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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

Reference number
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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

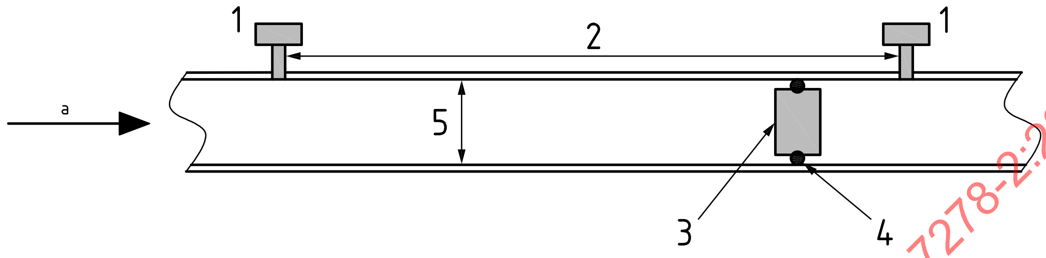
4.1 Common features

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.

Detectors are installed to sense the passage of the displacer at the beginning and end of the measurement section of the prover. When actuated, the detector triggers the counting of pulses from the output of the flowmeter being calibrated. Detectors can be directly actuated by the displacer or remotely through a connecting rod.

The volume of the measurement section, between detectors, is established through calibration. The volume of liquid contained is displaced from the pipe by the passage of the displacer hence giving an equivalent volume passed to the flowmeter under test. The flowmeter K-factor, error or meter factor can then be determined. The operating principle is shown in Figure 1.



Key

1 detectors

2 calibrated length and volume

3 displacer

4 seal

5 pipe inside diameter

[a] Flow (from flowmeter).

Figure 1 — Principle of operation

There can be one or two detectors at the start of the calibrated section and one or two detectors at the end. These may be designated by number or letter e.g. A&B, C&D or 1&2, 3&4.

Pipe provers are divided into four design classifications based on the displacer movement and type. The classifications are:

— unidirectional provers;

— bidirectional provers;

— sphere provers;

— piston provers.

A proprietary small volume provers (SVP), sometimes referred to as a compact prover, is a unidirectional piston prover specifically designed and constructed to operate, for the most part, as a small volume prover.

Further operational classification is given by the relationship between the volume of the prover and the characteristics of a meter being proved. This relationship relates to the resolution, internal volume and the time constants associated with the meter along with the maximum and minimum flowrates being covered. The operational classifications are:

— conventional;

— reduced volume;

— small volume.

Provers have a run-in length of pipe between the displacer launch position and the first detector to allow all valves used to start a proving pass to fully close and seal and to allow the displacer to achieve a stable velocity. Provers should never be operated at more than the maximum rated velocity and flowrate as the run-in length may prove inadequate. Operating above the maximum rating can also cause hydraulic shock, leading to damage the prover and components when launching, decelerating and capturing the displacer.

4.2 Sphere provers

4.2.1 General

Sphere or ball provers use a solid elastomer sphere for small diameters. More commonly a hollow, inflated elastomer sphere is used as the displacer. The sphere is inflated by filling with a liquid chosen to be compatible with the sphere and the duty. A sphere can travel around a bend while maintaining a seal to the pipe wall. This allows the prover measurement section of pipe to be constructed utilizing and combining lengths of straight pipe and bends forming a loop or loops. This minimizes the footprint occupied by the prover.

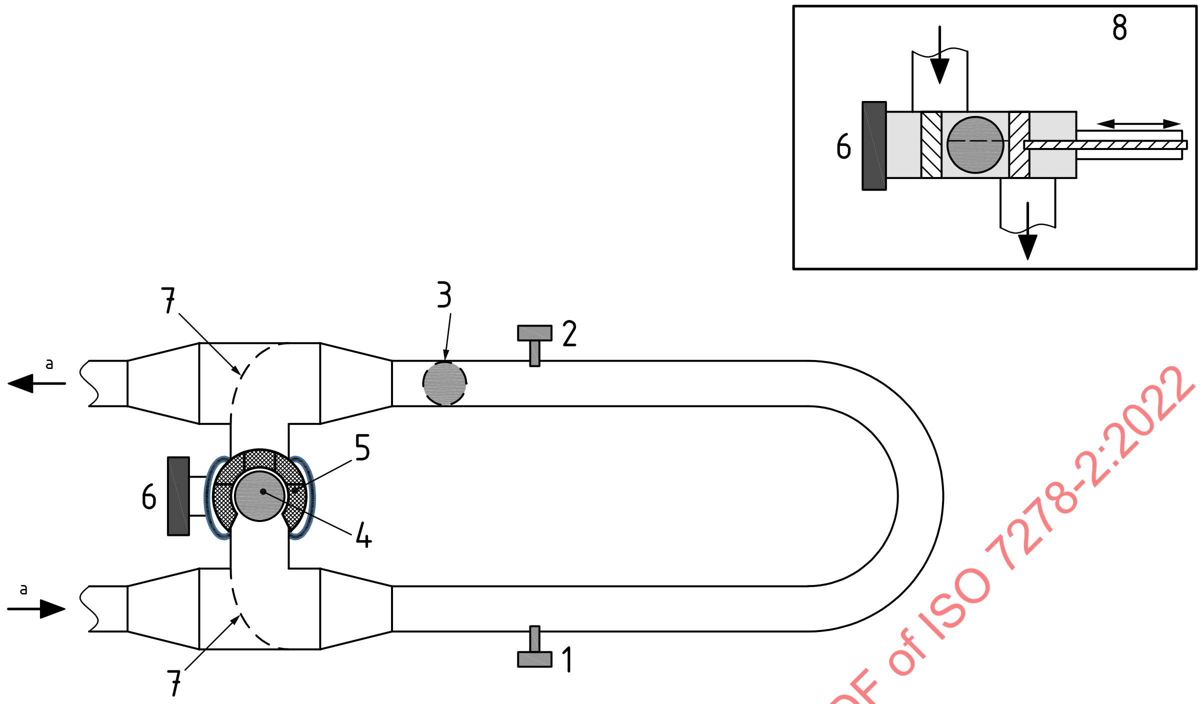
The sphere is nominally chosen to match the internal diameter of the pipe. A solid sphere has a diameter slightly larger than the pipe diameter. A hollow sphere is inflated to a controlled diameter larger than the inside diameter of the pipe. When introduced to the flow, the sphere travels with minimal resistance along the pipe while making a seal with the pipe wall.

The elastomer of the sphere is chosen to be compatible with fluids, products and temperature with which it is intended to be used.

Mechanically operated detector switches are used to signal the start and finish of a proving pass. Either one or two detectors may be placed at each end of the measurement section. Only one pair (two detectors) are required to establish one calibrated volume of a prover however the use of two detectors at each end allows four volumes to be established. This is good practice as it provides redundancy and an indication of a detector malfunction.

4.2.2 Unidirectional sphere provers

A unidirectional sphere prover uses an elastomer sphere as a displacer which travels through the pipe loop in one direction only. The most usual form of unidirectional prover is shown diagrammatically in Figure 2.



Key

1 detector 1(A)
2 detector 2(C)
3 sphere displacer – passing through prover barrel
4 sphere displacer – passing through sphere handling valve
5 rotating sphere handling valve
6 closure
7 separator bars
8 alternative slide type sphere handling valve
a Flow.

Figure 2 — Unidirectional sphere prover

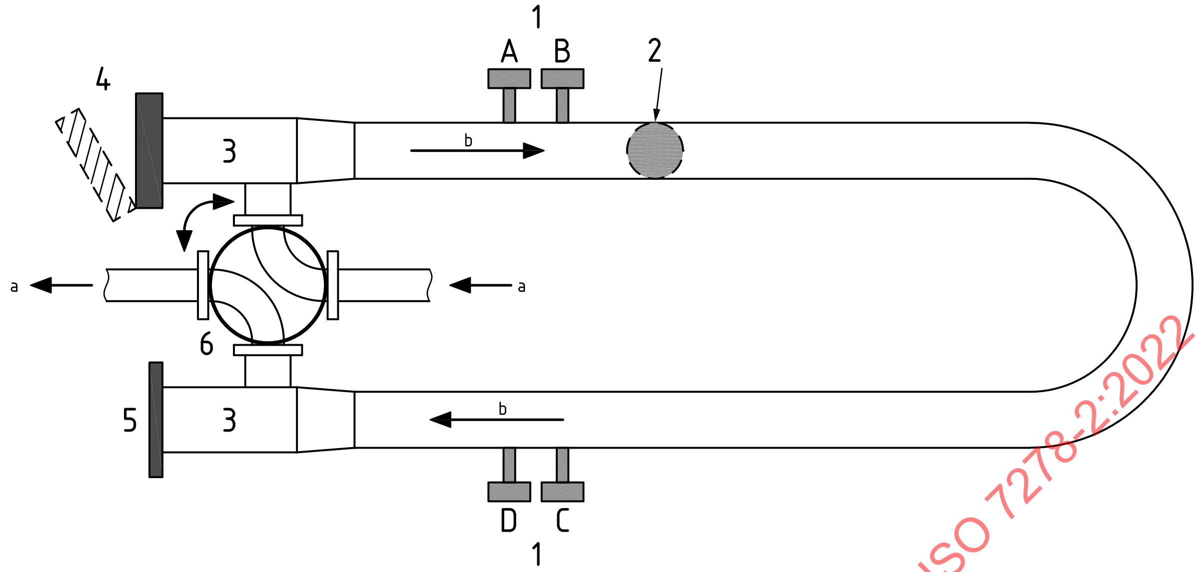
The critical component of a unidirectional sphere prover is the interchange, or sphere handling, valve. This is a mechanism, valve or assembly of valves which allows the sphere to be captured at the end of a proving pass and then transferred back to the upstream launch position. The interchange valve should demonstrably prevent liquid leaking or by-passing between the prover inlet and outlet during a pass. Flow through the prover should be continuous and not significantly changed during the transfer of the sphere. The operation of the valve should be such that, during a pass, it does not change the interface inventory i.e. the volume between the prover and the meter under test.

A run-in length of prover pipe is provided between the point of entry of the sphere and the first detector. This length is chosen to ensure the interchange valve is fully closed, sealed and the flow is at a constant velocity before the sphere reaches the first detector. For a unidirectional prover, a run-in length is only required at the upstream end of the prover barrel. This allows a unidirectional prover to be shorter than a bidirectional prover. A short length of pipe downstream allows the displacer to clear the detector and potentially decelerate before being captured. The stability of the flowrate and the delay times of a flowmeter should also be considered in the selection of run-in length.

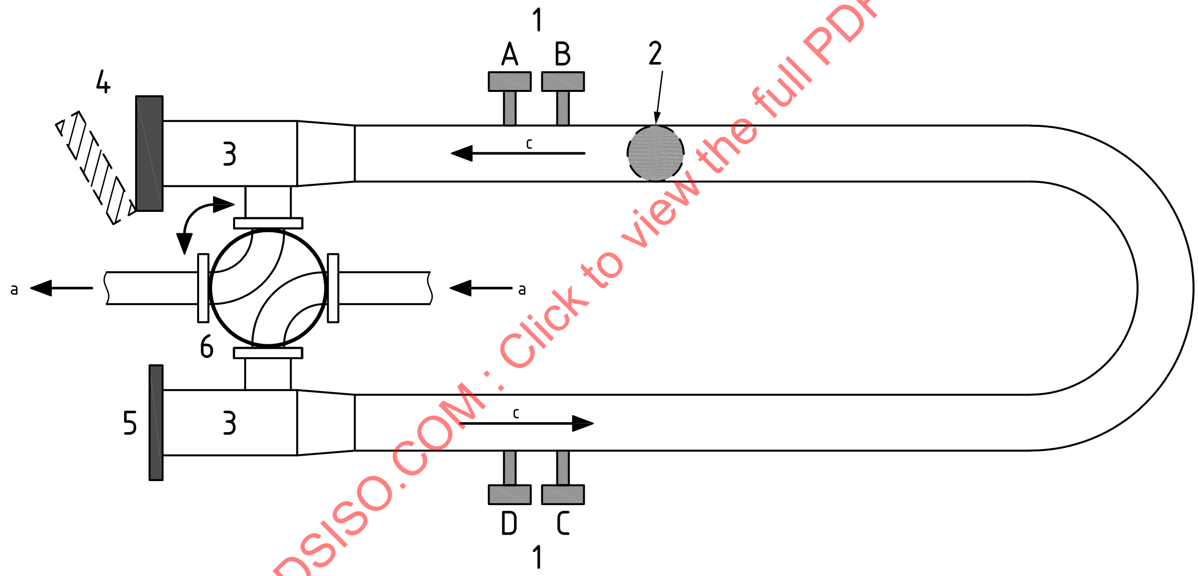
A less common form of unidirectional prover interchange mechanism is used in a multiple sphere prover. The short length of pipe linking upstream and downstream ends of the prover is designed to hold two or three spheres. To initiate a proving pass, the foremost of the spheres is introduced into the flowing stream while the remaining sphere(s) are mechanically held in place. These act as a seal against bypass flow. A sphere handling mechanism returns the sphere to the short holding section at the end of a pass where it again forms a seal. The second sphere can then be introduced to the flow for the next measurement.

4.2.3 Bidirectional sphere provers

A bidirectional sphere prover uses an elastomer sphere as a displacer, but in this case the sphere shuttles back and forth along the length of the prover. Forward and reverse passes are made alternately, with a proving run consisting of the sum of forward and reverse pass volumes, i.e. a round-trip volume. A run always starts with a forward pass. The most usual form of bidirectional prover is shown diagrammatically in Figure 3.



a) Forward pass



b) Reverse pass

Key

1 detectors A-D

2 sphere displacer

3 end chambers

4 home chamber with closure for sphere access

5 end chamber with flanged closure

6 four-way flow reversal valve

[a] Flow direction- in and out.

[b] Flow direction - forward.

[c] Flow direction - reverse.

Figure 3 — Bidirectional sphere prover

A four-way valve is employed to enable the flow through the prover to be reversed while the flow through the flow meter is continuous. This valve is usually a proprietary device however some small provers use four linked valves for flow reversal. Flow through the inlet and outlet of the prover should be continuous and not significantly changed during the operation of the valve.

The sphere rests in an end chamber. When the four-way valve is operated, the sphere is launched and starts to travel on its forward pass until being received at the end of the pass. The flow is reversed and the sphere launched for a return pass. After launch the sphere does not reach its full speed until the movement of the valve is complete and sealed. One end chamber should be designated as the home chamber and indicates the launch direction of a forward pass followed by the reverse pass from the other end. The home chamber is normally fitted with a closure to allow removal of the sphere.

A run-in length is chosen between the end chamber and the first detector to allow for the valve operating time. A run-in length is provided at both ends of the barrel. End chamber design may incorporate a means of holding the sphere delaying launch until the four-way valve has turned, hence reducing the run-in length required. The stability of the flowrate and the delay times of a flowmeter should also be considered in the selection of run-in length. The operation of the valve or the retaining or launch rams should be such that, during a pass, they do not change the interface inventory, i.e. the volume between the prover and the meter under test.

As with the unidirectional prover, one or two detectors may be installed and designated to indicate the ends of the calibrated section. The volume between sphere detectors A and C, ($V_{A\text{-}C}$), is not be quite the same as when the sphere travels between detector C and detector A, ($V_{C\text{-}A}$). If two detectors are installed, two single pass volumes may be determined; one in the forward direction and one in the reverse direction. When two pairs (four) detectors are installed, eight single pass volumes are possible. Comparison of these results may be used for diagnostic information.

