad \dots (10)$$

5.4.6 When the volume of a high-vapour-pressure liquid is known at any measurement temperature t and pressure P , pressure correction is done in two steps. The equivalent volume at such a liquid's equilibrium vapour pressure P_e at the measurement temperature can be calculated from the equation

$$V_{pe} = V_p \times C_{pl} \quad \dots (11)$$

where C_{pl} is calculated from equation (7).

When this volume is in turn temperature-corrected to 15 °C using equation (12), the value of C_{tl} taken from the appropriate table, or calculated, also corrects the volume for the change in pressure from P_e at the measurement temperature to the equilibrium vapour pressure at the standard temperature of 15 °C. It should be noted that, while P_e at the measurement temperature t may be higher than atmospheric pressure (101,325 kPa absolute pressure), equilibrium vapour pressure at 15 °C may have fallen to atmospheric pressure or less. As noted under equation (7), the distinction between a low-vapour-pressure liquid and high-vapour-pressure liquid is based on whether its equilibrium vapour pressure is less than or greater than atmospheric pressure at the measurement temperature.

5.5 C_{tl}

5.5.1 If a quantity of petroleum liquid is subjected to a change in temperature, its volume change will be dependent upon the magnitude of the temperature change, the location within a range of temperatures that this change occurs at and the density of the liquid.

The values of C_{tl} for the correction of volume to that at 15 °C shall be taken from tables referenced in ISO 91-1.

5.5.2 When the volume of a petroleum liquid is known at any temperature t , the equivalent volume at standard temperature (15 °C) can be calculated from the equation

$$V_{15} = V_t \times C_{tl} \quad \dots (12)$$

5.5.3 When the volume of a petroleum liquid is known at 15 °C, the equivalent volume at any temperature t can be calculated from the equation

$$V_t = V_{15}/C_{tl} \quad \dots (13)$$

6 Calculation of prover volume

6.1 Purpose and implications

6.1.1 The purpose of calibrating a prover is to determine its base volume, that is, the volume of the prover under standard conditions. The procedures to be used for a pipe prover are described in ISO 7278-2.

6.1.2 Base volume is expressed in cubic metres or litres. Whereas volumetric units (e.g. the litre) do not vary with temperature and pressure, the volume of a metal prover does. Therefore to define the base volume of a prover or volumetric standard, it is necessary to specify standard conditions, namely 15 °C and 101,325 kPa absolute pressure (atmospheric pressure).

6.2 Volume standard measures

Volume standards used to calibrate provers shall be certified by a government agency or by a laboratory traceable to the appropriate national standard. Their certified volumes are given in measurement units at standard conditions. The uncertainty figure of field standards is usually the main component in the uncertainty figure of the prover calibration.

6.3 Rule for rounding — Provers

When calculating a prover volume, determine individual correction factors to 6 decimal places by using the appropriate formula (4 or 5 decimal places for C_{tl} values when hydrocarbons are used). Record the combined correction factor (CCF) rounded to 6 decimal places.

When using the water draw method, each individual volume in a volume standard shall be corrected by C_{tdw} [see 6.6.1a)] and