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Petroleum measurement systems —

Part 2: Pipe prover design, calibration and operation

Systèmes de mesurage des produits pétroliers —

Partie 2: Conception, étalonnage et fonctionnement des tubes étalons

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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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 28, *Petroleum and related products, fuels and lubricants from natural or synthetic sources*, Subcommittee SC 2, *Measurement of petroleum and related products,* in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 19 *Gaseous and liquid fuels, lubricants and related products of petroleum, synthetic and biological origin,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 7278-2:1988), which has been technically revised. It also cancels and replaces the first edition of ISO 7278-4:1999, the content of which has been incorporated.

The main changes are as follows:

— The content and scope now covers the design of pipe provers given in ISO 7278-2:1988 and the guidance for operators given in ISO 7278-4:1999, which will be withdrawn.

— The different types of pipe prover designs and operating methods have been defined and described.

— The variety of operational methods and the means to apply them to flowmeter calibration of different relative sizes has been described.

— The design, calibration and use of small volume (compact) prover designs has been included.

— The document has been changed from a normative document to a guidance document to reflect best practices.

— The document takes into account changes in practice described in alternative standards produced by the American Petroleum Institute (API) and the Energy Institute (EI).

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

In the petroleum industry the term “proving” is used to refer to the calibration of devices used in the measurement of quantities of crude oils and petroleum products. Proving uses specified methods to show, or prove, that the result falls within specified acceptance criteria. Proving provides an assurance that the resultant measurement provides an acceptable uncertainty for the duty.

A pipe prover, otherwise called a displacement prover, is a volumetric reference device providing a calibration reference standard for flowmeters with an electronic pulsed output. The fluid remains contained within the piping system and proving can be carried out dynamically at various flowrates and pressures without interruption to the flow.

Pipe provers are used extensively within petroleum industry to provide in situ calibration of flowmeters used for fiscal, custody transfer and pipeline integrity applications. They are used with both crude and refined oils and products but may be used with many other fluids within and outside the petroleum industry.

A pipe prover consists of a length of pipe, a section of which has had its internal volume determined by calibration. A displacer, usually a piston or a tightly fitting sphere or ball, travels along this section of pipe displacing an accurately determined volume of liquid. This volume can be compared with an equivalent volume measured by the flowmeter under test.

The calibrated volume of the prover is established by the detection of the displacer passing along the calibrated section of pipe. Detectors sense the passage of the displacer indicating the start and end of travel through the calibrated section. The detectors trigger the counting of pulses produced by a flowmeter using electronic counters or counters within a flow computer. As the pulses represent the volume measured by the associated flowmeter, a calibration is achieved through the relationship with the calibrated volume of the pipe prover.

Pipe provers are of different designs and are manufactured with a wide range of pipe diameters and volumes. They are available for use as part of a fiscal measurement system in fixed locations and as mobile reference devices.

Any type of flow meter giving a pulsed output may be calibrated however the volume, design and type of the prover may impose limitations on the type and size of meter which would be compatible.

This document describes the design, construction, calibration and use of pipe provers primarily used for the calibration, proving and verification of flowmeters used for liquid petroleum products and may be applied to other liquid applications requiring a high standard of measurement accuracy.

Petroleum measurement systems —

Part 2: Pipe prover design, calibration and operation

WARNING — The use of this document may involve hazardous materials, operations and equipment. This document does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this document to establish appropriate safety and health practices.

1 Scope

This document provides descriptions of the different types of pipe provers, otherwise known as displacement provers, currently in use. These include sphere (ball) provers and piston provers operating in unidirectional and bidirectional forms. It applies to provers operated in conventional, reduced volume, and small volume modes.

This document gives guidelines for:

— the design of pipe provers of each type;

— the calibration methods;

— the installation and use of pipe provers of each type;

— the interaction between pipe provers and different types of flowmeters;

— the calculations used to derive the volumes of liquid measured (see Annex A);

— the expected acceptance criteria for fiscal and custody transfer applications, given as guidance for both the calibration of pipe provers and when proving flowmeters (see Annex C).

This document is applicable to the use of pipe provers for crude oils and light hydrocarbon products which are liquid at ambient conditions. The principles apply across applications for a wider range of liquids, including water. The principles also apply for low vapour pressure, chilled and cryogenic products, however use with these products can require additional guidance.

2 Normative references

There are no normative references.