It is common practice for a bidirectional prover to define the calibrated volume as that for a round trip, i.e. the sum of $V_{A\text{-}C}$ and $V_{C\text{-}A}$. The volumes may be calibrated as one round trip or calibrated and reported as the sum of the two directional passes. There are therefore one or four round trip volumes measured by calibration. Again, comparison of results from the different volumes may be used for diagnostic information.

In use, it is customary to totalize the sum of the pulses collected in each direction, ($n_{A\text{-}C}$) + ($n_{C\text{-}A}$), to give the round-trip pulse count (N) to compare with the round-trip volume. Single pass totals may also be recorded and in some circumstances compared with the single pass volumes and additionally reported as separate measurements.

4.3 Piston provers

4.3.1 General

Piston provers have a piston as the displacer with high integrity seals to the pipe wall. The prover pipe is a straight length with a smooth, round cross section across the full operating length to provide a sealing surface. Piston provers usually have the internal bore of the pipe honed and possibly have a hard coating or plating applied. Piston provers are usually specified for low viscosity or corrosive fluids where an elastomer sphere potentially has unacceptable leakage or wear. They are also used for low temperature applications where sphere elastomers or the liquid fill may be unsuitable

As mechanical switches can damage piston seals, these should be carefully designed and specified. Non-mechanical, high precision sensors are preferred. These include magnetic or inductance switches mounted on or through the wall of the prover or optical switches fitted externally and activated by a constraining rod, connected to the piston, projecting through a seal in the end of the pipe section. Proprietary small volume provers are usually of piston prover design with external detectors.

Piston provers are normally found with diameters between 50 mm (2 inch) up to 500 mm (18 inch) however can be of larger and smaller diameters.

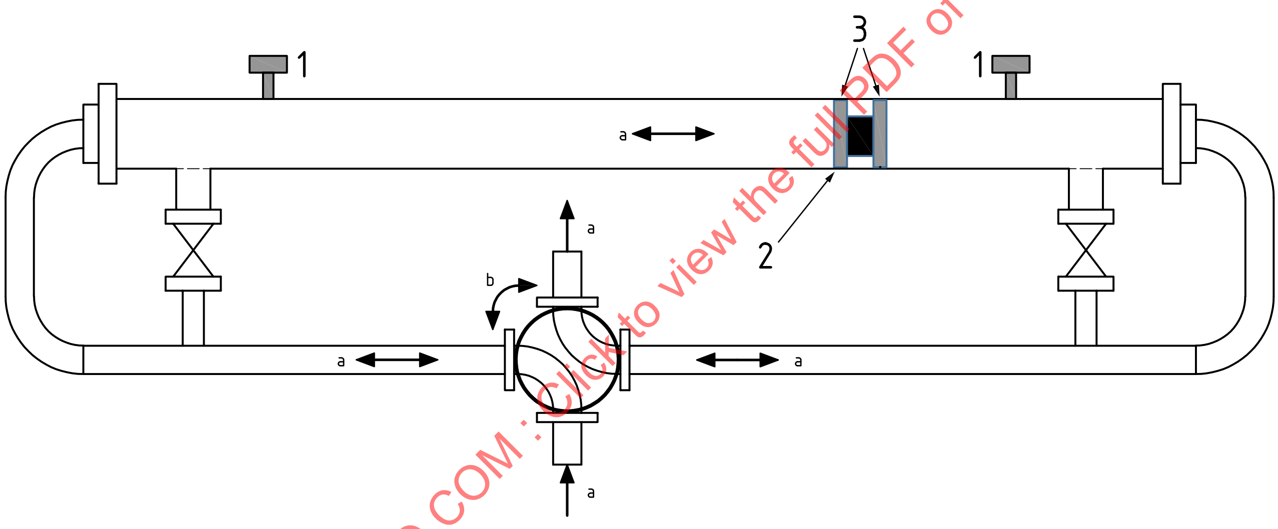
4.3.2 Unidirectional piston provers

The unidirectional piston prover has a forward measurement pass with the piston being returned to the start position by retracing its path. Some means, mechanical, hydraulic, or electromagnetic, is provided to enable the piston to be returned to its upstream launching position without interruption to the continuous flow through the flowmeter being tested. This can be achieved by a valve within the piston or an external valve arrangement allowing flow to bypass the prover during the piston retraction.

Unidirectional piston provers are normally manufactured as proprietary small volume provers and these are discussed further in 5.4.

4.3.3 Bidirectional piston provers

A bidirectional piston prover allows the piston to be shuttled back and forward though the pipe by reversing the flow. This flow reversal is accomplished by using a four-way valve, or four individual valves. In this way, proving passes can be made alternately in each direction to make up a proving run. The flow reversal valves should be configured to allow the piston to be stopped at the end of a run and reversed without undue shock loading or interruption of the flow. As a bidirectional piston prover has a straight calibrated section, provers are usually quite long and have a larger footprint than equivalent sphere provers. This type of prover is shown diagrammatically in Figure 4.



Key

1 detectors
2 piston displacer
3 piston seals
a Flow.
b Four-way flow reversal valve.

Figure 4 — Bidirectional piston prover

5 Operational classification of provers

5.1 General

The operational classification of a prover is based on the complex relationship between the calibrated volume of the prover, the resolution of the meter output signal, the internal volume of the meter and the meter time constants.

The relationship was first considered when twin-blade helical turbine meters were introduced as an alternative to multi-bladed meters. Previous to that, it was required to collect at least 10 000 pulses in a proving pass, hence providing a pulse resolution of less than 0,01 %. The reduced pulse content from fewer blades prevented this resolution from being achieved thereby increasing the repeatability of the calibration. There was however, no evidence to show the meters were less repeatable in service.

This issue was addressed through the introduction of pulse interpolation which effectively increased the resolution of the meter output during proving.

The introduction of small volume provers showed the limiting factor for satisfactory proving was not only the resolution of the meter output, but also an ill-defined relationship between the internal meter resolution and the volume of a proving pass. For a turbine or displacement meter, the internal resolution is effectively the number of revolutions of the rotor providing variation of pulse intervals and additional effects introduced by any external gearing. Satisfactory proving was however found to be achievable for twin-bladed turbine meters, in most cases, by increasing output resolution of the meter by pulse interpolation, and also increasing the effective volume of the prover by taking an average from multiple passes.

The introduction of electronic meters, such as Coriolis and ultrasonic meters, has shown the internal resolution of the meter is very important. While the meter output resolution can be chosen and increased arbitrarily by the meter electronics, this does not alter the internal resolution. The internal resolution of such a meter is based on the internal averaging of a large number of low-resolution measurements providing a single value which is then used to calculate the output frequency. The time constant associated with this calculation and the update of the output frequency plays a significant part in defining the internal resolution. As a result, the volume chosen for a prover used for the calibration of these meters should recognize this limitation and it may not be compensated for solely by providing multiple passes.

To assist in defining the operation of a prover, three operational classifications have been used in this document:

— conventional prover;

— reduced volume prover;

— small volume prover.

The small volume prover classification usually, but not exclusively, applies to proprietary small volume piston provers.

The classifications relate to the combination of the prover and the meter being calibrated. A prover may be operated as a conventional prover with one type and size of flowmeter, or as a reduced volume or small volume prover when combined with different meter size, resolution or type.

5.2 Conventional prover

Conventional provers can be of unidirectional, bidirectional, sphere or piston designs. They can be used to calibrate any type of suitable flowmeter where a minimum of 10 000 pulses collected in a pass. This guidance suggests they are generally sized to enable proving of multi-bladed turbine flowmeters where, without enhancement, a minimum of 10 000 pulses is collected in a pass. The guidance to determine the classification of a prover, for a particular duty, based on 10 000 pulses, should be adopted with care where electronic type meters may allow output pulse frequencies to be selected.

As a guide, designers suggest a calibrated volume for a conventional prover to be no less than 18 s when operating at maximum flowrate, i.e. half a percent of hourly flowrate. This is an indicative design guide from past practice and not a definitive value. Significantly shorter times for a pass are possible when all the design limitations of the prover equipment and the flowmeters are considered. These include the maximum velocity allowed for the displacer, the four-way or interchange valve design, the run-in length and the valve operating speed.

The number of passes to be combined as a run for also plays a part when considering bidirectional provers. Since a round-trip volume is used, i.e. two passes are averaged, some reduction in volume from the above guidance may be possible. This does not however suggest the calibrated volume is halved.

5.3 Reduced volume prover

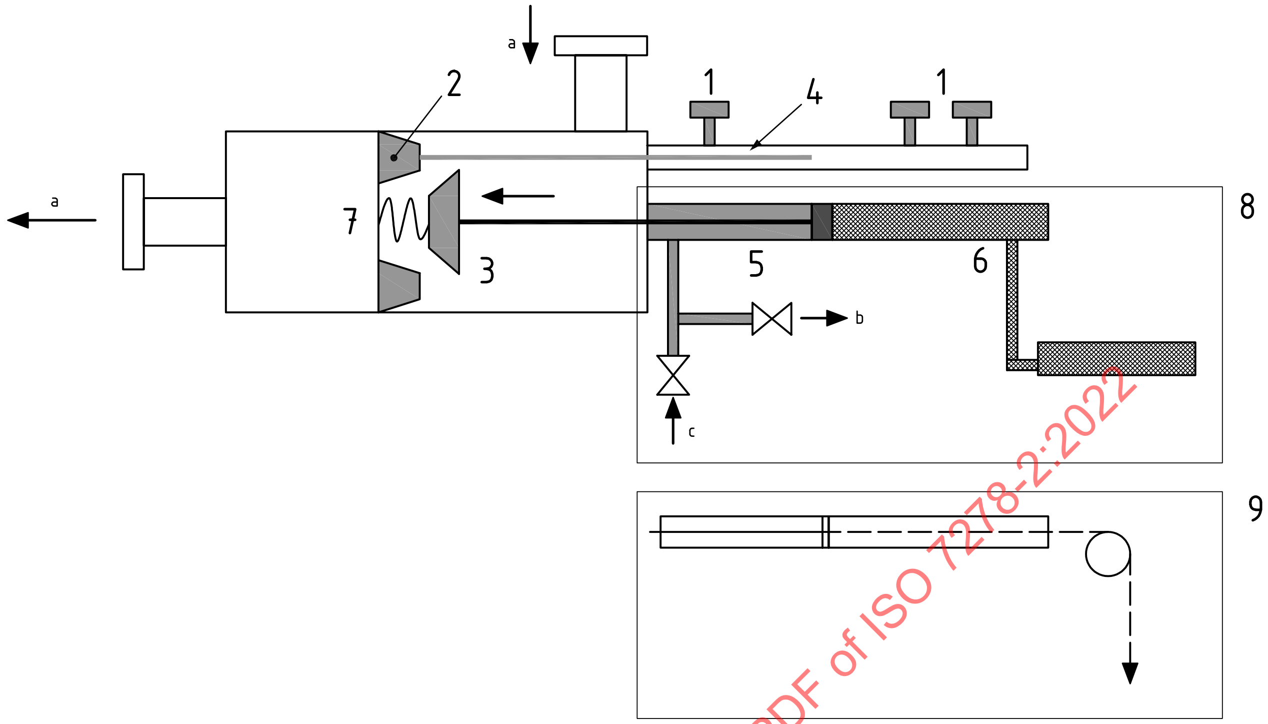
A reduced volume prover is designed as a conventional prover but is used where the meter output (pulse) resolution requires, to be enhanced through pulse interpolation. A reduced volume prover is used to prove low resolution output meters e.g. helical blade turbine meters. A reduced volume prover may also be used to prove meters where the effective volume can be increased by averaging multiple proving passes to enhance the meter internal resolution, e.g. to prove ultrasonic or Coriolis meters.

5.4 Small volume prover

This is a prover which is specifically designed to operate as a reduced volume prover for all meters normally calibrated. There are two types of small volume prover recognized. Both types employ pulse interpolation and use statistical evaluation of the calibration results from multiple passes to produce a reportable result.

a) A prover of more conventional design but with a volume significantly less than advised for the size, resolution or flowrate of the meters that are to be calibrated. Suitable performance enhancements are made to conventional design to improve uncertainty in volume, for example lower uncertainty and higher resolution detectors, leak reduction etc. Alternative application would be a conventional prover used where a calibration of a meter is required but a higher uncertainty than the normal is acceptable.

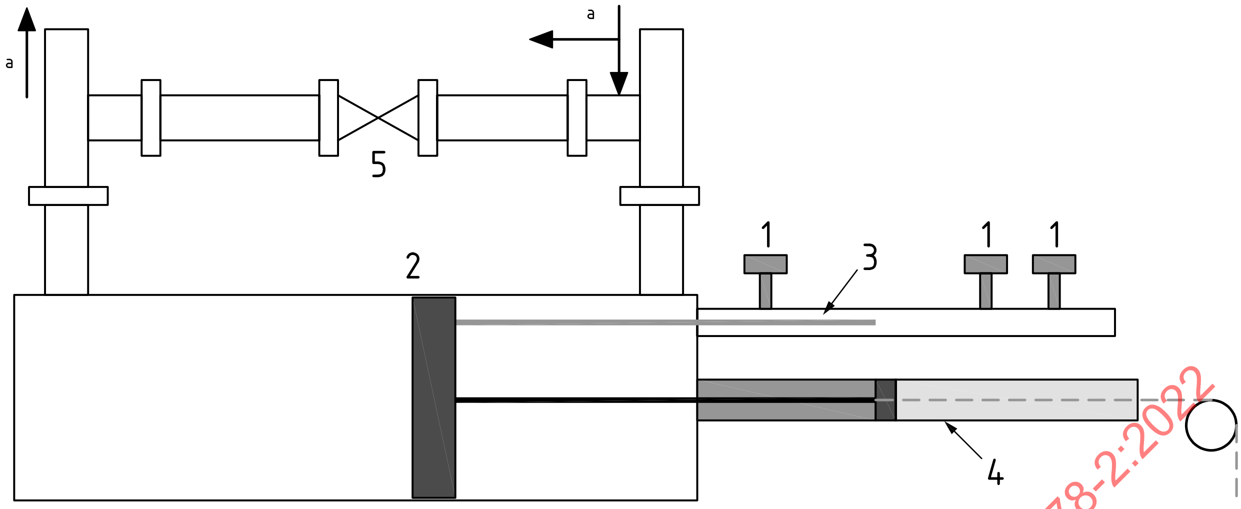
b) Proprietary small volume provers (SVPs) are usually unidirectional piston types and come complete with precision external detectors, associated electronics and control systems. These have a calibrated volume about one-tenth of that of a typical conventional prover designed for the same maximum flowrate. They have a precision-bore cylinder containing a piston displacer, whose position is detected by high precision, non-mechanical, switches. SVPs of this type can be custom built but are more usually of a proprietary design. The term compact prover is sometimes used, however this is a trade name of one particular manufacturer. Two schematic designs are shown in Figure 5 and Figure 6.



Key

1 detectors
2 piston displacer
3 poppet valve
4 detector rod
5 hydraulic cylinder to return piston
6 pneumatic pressure to assist shutting poppet valve
7 spring to shut poppet valve.
8 option; hydraulic-pneumatic system to return piston
9 option; mechanical (chain or belt), electro-magnetic or other means to return piston
a Flow.
b Hydraulic flow to launch.
c Hydraulic flow to return.

Figure 5 — Unidirectional small volume prover with internal valve



Key

1 detectors
2 piston displacer
3 detector rod
4 hydraulic cylinder or mechanical (chain or belt), electro-magnetic or other means to return piston
5 high integrity by-pass valve
a Flow.