3 Terms, definitions, symbols and units

3.1 Terms and definitions

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1.1
accuracy
closeness of the agreement between a measured quantity value and a true quantity value of a measurand

Note 1 to entry: The concept "measurement accuracy" is not a quantity and should not be given a numerical value. The quantitative expression of accuracy should be in terms of uncertainty. "Good accuracy" or "more accurate" implies small measurement error. Any given numerical value should be taken as indicative of this.

[SOURCE: ISO/IEC Guide 99:2007; 2.13, modified —Note 1 to entry modified; Notes 2 and 3 deleted.]

3.1.2
adjustment
set of operations carried out on a measuring system so that it provides prescribed indications corresponding to given values of a quantity to be measured

Note 1 to entry: Adjustment should not be confused with calibration which is a prerequisite for adjustment.

Note 2 to entry: After adjustment, a recalibration is usually required.

[SOURCE: ISO/IEC Guide 99:2007; 3.11, modified — Note 1 deleted; Notes 1 and 2 to entry shortened.]

3.1.3
batch
proving batch
set of consecutive proving runs that is deemed to be necessary to derive both a mean value of volume, *meter factor* (3.1.22) or *K-factor* (3.1.19), suitable for subsequent use and may also be used as an indication of the repeatability of the measurements

Note 1 to entry: A batch may consist of multiple *runs* or one *run* (3.1.38) of a significant number of multiple *passes* (3.1.24).

3.1.4
block-and-bleed valve
double-block-and-bleed valve
twin seal valve
high integrity valve with double seals and provision for detecting leakage past either seal

3.1.5
calibration
set of operations that establish, under specified conditions, the relationship between quantities indicated by an instrument and the corresponding values realized by standards

Note 1 to entry: Calibration should not be confused with adjustment of a measuring system.

Note 2 to entry: *Proving* (3.1.27) is used in the oil industry and has the same meaning but can include a check of the results against specified acceptance criteria.

[SOURCE: ISO Guide 99:1993[1]; 6.11, modified.]

3.1.6
calibrated volume
base volume
volume of a prover between detectors, or of a volumetric measure between a top and bottom datum, as determined by calibration and expressed at standard conditions

1) Withdrawn.

3.1.7
cavitation
phenomenon related to, and following, *flashing* (3.1.14), where vapour bubbles or voids form and subsequently collapse or implode

Note 1 to entry: Cavitation causes significant measurement error and also potentially causes damage to the pipes, valves and meter components through erosion.

3.1.8
cyclic distortion
periodic variation in the pulse frequency generated by a meter caused by mechanical asymmetry within the meter and accessories

Note 1 to entry: See also *intra-rotational linearity* (3.1.18).

Note 2 to entry: Examples of accessories are calibrators and temperature compensators, mechanical or electronic.

3.1.9
detectors
devices set to directly, or indirectly, sense the passage of the *displacer* (3.1.11) hence indicating each end of the calibrated volume

3.1.10
discrimination
ability of a measuring instrument to respond to small changes in the value of the input

3.1.11
displacer
sphere or a piston used to sweep out the calibrated volume between the *detectors* (3.1.9) of a pipe prover

3.1.12
correction factor
numerical factor by which the uncorrected result of a measurement at the measured conditions is multiplied

Note 1 to entry: Correction factors to standard conditions are used to convert a volume at observed conditions to the volume at another (standard) condition.

3.1.13
error
measured quantity value minus a reference quantity value

Note 1 to entry: Relative error is error divided by a reference value. This can be expressed as a percentage.

[SOURCE: ISO/IEC Guide 99:2007, 2.16, modified — Notes 1 and 2 deleted; new Note 1 to entry added; and admitted terms "measurement error" and "error of measurement" deleted.]

3.1.14
flashing
phenomenon which occurs when the line pressure drops to, or below, the vapour pressure of the liquid, allowing gas to appear from solution or through a component phase change

Note 1 to entry: Vapour pressure of the fluid can increase with increasing temperature.

Note 2 to entry: Flashing is often due to a local pressure drop caused by an increase in liquid velocity, and generally causes significant measurement error.

Note 3 to entry: The free gas produced remains for a considerable distance downstream of the meter even if pressure recovers.