Figure 6 — Unidirectional small volume prover with external valve

6 Design

6.1 General considerations

A prover should be designed or specified with the following considerations.

a) Mobility requirement for the application. Consider if the prover is to be mobile, transportable or located in a permanent location.

b) The available space and weight restrictions for a structure, ground conditions or transportation.

c) Means of transportation.

d) Range of flowrates and flowmeter types to be proved.

e) Physical properties of the liquids, including viscosity, lubrication characteristics, corrosive properties and vapour pressure. This should also include cleaning and calibration liquids.

f) Operating conditions, including range of temperature, pressure and the allowable pressure loss.

g) Requirements for continuous flow through the prover or through a by-pass when not in service.

h) Environmental protection from extremes of temperature, wind, precipitation etc. The need for a shelter, burial or insulation.

i) The hazardous area classification.

j) Power supplies and utilities available at site including water for calibration.

k) Provision for safe pressure relief, venting and drainage of liquids.

l) Adequate and safe access to and around the prover.

m) Manifolds and connections to the meter(s) under test.

n) Extent of automation and connection to wider plant instrumentation as part of a measurement system.

o) Space and access to allow access for lifting equipment for maintenance.

p) Equipment to facilitate calibration. This includes access for reference devices, means to extract displacers and working at height requirements.

q) Manifolds and connections to allow access and installation of calibration equipment.

r) The requirement to calibrate the prover at significantly lower flowrates than the normal operating range.

s) Storage for spares, including switches, seals, spheres, and sphere inflation and measurement equipment.

6.2 Prover barrel

6.2.1 End chambers (launch and receive chambers)

a) The cross-sectional area of the launch or receive chamber should be such that, with a displacer located within, it has sufficient unrestricted flow area to avoid unacceptable pressure loss at maximum flowrate.

b) End chambers should be fitted with vents at the highest point to allow venting of air and vapour in a safe manner. These are used during filling and operation to ensure all gas is removed from the prover. The vents should be demonstrably closed and leak tight during proving.

c) End chambers should be fitted with drains.

d) The receiving chambers of the prover should facilitate the deceleration, arrest and retention of the displacer with minimum hydraulic or mechanical shock and without damage to the displacer through impact or vibration within the chamber.

e) The launch chamber should be designed to provide a method of reliably launching the displacer to achieve required stable velocity in as short a time as practicable, while minimising hydraulic shock and flowrate disturbance. This may involve mechanical or hydraulic arrangements.

f) One chamber may be designated as the home chamber where the displacer can be installed and retrieved. The home chamber can be fitted with a hinged quick release closure to allow access to the displacer. The other launch chamber would normally be closed with a bolted flanged closure to allow access if required. Some provers may have access from both end chambers.

g) Provision should be made to retain the sphere within the home chamber and to prevent it being sucked back into the prover barrel during drain down. This is especially relevant to provers with inclined or vertical end chambers. Such provision may be in the form of drain points both above and below the displacer when it is in the end chamber. The drain allows the sphere to be exposed for extraction prior to the draining the rest of the prover.

h) To avoid the chance of a significant risk to operators, safety interlocks, vents and a means to ensure depressurisation before opening are strongly recommended for both chambers. This is particularly important for the home chamber. Releasing an end chamber closure where there remains residual pressure above or below the displacer provides a potentially fatal safety risk.

6.2.2 Run-in length

A run-in length is provided at one end of a unidirectional prover and both ends of a bidirectional prover. Sufficient length of pipe upstream of the first detector is necessary to ensure that:

a) All valves that can affect the integrity of the proving operation are either fully open, or closed and sealed, before the first detector is actuated. The run-in length can be reduced by employing mechanical means of restraining the displacer until all valve movements are complete prior to launch.

b) Before reaching the first detector the displacer is moving at a constant velocity. As a displacer is launched, the flowrate reduces. This is due to the friction between the displacer and the pipe wall. This is usually observed as a sudden drop in flowrate followed by a recovery to a marginally lower flowrate than before launch.

c) The flowmeter has responded to a change in flowrate and is stable before the first detector is activated. While turbine and displacement meters respond quickly, the output pulses from electronic based meters may lag behind a change in flowrate.

6.2.3 Prover pipe or barrel

a) The calibrated volume should be sized as recommended in 6.4.

b) The calibrated section of the prover barrel should be free of connections such as vents, drains and pressure relief valves. In those instances where a vent or drain is necessary within the calibrated length, it should be of such small diameter that a leak path around the displacer is not formed as it passes.

c) Where connections are fitted to any location on the prover barrel, care should be taken to ensure the inside bore of the barrel has no intrusions, sharp edges or changes in ovality due to welding stress.

d) The barrel is manufactured to ensure the internal diameter is round and to avoid ovality. This is most important in the selection or manufacture of long radius bends or elbows.

e) Flange unions located in the calibration section should be specially designed so that both flanges are of equal inside diameter and have concentric alignment of internal bores achieved during installation. When connected there should be no step or groove.

f) A means of leak detection should be provided associated with for all critical connections, e.g. vent and drain points and seal verification. It should be possible to inspect any flanges or joints and this may require removable sections of insulation or inspection pits.

6.2.4 Internal finish

The prover barrel may be lined or unlined depending on the material, the properties of the fluids which may enter the prover, the process conditions, and the prover type. The purpose of the lining is to:

a) enhance the seal between the displacer and pipe wall, hence minimizing the leakage of liquid past the displacer;

b) reduce friction between the displacer and the pipe wall;

c) provide a surface resistant to corrosion, abrasion and erosion from the fluids to be used and the displacer contact.

The fluids to be used should be considered. These should include the fluids used in operating, calibrating and cleaning the prover, as well as the atmosphere when empty. Potential changes for future service should be considered.

Unlined provers are normally made of stainless steel and the bore machined to provide a smooth finish. Piston provers may have a further machined finish by honing.

Linings are commonly applied to carbon steel pipe and are usually of epoxy, or phenolic material. Alternatively, particularly for piston provers, the lining may be a plating of chrome, or nickel. Most small volume piston provers have a hard metal (chrome) lining.

Care should be exercised in the choice of non-metallic linings since not all resist aromatic hydrocarbons, and some can become thermoplastic (soften and change thickness) at elevated temperatures.

6.3 Proprietary small volume piston provers

A proprietary small volume piston (SVP) prover has a piston running inside an accurately machined cylinder or pipe. Two designs are illustrated in Figures 5 and 6. The movement of the piston, and hence the location of detectors, is by means of a measurement constraining rod connected to the piston and extending out through one end of the cylinder. In most designs, this rod is on the upstream side of the prover. Typically, this separate detector rod carries flags to trigger detectors located at fixed positions indicating the location of the piston and triggering the measurement. Optical detectors are usually employed, however alternative precision detectors such as proximity switches can be used. Potentially linear velocity displacement transducers (LVDTs) can be used to monitor the position of the piston. Most designs have three fixed detectors. One indicates the piston is at the upstream piston, while the second and third are measurement detectors. The third also provides the control signal to detect the end of a pass and trigger a piston return. Alternative designs may use a single detector or utilize the constraining shaft rather than a separate detector rod.

Locating the detectors external to the cylinder allows precision electronic detectors to be used. The external rod and detector assembly should be enclosed to provide mechanical protection and stability. The enclosure should also provide environmental protection. Some designs purge the enclosure with dry gas to provide control of temperature and prevent condensation or icing. The enclosure may need to be removed to allow observation of the movement and approach to detectors during calibration. A transparent enclosure, permanent or temporary, may be considered.

The distance between detectors, hence the prover volume, is affected by the ambient temperature rather than the fluid temperature within the prover. This is a function of the materials used to position the detectors. To reduce the effect, some designs separate the detectors by low expansion coefficient materials such as Invar. Locating the detectors externally requires the temperature of the external assembly to be measured. Volume correction to standard conditions is derived from the linear expansion of the materials associated with the detector mounting combined with the area correction of the prover barrel.

All current designs of proprietary small volume piston provers are unidirectional. Flow is continued at the end of a pass by opening a by-pass valve located externally or by opening a concentric poppet valve located in the piston assembly, the latter being the most common approach. A constraining actuation shaft connected to the poppet valve and piston is extended through the end of the prover where a mechanism opens the valve allowing flow to pass through the piston. This allows the piston to be drawn back to an upstream position. It also provides the means to close and seal the valve in a controlled way hence launching the piston.

Mechanisms to control the piston and draw it back to the launch position may be mechanical (chain or belt driven by a motor), hydraulic or electromagnetic. With a hydraulic mechanism, the external shaft is connected to a hydraulic cylinder. Hydraulic pressure is applied to one side of which pulls the shaft backword, opening the poppet valve and pulling the piston to the start position. Pneumatic pressure may be applied to the upstream side of this hydraulic cylinder to apply a positive force to close and maintain the poppet valve closed when launched. This force may be set to also overcome the frictional resistance of the piston. This also reduces the change in flowrate when the piston is launched. The effect of this may be observed by the extent by which the flowrate may rise or fall when the piston is launched and is dependent on the pressure applied. This force may be adjusted in such a way as to reduce pressure loss across the piston which also reduces potential leakage. The force applied should however ensure the closure and sealing of the internal valve is not compromised.

Some designs may have a guide shaft extending from the other side of the piston to balance and stabilize the movement.

The volume occupied by constraining rod and shaft changes the volume within the calibrated section such that the volume displaced upstream and downstream of the piston is different. Where a downstream shaft is fitted, this reduces this difference and some designs ensure upstream and downstream rod and shaft volumes displace the same volume.

The presence of a rod and shaft along with the operation and displacement of the poppet valve and seals, leads to different upstream and downstream volumes for the prover. For this reason, SVPs are usually installed upstream of the flowmeter being proved hence utilizing the volume downstream of the piston.

The determination of the upstream volume is difficult and requires significant skill and detailed procedures to be developed and followed. This would require a liquid (water) to be introduced into the prover outlet from a volumetric measure. This would not provide sufficient pressure to drive the piston. Alternatively, the internal valve can be held closed and a return sequence initiated. Pressure is applied to the inlet, driving the piston to an upstream position and displacing fluid from the prover inlet to a reference measure. In this scenario, detectors are triggered from the opposite edge from that used when the piston is travelling in the forward direction. It should also be ensured that the valve seals adopt the same compression and hence displacement as they would in a forward stroke.

Upstream volume may also be derived from measuring the diameter of the external shaft and rod along with the distance between the detectors. The resultant shaft and rod volumes can be subtracted from the calibrated downstream volume. The volume of the rods should be corrected for the volumetric thermal expansion of the material, both in diameter and length, based on the fluid temperature. This correction is in addition to the thermal expansion of the distance between the detectors based on the external temperature.

As the master meter method of calibration does not provide the adequate uncertainty normally required, an SVP is calibrated and proved by water draw either gravimetrically or using a dedicated volumetric measure designed to match the prover volume.

A procedure for testing the internal valve for leakage should be prepared and followed. This test is normally a static test. Observation of the proving results is particularly important to ensure any sign of leakage from the internal valve is detected during service. One method of dynamic leak detection during calibration of the SVP is to perform calibrations at different flowrates. It is noted that leakage not detected by a static test has been observed to occur when the prover is in use. This has been noted particularly when higher viscosity fluids provide increased resistance to the internal valve closing.

To provide a mobile calibration system, an SVP may have a suitable flowmeter permanently installed on the outlet from the prover as a master meter. This combination may be used to calibrate operational flowmeters or large pipe provers. The meter is usually installed downstream of the SVP and within the envelope of the SVP package. This may provide significant flow disturbance upstream of the meter. The effect of this is minimized by installing a flow straightener to reduce installation effects and any remaining systematic errors should be insignificant as the meter is calibrated and used in situ.

6.4 Sizing of provers

6.4.1 General

The size of a prover depends upon its intended application and its type as classified in Clauses 4 and 5. The size is determined by the following factors:

a) The output resolution of the meters to be proved (minimum number of pulses per unit volume generated by the meters to be proved.).

b) The internal resolution of the meters to be proved (number of revolutions of a mechanical meter or the internal averaging times of an electronic type meter).

c) The maximum and minimum flowrate to pass through the prover and the meters to be proved.

d) The linear resolution of the displacer detectors.

e) The maximum tolerable pressure loss.

f) The maximum and minimum velocity of the displacer.

g) The viscosity and vapour pressure of the fluid.

h) Operation timing of the four-way valve in a bidirectional prover or the interchange valve of a unidirectional prover to determine run-in length required.

i) The response time of the flowmeter to ensure adequate the run-in length to allow the meter to reflect and recover from any change in flowrate or disturbance after launch.

These factors influence the prover design parameters. Further guidance is given in Annex B.

6.4.2 Calibrated volume

One of the factors which influences the choice of calibrated volume is the resolution of the meter pulse counting system. The resolution of a digital counter is unity. A counter can only indicate a whole number of pulses therefore the totalised number of pulses has a random uncertainty of ±1 pulse. It is therefore recommended to limit the uncertainty of ±1 pulse to a value which may be considered. To give an uncertainty of ±0,01 %, at least 10 000 pulses should be collected during a proving pass. Formula (1) represents the degree of uncertainty as follows:

$$u_r = \frac{1}{n} \tag{1}$$

where

u_r is the uncertainty due to the resolution of the pulse count arising from this source alone, commonly called the discrimination error;

n is the number of pulses collected during a proving pass.

The minimum volume between detectors is determined by Formula (2) as follows:

$$V_{min} = \frac{1}{u_r \times K_{min}} \tag{2}$$

where

V_{min} is the minimum volume between prover detectors;

K_{min} is the minimum K-factor (number of counts per unit volume) of any meter proved.

It follows that the required prover volume in relation to the output resolution of the meters can be reduced by increasing the pulse generation rate of the meters. Electronic means of pulse interpolation can be used and are described in Clause 8.

Increasing output resolution by electronic or mechanical means has a limitation. The internal resolution of the meter and the stability of the output frequency should be considered, as do the minimum number of revolutions of the meter or the internal averaging and time constant of an electronically based meter.

6.4.3 Length between detectors

The resolution of the prover detectors in terms of distance provides a second design criteria. The length of the calibrated section is dependent on the resolution, r_d, of the detectors. This is the resolution in the linear distance of the detector as it is activated by the displacer (or external flag). The relationship between the minimum length, L, and r_d is obtained as indicated in Figure 7.

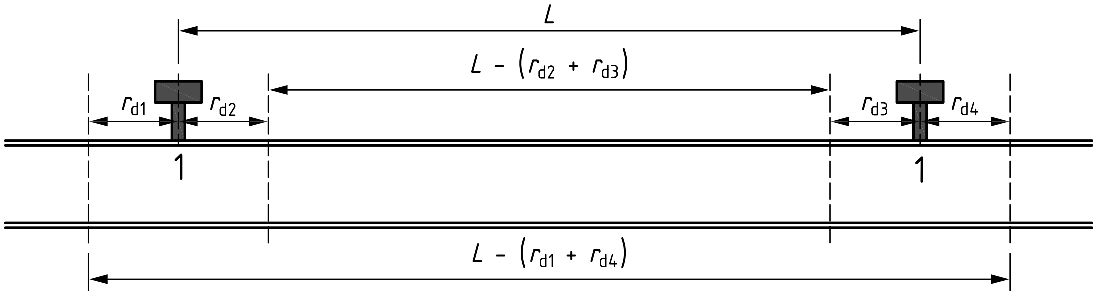


Figure 7 — Length between detectors

It is noted that r_d may normally be considered as a single value, however Figure 7 shows that it can be different for each detector and for a particular direction of travel of the displacer.

From this diagram, the maximum possible difference in length due to the resolution of the detectors is $4r_d$. Hence, to meet an acceptance criterion of repeatability of 0,02 %, the minimum length between detectors for a range is obtained from Formula (3):

$$L_{min} = \frac{4r_d}{0{,}02} \times 100 = 20\,000 r_d \tag{3}$$

The value of r_d for each particular detector should be obtained from the manufacturer. It is noted that commercial detectors of the mechanical piston type can have a resolution of 1 mm to 5 mm in any one direction. The resolution can be a combination of insertion depth and shape, vertical travel and the resolution of the electrical switch. External optical switches on a small volume prover have a resolution of between 0,1 mm to 0,001 mm.

NOTE The above simplified method yields a worst case value for L_{min}. When the probable length variation is expressed in statistical terms, the prover repeatability is based, not on the arithmetic sum of the detector resolution, but on the use of the root sum square method.

6.4.4 Diameter and Velocity

Having derived a design volume and a minimum length, the prover diameter, D, is calculated from Formula (4):

$$D = \sqrt{4V / \pi L} \tag{4}$$

The diameter calculated should be rounded up to the nearest standard pipe size.

From the estimated volume and diameter, the displacer velocity is now considered to determine the flowrate range which required. The velocities associated with minimum and maximum flowrates, should allow for a smooth travel of the displacer without judder or leakage and is discussed further in 6.6.

6.4.5 Pressure loss

The prover constitutes a source of pressure loss to the system and should be considered in the overall metering system design. Constraints may be imposed on the maximum tolerable pressure loss in the prover, which may further influence the sizing calculations in addition to the parameters set out in 6.1 to 6.3.

Pressure loss can be calculated from standard methods, taking into account the pipe diameter and length, connecting pipe diameters and lengths and making allowances for bends and connections.

Pressure loss through end chambers and valves may also be significant. When computing this initial pressure loss, the loss due to the displacer friction should be estimated and added to the hydraulic losses.

It is noted pressure loss may be significantly greater during a pass.

6.5 Displacers

6.5.1 General

The design of the prover displacer is such that:

a) There is no leakage of the liquid past the displacer as it traverses the calibrated section.

b) Friction between the displacer and the bore is low enough to ensure smooth judder-free travel across the full flowrate range and at the much lower velocities associated with calibration. Friction should be low enough to avoid wear or damage to the displacer, seals and pipe bore.

c) The displacer and seals should be compatible with the liquids being metered and the operating temperature range. Polyurethane, polychloroprene (neoprene), nitrile or rubber-fluoropolymer materials are the most commonly used materials. Other materials may be used provided that they can be shown to be suitable for the service requirements. Many rubber-based materials may swell with exposure to light hydrocarbons resulting in the displacer becoming jammed within the prover barrel.

d) The design and materials should not wear, damage or score the prover lining. For pistons, the risk of damage to the prover lining in event of a piston seal failure should be recognized.

6.5.2 Spheres

Prover spheres are usually manufactured from an oil resistant elastomer with polyurethane being the most common. Nitrile, polychloroprene (neoprene) and rubber-fluoropolymer materials are also employed with the material chosen to suit the fluid. Spheres are made available with different material compatibility and shore hardness (durometer) chosen to suit the fluid viscosity, lubricity and wall friction. Some materials have low friction additives in the compound to reduce wear.

Spheres are either one-piece mouldings or manufactured in two halves joined with a seam. They can be solid but are almost exclusively hollow for larger provers. A hollow sphere has the centre filled and pressurized with liquid. This allows the sphere to be inflated in a controlled manner to a diameter larger than the prover pipe bore.

Spheres are normally inflated using a hand pump and an appropriate liquid. All air should be removed from the interior of the sphere during the inflation process. The liquid chosen is normally water with a water/glycol mixture used when the operating temperature is potentially sub-zero.

The size and degree of inflation is recommended by the manufacturer of the prover and may be adjusted as necessary to suit the duty or for calibration. Both the inflated and un-inflated diameter should be recorded and stated on the prover calibration certificate. Inflated sphere diameters are typically between 2 % to 4 % oversize from the prover internal diameter chosen to suit the prover, the sphere material and the fluid. Sphere inflation higher than 5 % may be required for larger sizes of prover.

Spare spheres should be stored un-inflated in cool dark conditions where possible. They should be stored in such a way as to be fully supported and avoid developing a flat on the surface. Nets and sand beds are usually employed with protection to avoid the net or sand marking or embedding into the surface. As an elastomer can degrade with time and storage conditions, the date of manufacture and any use-by date should be documented.

The correct inflation kit should be made available and stored for use with the prover. As spheres are difficult to handle, and can be extremely heavy in larger sizes, a specialist tool to extract and handle the sphere should be available.

A means to verify the diameter of the sphere should be available. The use of a calibrated steel circumference tape measure is the preferred method. The diameter is calculated from the measurement of circumference. All measurements of diameter are taken with the tape in a vertical orientation. To achieve this, the tape is placed around the chosen equator of the sphere and the sphere rotated until the tape is vertical and then pulled tight. The supporting surface for the sphere should be chosen with care to ensure the sphere and tape are not damaged during the measurement process. It is noted that very large spheres may distort under their own weight and measurement procedures and methods should take account of this.

The sphere is measured several times across a number of diameters in order to identify any ovality in the sphere. Once diameter and ovality are established as being satisfactory the final reported diameter is the smallest of the diameters measured.

Callipers and diameter rings can be used to provide a validation that the sphere is not oval and to provide a rough guide to confirm the size of the sphere.

The sphere should be inspected for bulges, flats or surface defects not shown by diametric measurements alone.

When initially sizing or inspecting a sphere, it is good practice to over-inflate the sphere to check for leakage of fluid from the inflation (Schrader) valve, the seam or the body. The sphere can then be reduced to the correct inflation size by letting water out of the valve. The sphere is held with the valve in a vertical position thereby ensuring there is no air left in the sphere.

When ordering a new or replacement sphere, the manufacturer should be provided with both the prover inside diameter and the inflation size diameter, or the percentage of the oversize value required, so they can provide a sphere of the optimum size as well as matching to the fluid and conditions to ensure material compatibility.

6.5.3 Pistons

a) The design should be such that the seal integrity prevails throughout the proving operation at all velocities and flow conditions. This requirement applies to the piston diameter seals and any seals in internal valves and fittings.

b) The length and bearing surfaces of the piston should ensure smooth, judder-free travel with the face of the piston maintained at right angles to the direction of travel. The use of slide and wiper rings may facilitate this.

c) The design should ensure integrity during controlled acceleration, deceleration and arrest.

6.6 Displacer Velocity

6.6.1 General

The manufacturer should specify the velocity range within the prover. This may vary for different fluids and the displacer materials chosen. The figures given below are for guidance only and may vary significantly from a prover in service. A check should be made to ensure that the following criteria are observed over the operating flow range.

6.6.2 Minimum velocity

a) The minimum velocity is chosen to ensure smooth movement of the displacer and is particularly critical in highly compressible fluids or those with poor lubrication properties.

b) The minimum velocity should not adversely affect detector response.

c) The time for a pass at minimum flowrates should not be excessive, however it should encompass the velocities used for calibration as well as the lowest operating flowrates.

d) It is generally recognized that for conventional sphere provers, a minimum operational velocity of around 0,15 m/s (0,5 ft/s) may be achievable assuming fluids have lubricating properties.

6.6.3 Maximum velocity

a) The maximum velocity should be below that which creates hydraulic shock, or damage to the displacer or the detection devices. This is particularly important for larger provers where the inertia of a displacer is significant. There is also significant inertia in the flowing liquid when it is brought to a stop and then reversed within a bi-directional prover.

b) The maximum velocity should allow for both mechanical and electronic speed of operation of the detectors and detector response times relative to the calibrated length of the prover. The potential for detector switch bounce due to noise, impact or pressure wave transmission should be recognized.

c) There should be no leakage at maximum velocity, particularly at bends, where frictional forces may be greatest.

d) The maximum velocity is chosen to allow for the operating time of the flow reversal or interchange valve and the run-in length chosen for the prover and associated flowmeters.

e) Consideration of the volumetric flowrate and potential pressure loss or onset of cavitation/flashing within the prover system.

f) It is noted that some standards recommend a maximum velocity of 3 m/s (10 ft/s) for conventional unidirectional sphere provers. This figure is derived from experience and consideration of the equipment normally used in construction, and should be considered guidance rather than a rule. The maximum velocity of between 1,5 m/s (5 ft/s) to 2,5 m/s (8 ft/s) has been recommended for conventional bidirectional sphere provers to account for the inertia of the fluid when changing direction and the operation of the four-way valve. Conventional piston provers have a further reduced velocity recommendation of between 1 m/s and 1,5 m/s (3 ft/s and 5 ft/s) to allow for the inertia of stopping a solid piston at the end of a pass. Proprietary small volume piston provers may have significantly higher velocities as specified by the manufacturer.

6.7 Detectors

The resolution of the detectors directly affects the size of the prover.

Detectors should have an expected resolution of not greater than 0,005 % of the calibrated length.

Detectors actuated directly by the displacer are usually mechanical devices intruding into the prover barrel. The movement when impacted by the displacer actuating an electrical switch located external to the prover barrel. Various types of electrical switch are employed to detect and signal the operation of a mechanical detector. These include mechanically actuated micro-switches, reed-switches or remote sensing by proximity, magnetic, inductive, or optical means. Small volume piston provers have detectors actuated from a constraining rod connected to the displacer and located externally. External detectors are usually actuated by the passage of a flag through an optical switch, however alternative switch types may be used.

The most common type of mechanical detector used with sphere provers employs a steel plunger with a hemispherical end, which projects through the wall of the pipe by about a centimetre. When the displacer makes contact with the plunger, it forces it outwards against the action of a spring until it is flush with the inside of the pipe wall. At some predetermined point in its travel, the plunger operates an electrical switch, which may be either a micro-switch or a magnetic switch.

The detector plunger should have a specified insertion depth and position for the actuation of the switch given by the manufacturer. A change in insertion depth or switch actuation position results in a changed actuation point hence a change in calibrated volume. Switches should be locked and sealed after installation or adjustment.

Detectors provide the signal to initiate the proving measurements by gating the pulse counters and also provide signals to actuate control of the proving operation.

On operation, and at all velocities, the switch should operate cleanly with no switch bounce. This may result in a false signal triggering events or counters. The use of de-bounce circuits may be employed however these should accurately reflect the switch operation and not introduce delay.

Although provers operate satisfactorily with only one detector at each end of the calibrated length, it is recommended that conventional provers are fitted with two detectors at each end. This provides a safeguard and a check against the malfunctioning of a detector. This is explained further in Annex E.

When selecting detectors, the following features should be considered:

a) the resolution, r_d, and repeatability in each direction (see Clauses 5 and 6);

b) temperature stability of both the detectors and the associated mountings;

c) robustness of construction;

d) sensitivity to mechanical, magnetic, electrical or optical interference;

e) long-term reliability and stability of performance;

f) ability to be removed and replaced or adjusted with minimal change to the actuating position;

g) compatibility with the pulse counter gating circuitry;

h) requirement to flush a mechanical detector to remove debris or wax deposits;

i) requirement to avoid condensation or temperature affecting the operation of external switch enclosures.

Any replacement or adjustment of a detector should be recorded in the prover log book and records. Unless specific and proven procedures are in place, any replacement or adjustment of a detector should be followed by a calibration to establish a new calibrated volume.

6.8 Prover valves

Any valve situated between the prover and the meter under test or between the prover and a reference device used for its calibration, is deemed to be a critical valve. Any leakage or passing product would affect (invalidate) the results. Critical valves should be of a double block and bleed design, fitted with a means of verifying leakage or else a standard valve fitted with some other means of leak detection (e.g. a blind on the downstream side).

a) A four-way valve should have switches or indicators to ensure it is fully rotated and seated. This ensures the valve is shown to be sealed before the sphere reaches the first detector switch.

   NOTE It is customary to automatically abort a prove pass if the detector switch is reached before the valve is fully seated.

b) A means to ensure a four-way valve is leak tight, when seated, should be provided. Block-and-bleed systems that employ differential pressure as an indication of leakage may be operated either manually or automatically and should be regularly maintained.

c) A combination of four separate valves may be used rather than a proprietary four-way valve and should be designed to ensure the same performance as described for the four-way valve.

d) Flow control valves in the system should be of a quick-acting type and be capable of automatic operation.

e) Valves should be sized to avoid excessive pressure drop and to prevent cavitation.

On unidirectional piston provers, the valves used to initiate the proving operation may be internal or external to the prover and should have a means or procedure for checking piston seal integrity.

On unidirectional sphere provers, an interchange valve or mechanism may comprise any of the following typical arrangements:

a) a sphere-handling ball valve;

b) a sphere-handling plunger-type valve;

c) various combinations of ball and/or gate valves;

d) a two-sphere or three-sphere assembly, which employs the passive spheres acting as the by-pass seal.

If automatic seal leak detection is not fitted, there should be a manual means of checking seal integrity.

6.9 Additional design considerations

Further items for consideration when designing or installing a prover are given below.

a) The availability of space may affect the configuration of the prover pipe. In confined spaces a folded loop (scorpion) design may be necessary. Where provers are of a folded loop design, the bend radius in relation to the prover barrel diameter should be considered to ensure leak free and minimal friction when the sphere passes.

b) Large provers may be manufactured and assembled in sections and, in such cases, some means of accurate alignment of the sections ensured. Male to female flanges with spigots and metal to metal seating using “O ring” seals provide positive axial and longitudinal alignment. Welded joins to pipe sections should provide a smooth internal surface with no internal intrusions, raised edges or hollows.

c) Adequate support and foundations to maintain the alignment of the prover when both full and empty. These should be stable over time and account for changing ground conditions e.g. frost or water saturation.

d) Temperature and pressure measurement should be provided as detailed in Clause 7.

e) Calibration connections should be provided to meet the requirements of Clause 11. Where a master meter is to be used for calibration using the process liquid, the additional pressure loss imposed by the calibration system should be taken into account.

f) Adequate space to install calibration equipment.

g) Welding should conform to appropriate welding and pressure standards.

h) The temperature and pressure rating of the prover pipework. Relevant National or industry codes should be considered.

i) Provision for safe draining and venting of the prover and pipework with due regard to the environment and explosive gas release. There should be positive indication that there is no leakage from drains and vents during prover operations

j) Provision to provide pressure relief to any part of the prover or valve assemblies which may be isolated and sealed. Thermal expansion of trapped liquid may overpressure the pipework.

k) The position and size of calibration connections should be considered, for example if the initial factory calibration is by water-draw, the calibration connections may be small and connect to both upstream and downstream ends of the prover. If the onsite calibrations are to be by master meter, the calibration connections (along with any critical valves) are installed at only one end, usually downstream.

Alternative designs and operations of pipe provers are given in Annex G.

7 Ancillary equipment

7.1 Overview of temperature and pressure measurement

To account for thermal and pressure expansion of both the fluid and the materials of construction, accurate temperature and pressure measurements are required. These allow the correction of the prover volume at measurement conditions to and from standard conditions. These measurements also allow the correction for fluid thermal and pressure expansion between the prover, a reference device or the meter under test. Measurements are also required to ensure both temperature and pressure stability is achieved to ensure repeatable calibration results.

Pressure and temperature should be measured to best reflect the conditions at the measuring section of a prover, a meter under test or a reference device. This entails measurements to be made, as a minimum, at the prover outlet, at the meter under test and at any reference device. It is good practice to also measure temperature and pressure at the prover inlet hence providing a mean value for the prover, and also quantify stability and operating conditions.

Where there is insignificant difference in temperature or pressure between prover, a device under test or a reference device, a single representative measurement may be allowed.

It is good practice to record ambient temperature and pressure for information. Ambient temperature, pressure and humidity are required to derive the buoyancy correction factor if a gravimetric reference is used for calibration.

Pressure and temperature measurement systems should have valid calibration certificates. If, during a calibration, the instruments used are those normally associated with the prover or meter under test, these should be calibrated or verified prior to use.

Measurements of temperature and pressure should be taken for each and every pass. The number of measurements taken during a pass should be chosen to be commensurate with the time available and the variability of conditions.

The average of the measurements provide a single representative temperature and pressure associated with a pass or a run. This mean value would be used in the calculations.