3.1.15
four-way valve
flow reversal valve
single high-integrity valve which reverses the directional flow passing through a bidirectional prover

3.1.16
gating
initiation and cessation of pulse totalization in a counter, triggered from an external event or signal from detectors

3.1.17
interchange valve
sphere handling valve
high integrity mechanism to relocate the *displacer* (3.1.11) from the downstream end of a unidirectional sphere prover to the launch position

Note 1 to entry: The valve enables continuous flow through the prover barrel while preventing flow across the mechanism during a proving pass.

3.1.18
intra-rotational linearity
quantitative measure of the degree of regularity of spacing between the pulses produced by a flowmeter at a constant flowrate

Note 1 to entry: This is generally expressed as the standard deviation of the pulse widths around the mean value.

Note 2 to entry: This may be referred to as inter-pulse deviations.

Note 3 to entry: Inter-rotational linearity is the regularity which repeats in a periodic or cyclic manner normally attributed to the rotation of a meter internal mechanism. This may be referred to as pulse rate modulation.

3.1.19
K-factor
ratio of the number of pulses obtained from a meter to the quantity passed through the meter

3.1.20
end chamber
launch chamber
receive chamber
enlarged section at the ends of the pipe prover in which the *displacer* (3.1.11) rests prior to launch or decelerates and comes to rest upon completion of a pass

3.1.21
linearity
total range of deviation of the accuracy curve from a constant value across a specified measurement range

Note 1 to entry: The maximum deviation is based on the mean of derived values at any one flow point.

Note 2 to entry: The deviation is the largest minus the smallest value of mean values at each flowrate.

Note 3 to entry: Relative linearity is the range of values divided by a specified value, e.g. the independent linearity as defined in ISO 11631.

3.1.22
meter factor
ratio of the quantity indicated by a reference standard to quantity indicated by a meter

3.1.23
nominal volume
design volume of a prover or volumetric measure

3.1.24
pass
single movement of a *displacer* (3.1.11) between two detector actuations

3.1.25
pipe prover
displacement prover
device where a volume of fluid is displaced from a calibrated length of pipe and used to provide a calibration reference for flowmeters

3.1.26
performance indicator
derived value which may be used to indicate the performance of the meter

Note 1 to entry: Examples of performance indicators are *error* (3.1.13), *K-factor* (3.1.19), or *meter factor* (3.1.22).

3.1.27
proving
calibration with comparison to specified acceptance criteria

Note 1 to entry: The term proving is used in the oil industry and is similar to verification.

Note 2 to entry: Proving is a calibration, sometimes of limited measurement range, according to methods specified in standards, regulations or procedures, providing a determination of the errors of a device and showing (proving) it performs to specified acceptance criteria.

3.1.28
pulse interpolation
means of increasing the effective resolution of the pulses output from a meter by multiplying the pulse frequency or measuring the fraction of a pulse associated with the total collected across a time period

Note 1 to entry: The most common method employed is the double timing (chronometry) technique.

3.1.29
pulse interpolation divisor
ratio of the enhanced pulse frequency to the frequency of the pulses generated by the meter

Note 1 to entry: A pulse interpolation devisor is usually associated with the phase-locked-loop system of pulse interpolation.

3.1.30
range
measuring range
set of values of flowrate for which the *error* (3.1.13) of a measuring instrument (flowmeter) is intended to lie within specified limits

[SOURCE: ISO Guide 99:1993[1)], 5.2]

3.1.31
range
range of values
difference between the maximum and minimum values of a set of values

Note 1 to entry: This can be expressed as a half range (±) number. Relative range is normally expressed as a percentage of a specified value e.g. mean, minimum or other calculated value.

3.1.32
reference condition
reference conditions of measurement
operating condition prescribed for evaluating the performance of a measuring instrument

Note 1 to entry: The reference conditions generally include reference values or reference ranges for the influence quantities affecting the measuring instrument.

[SOURCE: ISO/IEC Guide 99:2007, 4.11, modified — Notes deleted; new Note 1 to entry added.]

3.1.33
reference measure
volumetric measure calibrated, used and maintained to provide traceability to other volume measures and devices, including *pipe provers* (3.1.25) and reference flowmeters

Note 1 to entry: A reference measure can be calibrated gravimetrically (primary measure) or volumetrically by means of a primary measure which itself has been calibrated gravimetrically.

Note 2 to entry: A reference measure may be a test measure or proving tank as described in ISO 8222.