Temperature of a volumetric measure is recorded when the measure is full. For a gravimetric reference, measurements of the ambient conditions of temperature, pressure and relative humidity are recorded.

7.2 Temperature measurement

a) Temperature measurement should be by means of Resistance Thermometer(s) fitted in thermowell(s). Resistance thermometers compliant with BS/EN/IEC 60751[5] class A, or an equivalent specification would be expected.

b) Temperature should be measured where it best reflects the temperature of the flowing fluid in both normal operations and during a prover calibration. The immersion depth within the flowing fluid of both the thermowell, and the probe within it, should be adequate. Location of thermometers should be such that the prover wall temperature and the fluid temperature can be assumed to be the same.

c) As the prover barrel temperature is normally assumed to be the same as that of the fluid, insulation and/or protection from ambient conditions of wind, rain and sun should be considered for the prover barrel. Consideration should be given to lagging or insulating thermometer heads and the pipework adjacent them to reduce the effect of ambient conditions.

d) Thermometer probes should be a tight fit to the thermowell and the well filled with conducting fluid or paste.

e) The potential for self-heating of resistance thermometers when the flow is very low during calibration should be recognized.

f) Sufficient wiring should be provided to allow the removal of an installed probe from the thermowell and repositioning in a calibration block or container without disconnection.

g) Test thermowells may be installed adjacent to the measurement locations to allow installation of a reference thermometer for verification. These only provide accurate verification when there is significant flow passing the thermowells.

h) The temperature measurement system includes the probe, possibly a local transmitter, the signal transmission and readout. To mitigate the effect of environment and location a four-wire connection should be employed between the probe and the readout or temperature transmitter.

i) For fiscal applications the temperature measurement system is normally expected to have a resolution no greater than of 0,1 °C and be expected to measure temperature with an expanded uncertainty of no greater than 0,3 °C. This expectation ensures an uncertainty in C_{tl} and C_{ts} to be not more than 0,000 1.

7.3 Pressure measurement

a) Pressure should be measured where it best reflects the pressure of the flowing fluid for both normal operation and a prover calibration. Pressure should be measured as close as possible to the inlet and outlet of the prover barrel and measured in pipework with, ideally, the same cross-sectional diameter. This ensures the velocity/head (pressure) is equivalent.

b) Pressure tappings should have clean sharp edge at the entry to the pipe bore without any intrusion into the flow.

c) Pressure transmitters or gauges should be located as close to the pressure tappings as possible and suitably mounted and protected against vibration and environmental changes. Environmental protection through sun shading and temperature-controlled enclosures should be considered. Tappings and impulse lines should be routed to avoid collection of air or debris.

d) Isolation and vent valves should be provided to ensure that transmitters can be calibrated, verified or changed without risk of injury to the operator or release of fluid.

e) Where pressure is measured by transmitters without local indication, additional pressure gauges should also be provided to clearly indicate the pressure locally.

f) The pressure transmitters or gauges should be chosen to provide adequate uncertainty in the correction factors C_{ps} and C_{pl}. A resolution of no greater than 10 000 Pa (0,1 bar) and an expanded uncertainty of no greater than 5 000 Pa (0,5 bar) is recommended.

7.4 Calibration connections

Connections to the prover should be provided to allow for calibration. The connections required depend on the size and type of prover and also the calibration technique to be used. Connections and interconnecting pipework should be as short as practically possible and sized to allow adequate flow for the calibration. They should be isolated when not in use by using blank flanges, spades, or valves.

For safety considerations blank flanges or spades should be fitted with an associated valve to allow release of pressure and venting before removal.

For calibration methods involving closed systems, there should be a means of positive isolation, e.g. block-and-bleed valve or spade, between the calibration connections. For open tank systems, a positive means of isolating the prover from the rest of the metering system should be provided, e.g. blank flanges, spades, or block-and-bleed valves.

Calibration connections should be positioned to ensure flow passes temperature and pressure tappings of the prover or that alternative instrument tappings are provided.

7.5 System control

The prover data collection and processing equipment may consist simply of a pulse counter triggered from the detectors to record the meter pulses, with the operator manually controlling the operation of the prover and recording temperature pressure and time measurements. Calculations would be carried out manually. Alternatively, microprocessor techniques allow for fully automatic proving runs and calculations, including pulse interpolation (see Clause 8). Automatic control may be provided by a standalone controller for the prover, or as a separate program within a flow computer or measurement system.

It would be expected that the control system would record the number of meter pulses for each pass and the time taken for each pass. Measurements of temperature and pressure should be taken as often as is required to obtain a representative value during each pass. This may depend on the stability of the flowing conditions.

The pulse counter should have a frequency response and input trigger level suitable for the meter under test. It is normal practice to amplify a meter output locally to provide a clean square wave at a constant amplitude for transmission to the pulse counter. This ensures correct triggering is achieved. The counter should have a response to accommodate the frequency range and pulse shape of the meter to be calibrated. It is advised to use low pass filters and to avoid a counter with too high a frequency capability. This reduces the potential for noise pick up.

8 Pulse interpolation

Pulse interpolation is the process of increasing the resolution of a pulse count by electronic means. Three pulse interpolation methods are recognized in ISO 7278-3[6], double chronometry, quadruple chronometry and pulse multiplication.

Double chronometry is the most commonly used method to determine the number of pulses, with an estimate of the fractional part of a pulse, collected between detector actuations. This method employs one pulse counter and two timers. The number of pulses is as shown in Formula (5):

$$N' = N\left(\frac{t_2}{t_1}\right) \tag{5}$$

where

N' is the number of pulses including the decimal fraction of a pulse interpolated from the time ratio;

N is the whole number of meter pulses accumulated between actuations of the detector switches;

t_1 is the time (number of high-frequency timer clock pulses) accumulated between the first meter pulse after the first detector signal and the first meter pulse after the last detector signal;

t_2 is the time (number of high-frequency timer clock pulses) accumulated between actuations of the detector switches.

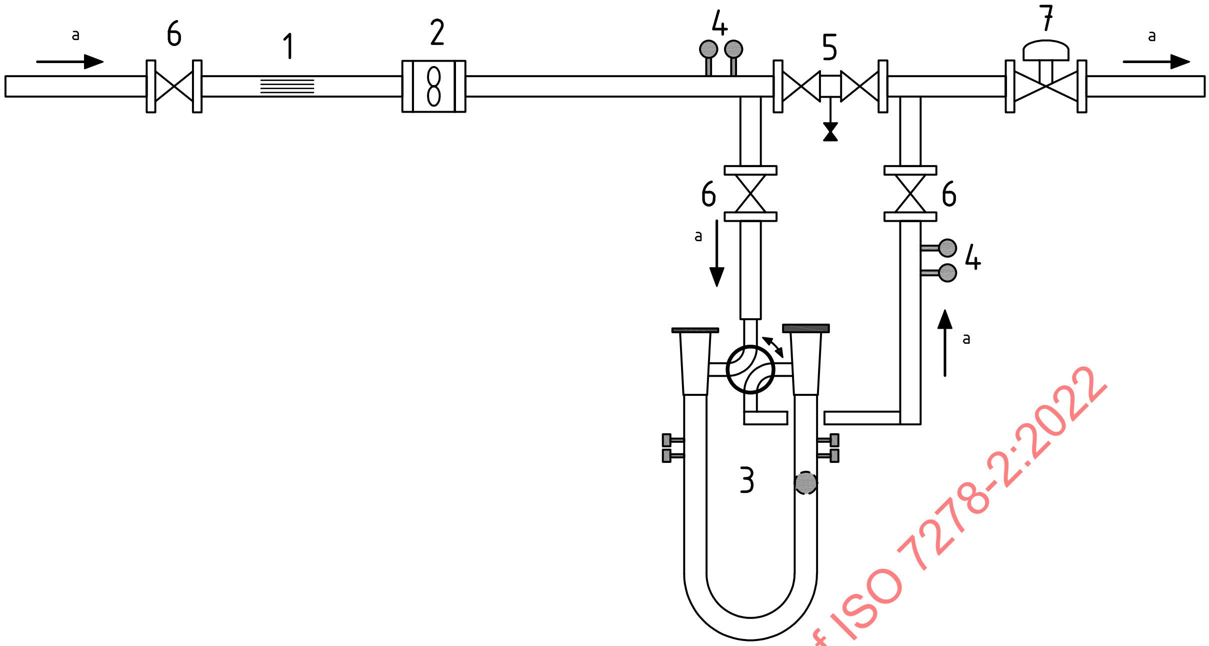
These methods are described, along with more details of the uncertainty and design considerations in Annex F.

9 Installation

9.1 Mechanical installation

9.1.1 General

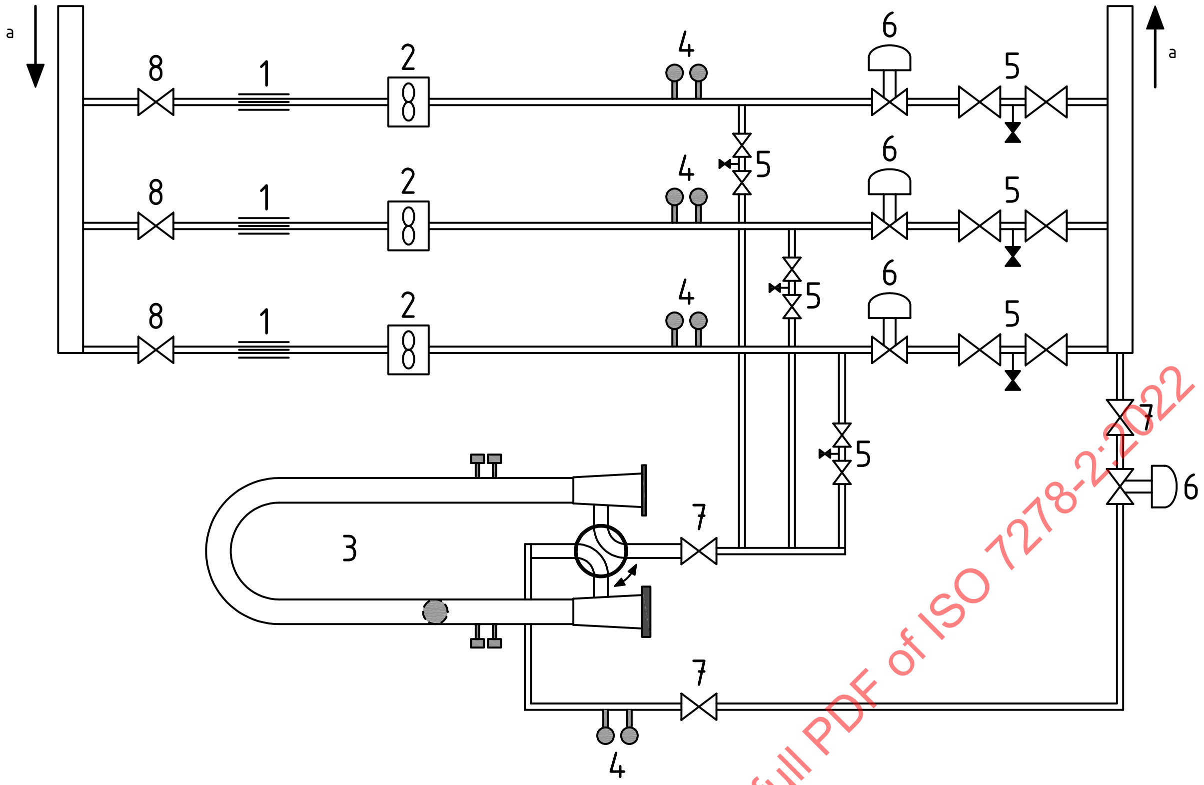
Two schematic diagrams showing provers installed in flow systems are given in Figures 8 and 9.



Key

1 flow conditioner
2 flowmeter
3 prover
4 temperature and pressure
5 double block and bleed valve
6 isolator valve
7 flow control valve
a Flow direction.

Figure 8 — Single meter installation



Key

1 flow conditioner
2 flowmeter(s)
3 prover
4 temperature and pressure
5 double block and bleed valve
6 flow control/balancing valve
7 isolator valve
a Flow direction.

Figure 9 — Multiple meter station installation

When installing a prover, the following should be considered.

a) The temperature and pressure rating of the materials and components comprising the proving system should conform to the relevant codes and all materials be compatible with the process fluids. Particular care is required when handling sour and corrosive liquids and liquefied gases.

b) By preference, conventional provers should be installed downstream of the meters being proved. This reduces interaction between the prover and the meter. Proprietary small volume piston provers are usually installed upstream of the meter under test as the calibrated volume is downstream of the displacer.

c) The pipeline distance between the prover and the flowmeters to be proved should be minimized to reduce the possible difference in pressure and temperature.

d) Consideration should be given to the potential for the prover installation to change the flow profile at the flowmeter under test, hence changing the K-factor.

e) The potential for localized pressure loss should be considered to avoid the onset of cavitation and flashing within the system.

f) Safe means should be provided to isolate the prover for maintenance purposes.

g) In addition to the recommendations given in 6.8, any other valves in the proving system which can constitute a bypass round the prover and meter, e.g. drain or vent valves, should be fitted with a means for checking for leakage.

h) Provision should be made to drain the prover completely and to vent air or vapour from the system. Appropriate facilities should be provided for disposal of drained or vented liquid and vapours. The disposal system should allow for vaporization as hydrocarbon liquids are depressurized.

i) Pressure relief should be provided to allow for liquid thermal expansion when the prover, or associated pipe sections, are isolated from the adjoining pipework.

j) All pipework, above ground or buried, should be protected against external corrosion. Reference should be made to relevant pipeline safety codes.

k) Provers used on liquids with a high viscosity and/or high wax precipitation temperature may require trace heating and thermal insulation. This is particularly important where provers are in intermittent use. Even where thermal insulation of the prover is not required as part of the process, consideration should still be given to insulating the prover to improve the thermal stability of the volume and to reduce the time required to attain thermal stability.

l) Protection from sun, wind and other environmental effects may be required to obtain thermal stability. Insulation and sun and wind screens should be employed. Thermometer heads should be insulated.

m) The prover should be protected from damage by dirt or debris which may enter the system upstream of the installation. The manufacturer's recommendation for strainer or filtration requirements should be adhered to. Provision to flush or clean the prover and/or detectors from debris or wax deposition should be considered.

n) Provision should be made for safe removal and replacement of the displacer with minimum loss of liquid.

9.1.2 Fixed provers

a) Hydraulic and stress analyses should be undertaken for all anticipated conditions of flow, pressure, temperature and vibration in the design, and checked before installation and future use.

b) The design of foundations and supporting structures should take into account all relevant factors such as soil conditions, external forces to and from adjoining pipework, and change of weight when empty and when full.

c) Where the prover and/or its associated pipes and fittings are buried, access pits are recommended for flanged connections, valves, sphere detectors and transducers. The access pits may be sand-filled in the case of buried flanges.

d) Installations should be designed to prevent accumulation of foreign materials and sediment, especially in sections of pipework which are of larger diameter than the main stream.

e) Connections for routine calibration of the prover should be located so that proper safety precautions can be observed. Consideration should be given to such aspects as space, access and hard standing for mobile calibration equipment and provision made for the supply and disposal of fluids used for calibration.

9.1.3 Mobile provers

a) Where mobile provers travel on public roads, the relevant regulations should be considered. They should be drained and flushed and/or filled with inert gas prior to transporting.

b) A means of remotely isolating the mobile prover and its connecting hose or connecting pipework from the process in the event of an emergency should be provided. This is essential in respect of high vapour pressure liquids such as LPG.

c) Hydraulic and stress analyses should be undertaken for all conditions of flow, temperature, pressure and vibration to ensure forces applied to the prover, hoses, and site pipework remain within permissible limits.

d) Provision should be made to enable proper safety precautions to be taken when installing, operating or removing a mobile prover. Consideration should be given to access and hard standings suited to the size, weight and construction of the mobile prover to be used. Provision should be made for the supply and safe disposal of calibration liquids.

e) Where it is necessary to purge the prover with nitrogen to displace heavier-than-air gases for transport, storage, etc., provision should be made for nitrogen to enter at a high level and to be vented at a low level. The appropriate safety precautions when dealing with nitrogen should be observed.

f) A written procedure should be agreed between the installation operator and the calibrating authority for the connection, use and disconnection of mobile proving equipment.

9.2 Electrical installation

The standards laid down in national and local regulation, including those for in potentially explosive atmospheres, should be considered. Written procedures should be made for the following:

a) electrical earthing requirements;

b) power supply requirements;

c) temporary connection to plant instrumentation;

d) sequence of connections and disconnections with particular regard to earth bonding and the potential for static electricity.

e) maintenance and testing of all electrical and electronic apparatus.

9.3 Other installation recommendations

a) While the operation of a prover is normally automated and controlled remotely, local manual controls should also be provided. Local controls should be located to allow safe and convenient operation. Remote operation should be securely disabled when the system is on manual control.

b) Local indicators for thermometers, pressure gauges and detector switch operation should be placed so that they can be safely, easily and conveniently observed.

c) Safety interlocks and sealing devices should be installed to prevent unauthorized tampering with equipment, particularly detector switches and end closures.

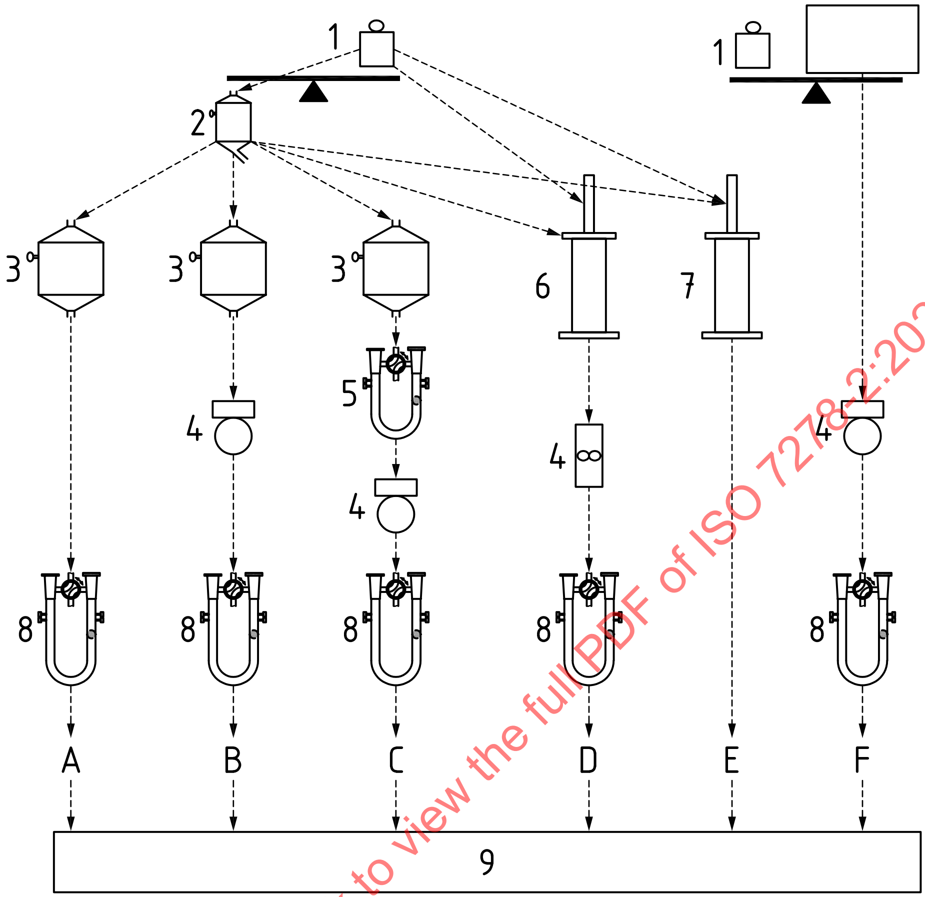
d) Access to fire-fighting equipment should be provided.

10 Traceability

Pipe provers have a hierarchy in a traceability chain. All have a volume traceable to standards of mass combined with the derived density of pure water or an alternative stable and characterized liquid, e.g. light non-volatile petroleum product. There is a hierarchy for traceability which is followed to provide the uncertainty required by the final application.

The uncertainty for volume determination should be specified according to the requirements of the application.

Figure 10 shows schematically different traceability chains associated with the use of a pipe prover to calibrate a working flowmeter.



Key

1 mass
2 primary measure
3 proving tank
4 master meter
5 master pipe prover
6 master small volume piston prover
7 small volume piston prover
8 pipe prover
9 measurement flowmeters

Methods:

A volumetric tank water draw
B volumetric tank / master meter
C master prover/master meter
D master small volume prover/master meter
E primary measure or gravimetric water draw
F master meter calibrated gravimetrically

Figure 10 — Traceability

11 Calibration

11.1 General

A prover is manufactured to have a nominal volume displaced between the detectors. The actual volume is established through calibration. This resultant calibrated volume is expressed as the volume at standard, or base, conditions. The volume is established before the prover is brought into service though a factory calibration followed by further calibration or verification when commissioned.

Subsequently, recalibration is normally carried out at specified intervals which may be set by national or local authority regulation and/or agreement between stakeholders. Recalibration intervals, if not prescribed, should be established based on risk. The history of stability, the risk of a change in the volume measured and the value of the product being transported, are examples of the risk considerations.

The prover volume is also re-established after damage, a change to any critical component of the prover system or a risk analyses. The adjustment, replacement or repositioning of a detector normally necessitates recalibration.

Where a prover has multiple detectors, all possible volumes should be determined. For example, for a prover with four detectors, two at each end, four calibrated volumes should be derived.

For bidirectional provers, the calibrated volume is usually the round-trip volume however the individual pass volumes may also be recorded or required to be reported.

The calculations and formulae which may be used to derive the base volume are summarized in Annex A.

Calibration is carried out with adequate number of determinations to establish a mean value and the repeatability to determine the uncertainty of the value. The volume is determined from the mean of a number of passes or the mean of runs made up of multiple passes. For bidirectional provers, a run is normally the sum of two passes i.e. the round-trip volume. For this case some authorities also require the individual directional pass volumes to be reported in addition to the round-trip volume. Unidirectional provers, in particular small volume piston provers, may have the volume determined through either one run of a significantly large enough number of passes, or from a batch of runs each comprising a number of passes.

Repeatability criteria are specified and normally based on the results of 3 or 5 consecutive passes, or runs, falling within an agreed range. Alternative repeatability criteria based on statistical equivalence is not precluded nor is the use of an increased number of runs or passes (see Annex C).

As the determined volume should be independent of the flowrate, some regulations require at least one determination to be derived at a flowrate a minimum of 25 % different from the highest flowrate chosen. Flowrate is estimated from the time between detectors or from an in-line flowmeter during a pass. This test may be specified as a diagnostic test or the result included within the determination of the mean and repeatability. The result would be expected to lie within the repeatability criteria agreed for the calibration. If leakage past the displacer is suspected, additional runs at a flowrate 50 % different from that used for the initial set or batch of runs can be carried out as a diagnostic test. This provides a more sensitive indicator of leakage.

It is noted that API MPMS:2010, 4.9[7] suggests that, when using the master meter calibration method, three batch determinations are obtained, with the average of the three to be used as the result. One batch would be carried out at a flowrate different from the other two.

There are two recognized methods for a prover calibration; water draw and master meter methods. Both share common requirements for the fluid, circuits and much of the equipment.

11.2 Calibration circuits and equipment

Schematic diagrams of typical calibration circuits are given in Figures 11 to 16.

A supply of clean, filtered and stable liquid is required. Fresh, drinking quality, water is the recommended fluid for the water draw method. The definitions describing water characteristics are given in of ISO 8222:2020, Table A.1[4].

When water of drinking quality is not available, or practicable, other liquids may be used. These include impure or saline water, water including the addition of small quantity of corrosion inhibitor, or light stable hydrocarbon oils. The liquid should be filtered from all solids and be characterized in terms of physical properties such as thermal and pressure expansion factors, density and viscosity. Where the reference is gravimetric, the density or relative density should be known accurately. When a volumetric reference is used, the volume expansion factor should be known. For fresh water this is usually derived from the density of pure water at two temperatures whereas for hydrocarbon liquids, ISO 91[9] provides acceptable expansion factors for crude oils and products. Acceptable formulae are given in ISO 8222[4] for pure and saline water. The formulae for pure water in Annex A are recommended for the calculation of the thermal expansion factor of water. These formulae give the density of pure water but also provide acceptable estimates of thermal expansion for clean fresh and drinking quality water. For gravimetric calibrations, the calculated density for pure water is corrected by multiplying by the measured relative density.

The influence due to viscosity of the fluid should be recognized. The viscosity of an oil product at ambient and operating temperature should be determined as an influence factor. This may be the effect on the drainage time for a volume measure or the variation in the meter factor of a master meter.

Due to the relatively small volume of fluid required to calibrate a small volume piston prover, water may be drawn directly from a drinking water supply and run to waste. It is however more common practice for all provers to draw and return the liquid from a reservoir. This reservoir should be large enough to fill the complete calibration system, including any reference tanks or vessels, while ensuring sufficient depth remains to keep the pump suction submerged to avoid air entrainment. The reservoir should also have a large enough thermal capacity to ensure temperature stability across the calibration period and certainly during each pass of the prover displacer.

The return of liquid to the reservoir should not provide a source of air entrainment back to the pump suction. Liquid collected in a reference tank or vessel may be returned directly to the reservoir or via a secondary reservoir.

The pump chosen to circulate the liquid should be, as far as possible, free of pulsations and chosen to provide adequate flowrate and pressure to maintain flow but not impart too much heat energy into the fluid. The use of motor speed control or spill back circuits is advised. The pump and system should allow for the flow to be stopped without excess pressure surge or damage to the pump.

Circulation of liquid should be through solid pipe, or non-delating hose. The length and distance between the prover and the reference should be as short as practicable. This pipe section should be insulated if required to minimize temperature variations. A means to allow flow to continue through the prover under test between proving passes should be considered to maintain stability.

For the master meter calibration method flow is continuous and hence the requirement for valves is limited to those required to control the flowrate and pressure. For a water draw calibration, the flow is started and stopped, or diverted, into the reference measure. This requires the use of a fast-acting (solenoid) valve triggered by the prover detectors. As fast acting valves are usually of small diameter, a second larger valve may be installed to allow a higher flow during the pass, opening after a pass starts and closing before the end of the pass flow continuing through the fast acting valve. A third valve is installed to allow the flow to bypass the reference until the displacer reaches or approaches the first detector and then to allow the displacer to move on after the end of the pass.

The transfer point between the prover and the reference is established at a point where the fluid enters the collection tank. This may be a valve, a weir or the meniscus at the end of the reference entry pipe.

Valves are sized to match and control the flowrate required for the calibration. They are operated, or actuated, at a speed to allow the flow to be reduced and stopped on the actuation of a detector, the approach to a detector or observing the level in the neck of a volumetric measure. The valve used to stop the flow from a detector signal should be sized, and the speed chosen, to give minimal uncertainty due to fluid passing the valve after the detector is actuated. The valve operation should be repeatable. The size of the solenoid valve commonly associated with small volume provers ranges from 6 mm to 12 mm, but may be larger for conventional provers.

The temperature and pressure of the liquid should be measured as described in 7.1. Calibration certificates should be available for any instruments used.

11.3 Water draw calibration method

11.3.1 Description

Water draw is the calibration of a prover by direct displacement of water from the prover into a reference measure. The reference measure may be either volumetric or gravimetric.

The volume displaced to the reference between the actuation of the start detector and the actuation of the end detector provides the calibrated volume. Water draw can also be employed for proprietary small volume piston provers by withdrawing liquid from a reference measure to the upstream volume of the prover if this is a requirement.

Water draw is the traditional choice of calibration method and is still favoured by some regulating authorities for all calibrations, especially where the volume of the prover is relatively small. Water draw is usually the preferred method for the initial calibration of a prover after manufacture and prior to installation on site. It is also the preferred method for small volume piston provers.

Where the volume of a prover is large, or an oil product has been used and cleaning the internal surfaces difficult, the master meter method is generally the preferred method of calibration, particularly when the calibration is on site as it reduces time on site and provides for better stability in difficult conditions.

Water draw is normally carried out when the prover is clean and free from traces of oil. Although not a requirement, clean fresh water is normally used as the calibration fluid. The use of clean fresh water provides control and stability of fluid properties. The principles of the water draw method may be applied using clean, low viscosity, low vapour pressure hydrocarbon products. The properties of the fluid should be stable and the thermal expansion and compressibility known to the required uncertainty.

A calibration circuit is set up in which liquid (water) flows from a reservoir, through a pump, through the prover to be calibrated and back to the reservoir. A reference measure, volumetric or gravimetric, is set up downstream of the prover in such a way that the flow can be temporarily diverted into the measure as required.

Flow is controlled through a number of valves. One larger valve allows a faster flowrate to be set when circulating flow to achieve stability of conditions. It also controls or sets the flowrate when running the displacer from the end chamber or start position towards the detector, during a pass and to allow the displacer to move forward after completion of a pass. A second smaller valve restricts flow when the displacer is on final approach to a detector. On approach to a detector, the larger valve is closed with flow being maintained at a low rate through the smaller valve. This smaller valve acts as a control valve and will be installed upstream of the fast-acting solenoid valve. This fast-acting valve is actuated from the signal from the detectors, stopping the flow to the reference.

A diverter valve is installed to allow the flow to continue directly back to the reservoir prior to the actuation of the first detector and following the actuation of the second detector. After the flow is stopped at the first detector, the flow direction is diverted into the reference measure and restarted. Flow may be increased in rate to reduce the time taken for the pass but is again reduced on approach to the second downstream detector and stopped when the downstream detector is actuated. Flow path is then redirected back to the reservoir and restarted moving the displacer beyond the downstream detector.

For a bidirectional prover the flow direction is reversed and the process repeated.

Ideally the water draw should be carried out so that there is no interruption to the flow and the displacer is not stopped during a pass. This is easily achieved when the reference has the same nominal volume as the prover. For larger volume provers this may not be practicable and multiple fills of the reference are required. In this case, when a single reference measure is used, the displacer is stopped between fills. If two or more measures are available, one may be filling while the second drains. The flow would be diverted between measures as required. This ensures the displacer moves smoothly and continuously down the barrel of the prover. Not only does this reduce the uncertainty of the calibration, it considerably reduces the time taken. As it is common that reference measures fill faster than when draining, careful planning and timing is required. All valves and filling pipework should remain full and all liquid is transferred without loss during diversion. Alternatively, two or more measures can be filled simultaneously stopping the flow into each when full and finally coincident with the end of the pass.

Where reference volume(s) are not an exact sub-multiple of the prover volume, an additional smaller measure is required. There is no preference as to when the smaller measure is used; during the pass or as a final measure. If the reference measure(s) are larger than the volume of the prover this additional measure may be used to “top up” a larger measure to fill it to the middle of the scale. If the reference measure(s) are smaller than the volume of the prover, some volume may be withdrawn to the smaller additional measure. A gravimetric measure may be used to provide this additional capacity and provides more flexibility and range to provide the exact volume required.

For any system, an established transfer point such as a valve, solenoid valve, swan neck, weir or meniscus on the bottom of a filling pipe, is established to ensure all fluid displaced is transferred to the measure.