3.1.34
repeatability
measurement precision
closeness of agreement between indications or measured quantity values obtained by replicate measurements under specified conditions

Note 1 to entry: Specified conditions normally implies the same reference, same conditions, same operators and procedures and that the data are obtained sequentially over a short period of time.

Note 2 to entry: Repeatability can be expressed as the range (difference between the maximum and minimum) values of *error* (3.1.13) or *K-factor* (3.1.19). Alternatively, repeatability can be expressed as a function of the standard deviation of the values.

Note 3 to entry: Dividing repeatability by the mean value gives the relative repeatability which can be expressed as a percentage. It is noted some standards suggest dividing by the minimum value.

[SOURCE: ISO/IEC Guide 99:2007, 2.15, modified — Notes to entry have been revised; term "repeatability" added as preferred term.]

3.1.35
resolution
quantitative expression of the ability of an indicating device to distinguish meaningfully between closely adjacent values of the quantity indicated

3.1.36
round-trip
movement of the *displacer* (3.1.11) between the detectors of a bi-directional prover that corresponds to a run being a pass in both the forward and reverse directions

3.1.37
round-trip volume
sum of the swept volumes in both the forward and reverse directions in a bi-directional *pipe prover* (3.1.25)

3.1.38
run
single determination of a prover volume or of a flowmeter meter *performance indicator* (3.1.16) [*error* (3.1.13), *meter factor* (3.1.22) or *K-factor* (3.1.19)] suitable for reporting

Note 1 to entry: A run may consist of a single prover pass for a unidirectional prover, two passes of a bidirectional prover or a larger number of consecutive passes for a small volume prover to give single a reportable result.

Note 2 to entry: The individual results within a multi-pass run are not normally reported unless required, but may be recorded and retained for diagnostic purposes.

Note 3 to entry: The repeatability of a multi-pass run may be used to monitor performance consistent with an acceptance criteria.

3.1.39
run-in length
pre-run length
length of prover barrel between *displacer* (3.1.11) launch point and the first detector chosen to ensure all valves have fully operated, sealed and the flowrate and flowmeter are stable

Note 1 to entry: The design run in length is chosen for the maximum rated flowrate.

3.1.40
standard condition
base condition
condition of temperature and pressure to which measurements of volume or density are referred to standardize the quantity

Note 1 to entry: These are the specified values of the conditions to which the measured quantity is converted.

Note 2 to entry: For the petroleum industry, the standard conditions are usually 15 °C[2)], 20 °C and 101 325 Pa.

Note 3 to entry: Standard conditions can refer to the liquid or the volume of the measure. These may be different.

Note 4 to entry: Quantities of volume expressed at standard conditions may be indicated by prefixing the volume unit by “S”, e.g. 4 Sm^3 or 700 kg/Sm^3. This abbreviation is used in place of the unit m^3 (standard conditions) where there is limited space and there is no risk of confusion regarding the unit.

Note 5 to entry: Standard conditions should not be confused with the reference (operating) conditions prescribed for evaluating the measure.

3.1.41
standard volume
base volume
volume expressed as being at standard conditions

3.1.42
traceability
metrological traceability
property of a measuring result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty

[SOURCE: ISO/IEC Guide 99:2007, 2.41, modified — Notes to entry deleted; term "traceability" added.]

3.1.43
transfer point
point or location in a fluid transfer where the quantity and accountability of the fluid passes from one measurement system to another

Note 1 to entry: For any system a transfer point be designated as being a valve, a solenoid valve, a swan neck or weir. It may also be the meniscus formed at the bottom of an open ended filling pipe,

2) In the US, the standard conditions are usually 60 °F (15,6 °C).

3.1.44
uncertainty
non-negative parameter characterizing the dispersion of the quantity values attributed to a measurand, based on the information used

[SOURCE: ISO/IEC Guide 99:2007, 2.26, modified — Notes 1-4 deleted; new Note 1 to entry added.]

Note 1 to entry: The uncertainty is normally expressed as a half width range along with the probability distribution with that range. It can be expressed as a value or as a percentage of the perceived true value.

3.1.45
volumetric measure
measure used to provide an accurate measurement of volume to provide a reference for other volume measuring devices e.g. *pipe provers* (3.1.25) or flowmeters

Note 1 to entry: Proving tanks are volumetric measures of larger size with a top and bottom neck.