11.3.2 Volumetric measure as reference

The design and specification of volumetric measures is given in ISO 8222[4].

Standard (sized) measures may be used or a bespoke measure may be available to match the volume of a specific prover, as is the case for many small volume piston provers.

Test measures or proving tanks may be either bottom or top fill designs. Top fill measures should ensure the filling pipe has suitable entry to the tank and is not submerged when the measure is full.

Reference measures are normally required as a minimum however a primary measure is usually specified for use with a small volume prover, particularly if this is to be used subsequently as a reference or master prover.

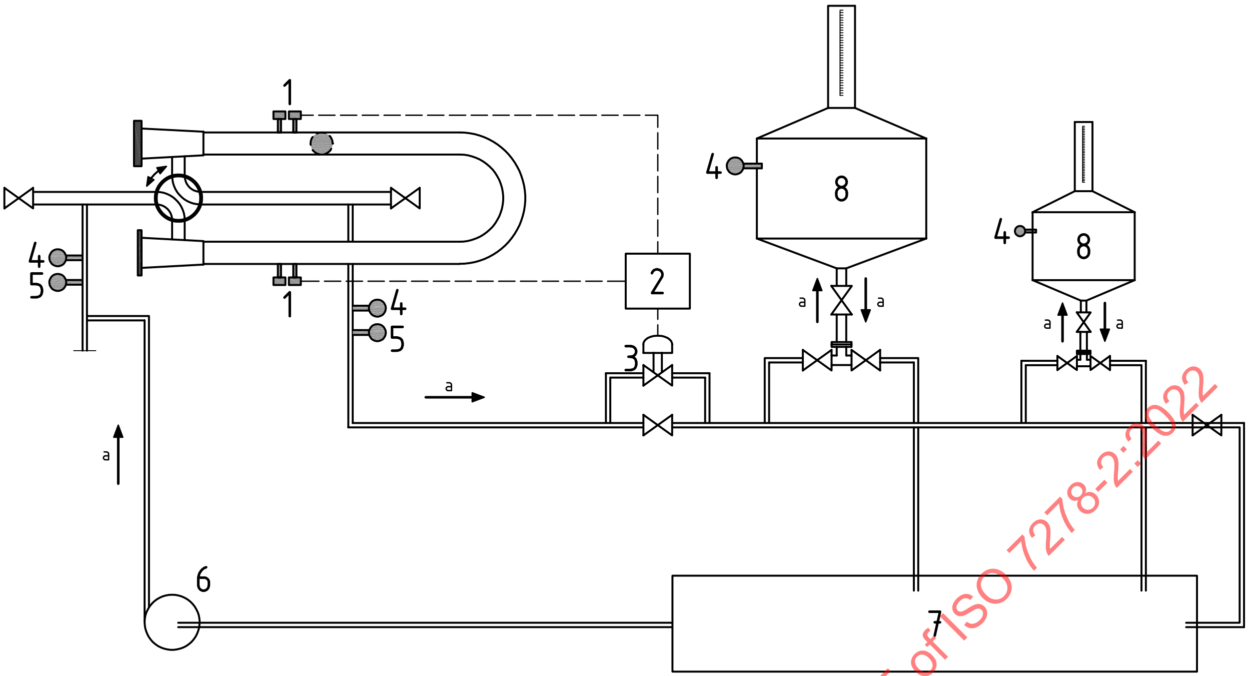
It is presupposed that measures are calibrated, certified and traceable to national standards at appropriate intervals with the certificates available for inspection.

In bottom fill designs, the fluid is introduced through a valve manifold into the bottom of the measure. The valves on the manifold should be demonstrably leak tight and the pipework connecting the prover to the measure should remain full both before and after each run.

For any system, a transfer point such as a solenoid valve, a swan neck, a weir or meniscus on the bottom of a filling pipe, is established to ensure all fluid displaced is transferred to the measure.

Drainage of the measure should follow the specified drain times and method set out in the measure’s calibration certificate and should not be compromised by added restriction to flow in the drain hose or pipe from that specified when the measure was calibrated.

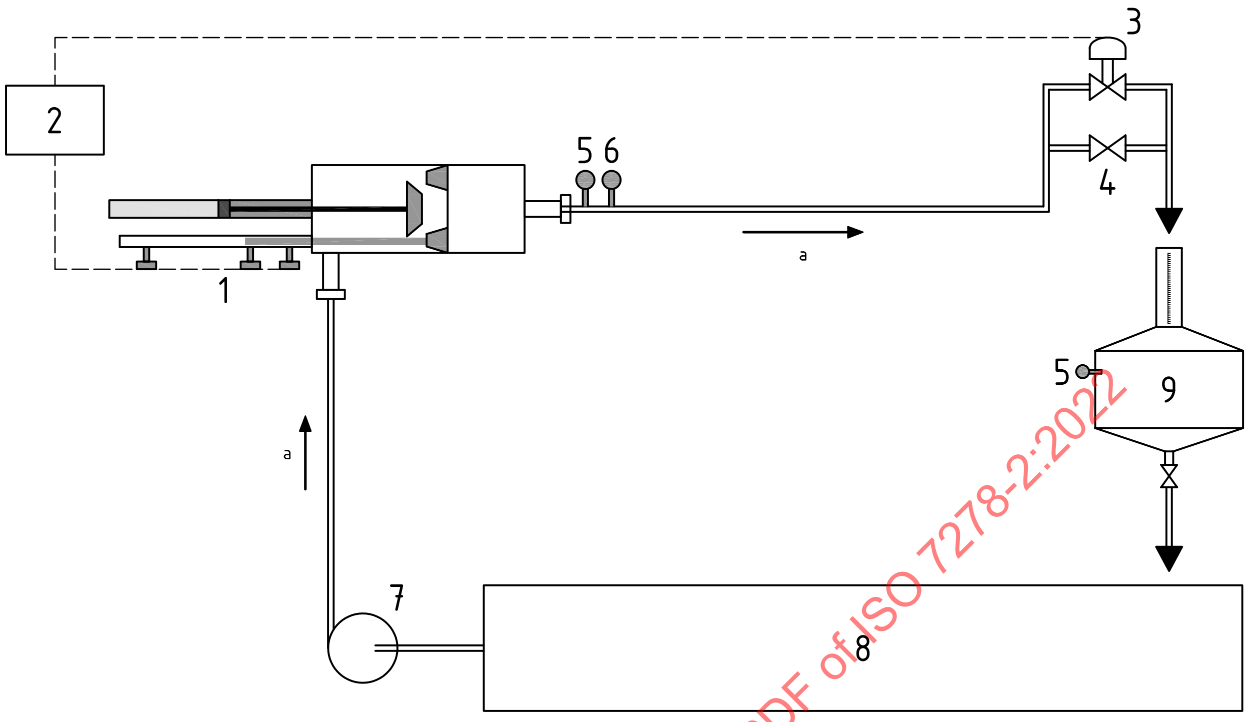
Figure 11 shows the installation of a bottom fill prover tank used as a reference. Figure 12 shows a top fill proving tank or test measure used as reference.



Key

1 detectors
2 logic circuit
3 solenoid valve
4 temperature
5 pressure
6 pump
7 reservoir
8 proving tank(s)
a Flow direction.

Figure 11 — Water draw using bottom fill volumetric measures.



Key

1 detectors
2 logic circuit
3 solenoid valve
4 fast fill valve
5 temperature
6 pressure
7 pump
8 reservoir
9 proving tank
a Flow.

Figure 12 — Water draw of an SVP using a top fill volumetric measure

11.3.3 Gravimetric as reference

A gravimetric reference consists of a collection tank (weigh tank) mounted on a weighing platform.

In a gravimetric water-draw, the quantity of liquid between detector switches is displaced into the collection tank and weighed. The net weight of liquid in the collection tank is corrected for air buoyancy to determine the mass. The mass is then divided by the density of the fluid to give the volume. This is then corrected to standard conditions.

The collection tank should be rigid, not too high to reduce instability, and balanced symmetrically to ensure even weight distribution on the weighing platform. The tank should allow for drainage without a connection interfering with the weighing. The tank is top filled through an entry pipe which is not submerged and there is no loss through splashing. There are no requirements for a wetting run, nor are there any drain-time stipulations.

The capacity of the weighing machine should be selected to measure the weight of the tank and the liquid collected. The resolution, traceability and uncertainty should be consistent with the overall uncertainty required of the calibration.

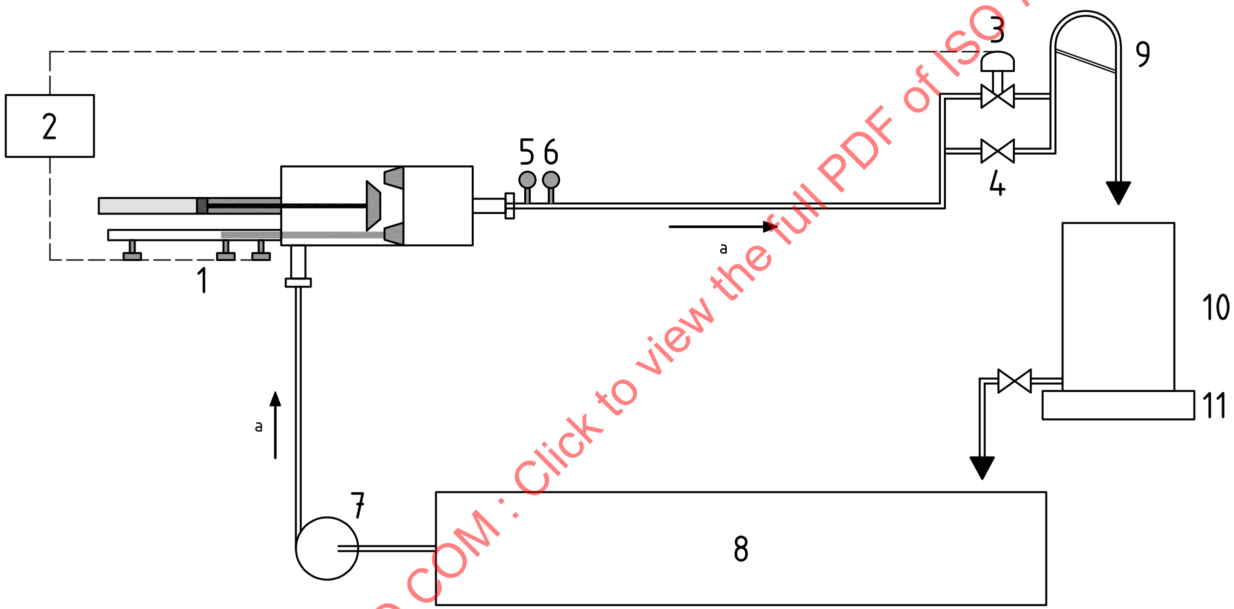
Calibration frequency is related to the use of the machine and the history of stability but should not exceed one year. More frequent verification prior to each use is recommended.

The weights used for the calibration of the weighing machine should be traceable to national standards and calibrated to the required accuracy or class as described by the International Organization of Legal Metrology (OIML).

The gravimetric method is more suitable for use in a controlled environment. It is adversely influenced by factors such as wind and rain. The method finds particular use for the calibration of small volume piston provers where the traceability to mass is important.

Gravimetric weighing allows a significantly wider range of volumes to be measured in a single fill as there is no requirement to fill to a fixed volume or weight. Multiple fills are permissible to suit the available weighing scale. A gravimetric measure may be used to complement volumetric measures providing additional variable measurement where the prover volume does not equate to the volumetric measures available.

Figure 13 shows the use of a gravimetric reference.



Key

1 detectors
2 logic circuit
3 solenoid valve
4 fast fill valve
5 temperature
6 pressure
7 pump
8 reservoir
9 swan neck and weir
10 weigh tank
11 weighing machine/platform
a Flow direction.

Figure 13 — Water draw of a SVP using a gravimetric reference

11.4 Master meter calibration method

The master meter method is increasingly being adopted for the calibration of large conventional pipe provers, particularly for those used in crude oils and refined products. The main advantages are that it takes less time than a water draw, requires less specialist equipment and enables multiple volumes from four detectors to be determined simultaneously. The master meter method is not recommended for the calibration of small volume piston provers.

A master meter calibration may be performed using clean water or another liquid such as salt/ saline water or light hydrocarbon (diesel) oil, providing the coefficients of thermal expansion and compressibility are known. The advantage of using clean water as the calibration medium is that it has a relatively low coefficient of thermal expansion and is usually stable, making calibration much easier. If a liquid has a high coefficient of expansion and is not relatively stable, it can be difficult to achieve the required repeatability.

A prover may require cleaning prior to calibration. This is to avoid contamination of the reference and calibration circuit. Cleaning using water or a light hydrocarbon liquid may remove wax layers from the internal surface of the prover during the calibration. This results in a volume comparable with the prover when new, but may differ from the volume when in service.

The calibration circuit is set up as in 11.3.1, noting the requirement for valves to reduce, stop and divert the flow are not required.

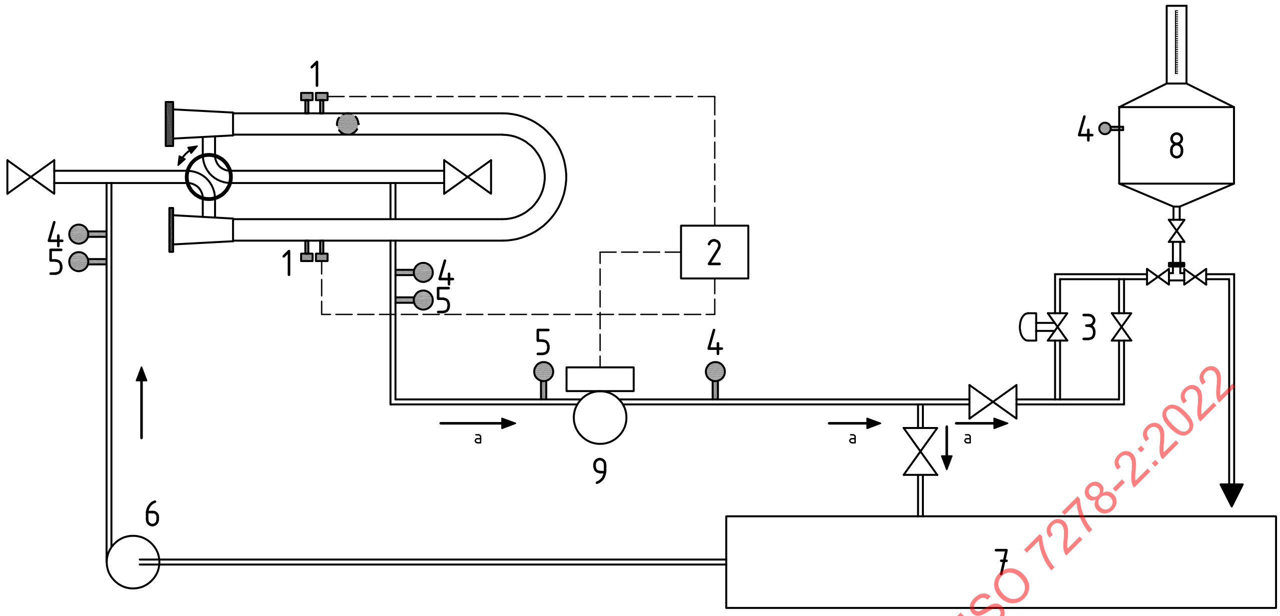
The equipment used to calibrate a prover comprises a master meter, a reference device, thermometers, pressure gauges, pulse counters, interconnecting pipework and an electronic control system. The reference device may be a volumetric reference measure or master prover. The master prover may be a sphere prover, significantly smaller that the prover under test, or a small volume piston prover. The components may be assembled at the location of the calibration, or be complete as a skid or trailer mounted assembly. The equipment should be selected to achieve the performance requirements and if appropriate, be suitable for use in areas associated with potentially explosive environments.