3.1.46
water-draw
technique for calibrating a *pipe prover* (3.1.25) or *volumetric measure* (3.1.45) by withdrawing liquid from the prover or measure into a *reference measure* (3.1.33) (volumetric or gravimetric)

3.2 Symbols and units

Symbol	Quantity	Unit
$C_{subscript}$	volume correction factor to correct a volume to or from a standard condition. The subscripts define the correction parameter. There may be up to three subscripts.	
C_{pl}	volume correction factor for the pressure expansion of liquid from measured pressure to the standard pressure	
C_{ps}	volume correction factor for effect of pressure change on material (steel) of construction from measured pressure to the standard pressure	
C_{tl}	volume correction factor for thermal expansion of liquid from measured temperature to the standard temperature	
C_{ts}	volume correction factor for thermal expansion of material (steel) of construction from measured temperature to the standard temperature	
	Additional subscripts can be used to denote the device, condition or source. These may be applied as a third subscript to the correction factors or to a measurement correction and is defined where used. The following are commonly used:	
$_{D}$	the difference between a reference device and the device under test rather than correction to standard conditions;	
$_{M}$	a flowmeter	
$_{R}$	a reference device;	
$_{T}$	a device under test or calibration.	
D	internal diameter of prover	mm
E	elastic modulus of prover barrel	
F	meter factor	
f_i	pulse interpolation factor	
K	K-factor of a flow meter	Pulses/m^3
K_n	nominal K-factor of meter	Pulses/m^3
L	length between detectors	m
m	mass throughput during a delivery	kg
m_t	mass of water collected in weight tank	kg
N	number of pulses collected during a delivery or a run	

Symbol	Quantity	Unit
n	number of pulses collected during a proving pass	
p	Pressure. Unless specifically stated, this is the pressure in excess of atmospheric pressure. i.e. gauge pressure. Atmospheric pressure may be assumed as 101 325 Pa.	Pa (bar)
R	pulse interpolation divisor	
r_d	detector resolution	
t	Temperature. A subscript indicates the temperature referred to.	°C
t	value from the Student's t-distribution	
U	uncertainty - expanded	
u	uncertainty - standard	
V	observed volume, i.e. volume of fluid at actual pressure and temperature	m^3
V_M	volume indicated by a flowmeter at observed temperature and pressure	m^3
V_R	volume from reference device, at standard or observed temperature and pressure	m^3
V_S	volume at standard conditions, 15 °C and 101 325 Pa (see NOTE 2)	m^3 (at standard conditions)
w	wall thickness of prover	mm
W_a	weight of water (in air) collected in a weightank	kg
α	linear coefficient of thermal expansion of metal	$°C^{-1}$
β	compressibility factor of liquid in use	bar^{-1}
ρ	density of liquid at measured pressure and temperature	kg/m^3
ρ_a	density of air	kg/m^3
ρ_n	nominal density of weights used to calibrate weighing machine (8 000 kg/m^3)	kg/m^3
ρ_p	density of fluid in pipe prover during calibration	kg/m^3
ρ_t	density of pure water at temperature t	kg/m^3
ρ_w	density of water	kg/m^3

NOTE 1 The preferred unit for kinematic viscosity is metre squared per second (m^2/s) or millimetres squared per second (mm^2/s). The practical unit used in this document is the industry recognized unit centistoke (cSt); 1 cSt = 1 mm^2/s.

NOTE 2 The preferred unit for a volume expressed at a standard condition is m^3 (standard condition). In practice this is conventionally abbreviated to Sm^3 where there is limited space and there would be no confusion of units used.

4 Design classification of pipe provers

4.1 Common features

A pipe prover consists of a length of cylindrical cross section pipe through which flow is directed. The pipe can be straight or in the form of a loop consisting of straight lengths joined by long radius bends or elbows. The pipe can be assembled from standard pipe sections or specially manufactured and machined pipe sections. It can be made from carbon or stainless-steel, or an alternative material. The internal bore should be cylindrical and smooth, and usually has a hard plated, epoxy or phenolic internal coating. Provers are normally found with pipe diameters ranging from 50 mm (2 inch) to over 1 050 mm (42 inch).

A displacer is inserted into the pipe. The displacer may be a piston, free or constrained (captive) piston or a free elastomer sphere (ball). A sphere is able to pass through bends or elbows while maintaining a seal, hence allowing a shorter footprint for the prover assembly. When introduced to the flow the displacer travels along the length of the pipe displacing fluid to the flowmeter under test.