The master meter should be of high quality and provide short-term repeatability well within the required criteria when in use. A displacement meter or a turbine meter is usually the preferred choice for a master meter, although a Coriolis meter may be considered. The meter is chosen to suit the conditions of flowrate, pressure, temperature and viscosity at the location. A displacement meter is generally preferred if it is necessary to start and stop the flow when the reference is a volumetric or gravimetric measure. A turbine meter may be preferred if the flow is continuous in association with a master prover. A displacement meter should be fitted with a high-frequency pulse generator connected directly to the rotor (no gearing and minimum torque resistance). Multi-bladed turbine meters are preferred over twin-bladed helical meters to increase the number of whole collected pulses.

The master meter should have a specified operating flow and viscosity range across which the linearity lies within specified limits. This determines the limits of acceptable flowrate variation during the calibration process.

When the reference is a master prover, it is possible to install the master meter, master prover and the prover under test in any convenient order in relation to the flow. The flow control should be installed downstream of the assembly to ensure a minimum back-pressure is maintained across the entire system to avoid cavitation or flashing. The flow should be controlled and consistent throughout the entire calibration to ensure the performance of the master meter remains constant.

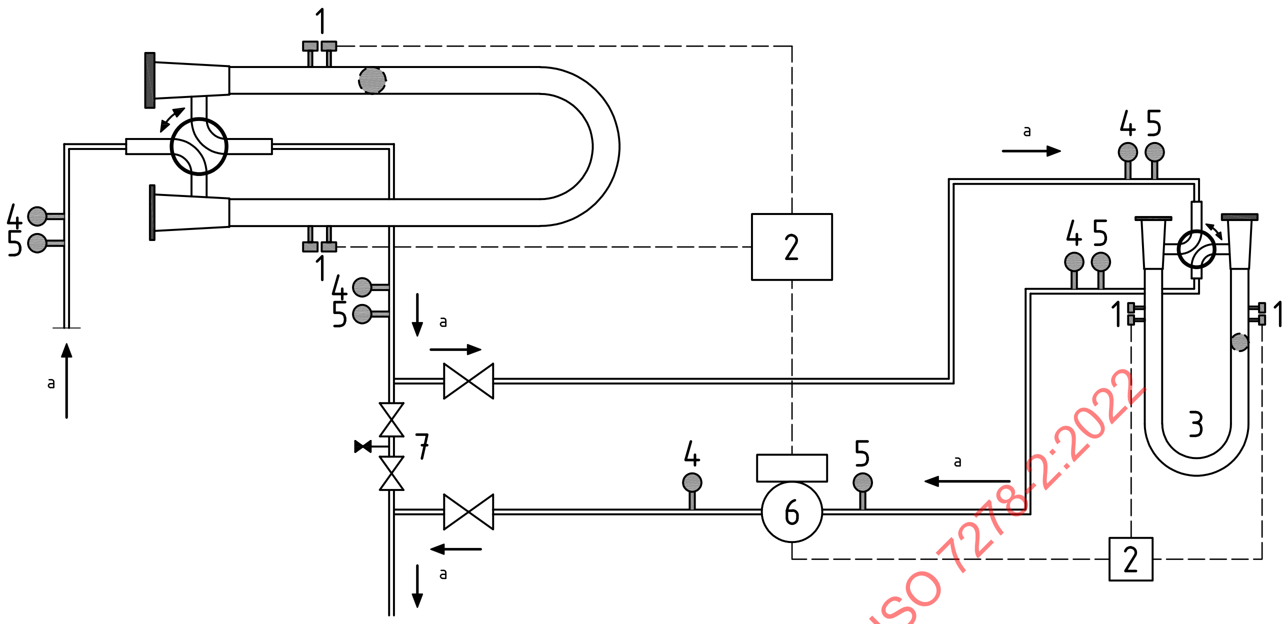
Example installations are shown in Figures 14, 15 and 16.



Key

1 detectors
2 counter
3 measure fill valves
4 temperature
5 pressure
6 pump
7 reservoir
8 proving tank
9 master meter
a Flow direction.

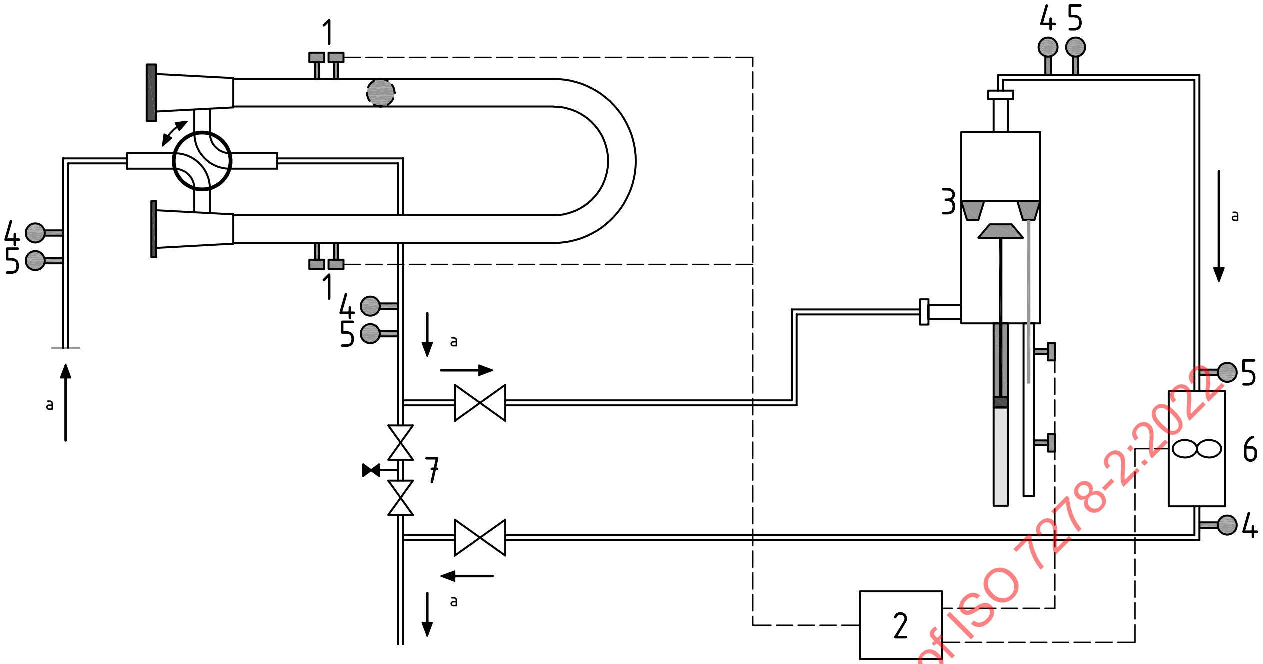
Figure 14 — Master meter method with a volumetric reference



Key

1 detectors
2 counter
3 master prover
4 temperature
5 pressure
6 master meter
7 double block and bleed valve
a Flow.

Figure 15 — Master meter method with a master prover reference



Key

1 detectors
2 counters /controller
3 master prover
4 temperature
5 pressure
6 master meter
7 double block and bleed valve
[a] Flow direction.

Figure 16 — Master meter method with a SVP master as reference

11.5 Sequential master meter method

A master meter calibration using sequential or consecutive proving is carried out in three steps.

a) The master meter is calibrated against the reference measure or master prover to establish an initial K-factor. The master prover or volumetric measure should have been previously calibrated by the water draw method and have an uncertainty in volume less than that required for that of the prover under test.

b) The prover under test is calibrated from the volume measured by the master meter.

   The calibration of the prover under test is carried out by counting the pulses generated by the master meter with the counter(s) gated from the prover detectors. Multiple volumes may be calibrated in a single pass by using multiple counters. The flowrate, pressure and temperature used should be as close as practicable to that used to calibrate the master meter.

c) The master meter is re-calibrated to ensure stability.

The initial K-factor may be used during the calibration to provide an initial volume for the prover under test and show repeatability criteria is met. The final reported base volume would be derived from the mean K-factor taken from steps a) and c).

The repeatability of the master meter at the operating flowrate(s), and agreement between the pre- and post-calibrations, should be tested against the specified acceptability requirements as described in Annex C.

11.6 Concurrent master meter method

The concurrent proving method may be employed where a master meter and small volume master prover combination is used. For concurrent master meter proving, the master meter is calibrated during each pass of the prover under test rather than sequential calibrations before and after the test.

Prior to starting the prover calibration, the performance of the master meter should be verified to ensure the performance, K-factor and repeatability is within the expected acceptance criteria.

The prover under test is then calibrated. During each pass of the prover under test, the master meter is proved through repeated calibration passes of the master prover. A sufficient number (minimum of five) calibration passes of the master prover should be taken during each pass of the prover under test.

It should be demonstrated that the operation of the master prover does not give significant pulsation or change in flowrate within the prover under test when a master meter proving pass takes place. The passes should be distributed evenly across the duration of the pass of the prover under test.

There are two options to derive the volume of the prover under test.

The number of pulses collected from each pass of the master prover is used to calculate the mean K-factor from the batch corresponding to the pass of the prover under test. The mean K-factor is then used along with the total number of pulses collected during the pass of the prover under test to derive the volume associated with the pass. In this case, correction factors applied to the calculation of K-factor are based on temperature and pressure measured at master meter and master prover for each determination of K-factor.

Alternatively, the mean number of pulses collected from each pass of the master prover is used to transfer the volume of the master meter to the volume of the prover under test without calculating the K-factor of the master meter. In this case, the correction factors used to transfer the master meter prover volume to the prover under test are based on the mean temperature and pressure measured at the master prover during the prover under test pass, and temperature and pressure are not required at the master meter.

11.7 Calibration procedures

Procedures for any calibration should be established and agreed with all parties prior to commencing work. These procedures should cover the requirements for installation and decommissioning of the calibration equipment, the method of test, and the establishment of acceptance criteria.

Examples of calibration procedures are given in Annex H, and the calculations for the determination of standard (base) volume given in Annex A.

A successful prover calibration demonstrates acceptable performance based on a repeatability, change from previous calibrations, and an acceptable uncertainty. Recommended acceptability criteria are given in Annex C.

A calibration certificate is provided on completion. Guidance of the content of a certificate is given in Annex I.

12 Operation to prove a flowmeter

12.1 Setting up a prover

Operational procedures for provers in a fixed location as part of a measurement system should be specified and documented. They should describe the safe filling, venting, and draining of the prover, ensuring the critical valves are leak tight and establishing stable conditions.

Mobile provers are expected to have enhanced operating procedures as there is significantly more preliminary work to be done before a prover is safely installed at a location and connected for use.

12.2 Mobile prover prior to arrival on site

a) The specification of the metering station and the mobile prover is compared to ensure that the prover is suitable for the job. In particular, the flowrate, pressure, temperature and nature of the liquid to be handled should be checked. The pressure rating of the hoses should be capable of containing the maximum pressure expected including potential surges and emergency shutdown conditions.

b) The K-factors of the meters to be proved are ascertained. A check should be made that the required number of pulses collected during a proving pass is compatible with the accuracy required. If not, it is possible to use a pulse interpolator during proving.

c) As pulse resolution is not the only criteria, it should be verified that the pulsed output stability and internal resolution of the meter is compatible with the pulse counter. It should be verified that a pulsation free and stable flowrate can be supplied for the proving operation.

d) The run-in length is checked to ensure it is suitable for the meter to be calibrated.

e) It should be ensured that all required permits and permissions are available.

f) The suitability, position and availability of all required hoses, connections, critical valves, access to fluids and drainage facilities should be ensured.

g) There should be access to the required location and the ground should support the weight of the filled prover in a location close to the meter or prover to be tested.

12.3 Mobile prover on arrival on site

a) All required permits and permissions are obtained.

b) Safe access to the location and suitable ground should be confirmed. When in place, brakes or jacks are applied to remove the load from the wheels. Before connecting the prover to the flow line, it is important to ensure provisions are in place to allow for spillage and that any connections can be monitored for pressure before opening.

c) All the necessary electrical connections are made, paying special attention to earth bonding. Connecting to the detectors may require the seals to be broken.

d) If required, the displacer should be inspected prior to being re-inserted and the end closures securely fastened.

e) The flowline, using suitable non-dilating hoses is connected. A pressure test is performed to at least the maximum line pressure. There should be no leakage

f) The prover and the meter under test are filled slowly while venting air and gas safely. Any flowmeter in the line should not be subjected to over-speeding when venting and monitor hoses and flanges throughout.

g) Live crude oil, liquefied gases and other high-vapour-pressure liquids should be vented to a safe area or flare line. The prover may require to be purged with an inert gas (N_2) prior to filling with liquid.

h) It is important to ensure that on completion, the prover can be isolated, and drained in a safe manner. If no local drainage facilities are available the prover and hoses may be isolated, disconnected, and then transported to a location for safe draining. For onward transport on public roads the prover may require to be flushed and degassed.

12.4 Stabilizing temperature

Before proving can be started, thermal equilibrium should be established by flowing product through the prover and the meter under test. During this stabilization, a number of preliminary runs of the prover can be carried out. During these preliminary runs the opportunity should be taken to vent any remaining air or vapour, check for leakage and that the detector switches and the prover counters are all functioning correctly. Calculated results may be derived as preliminary results to give early indication of potential errors, meter malfunction or to determine the number of passes required to constitute a run for a small volume prover.

The temperatures at the prover and the meter or the prover under test should be monitored during the warming-up period. If the temperature of the liquid is not too far from ambient, stable conditions should be reached when the temperatures at the meter and the prover are practically the same. It is expected that temperatures stabilize to within ±0,2 °C at each measurement location. A temperature difference between locations is usually observed. If this difference is significant or unexpected in value, the temperature measurement and thermometers should be checked and verified. Stable conditions are assumed when the temperature difference settles to a constant value.

The time taken in reaching thermal equilibrium is time well spent, as instability is liable to lead to poor repeatability.

12.5 Periodical checks of factors affecting accuracy

There are checks which should be made periodically either during, or at intervals between, operations of a prover.

a) At intervals specified in operating procedures, or at the beginning of each use, a sphere displacer should be removed and its diameter and/or inflation pressure checked against specifications. Similarly, for a piston prover, a piston leak test should be carried out.

b) All critical valves, including a four-way valve or sphere interchange valve, should be checked for leakage.

c) Drains and vents should be checked for leakage and the vents opened periodically between runs to ensure no further air or gas is present during a proving operation.

12.6 Meter proving operation

a) Stable conditions of pressure, temperature and flowrate are checked and then, without delay, the displacer for the first proving pass is launched.

b) In the case of a unidirectional prover, the readings of the liquid temperatures and pressures at each measurement location are recorded during each pass. This may be single or multiple readings across the pass time. The total number of pulses collected and the time of the pass is recorded at the end of the pass. If a run should consist of multiple passes, these should be then continued in immediate succession.

c) In the case of a bidirectional prover, immediately the first pass has been completed the return pass is initiated to complete the run. Many provers are programmed to automatically initiate the return pass. The temperatures and pressures at each location are recorded during each pass. The time of each pass should be recorded. The total number of pulses for the run (round-trip) is recorded. It is recommended that the total pulses for each pass is recorded and then summed. Recording the results for each pass may be required for reporting within the specifications. Recording each pass also aids fault-finding and investigation.

d) If practicable, the flowrate as indicated by the meter (frequency) should be monitored. This not only shows the stability of the flowrate, but acts as an indicator of any problems associated with the launch or passage of the displacer. It is not required to record this data.

e) The meter factor or K-factor is calculated as described in Annex A. The flowrate from the volume and the time of the pass or run is calculated.

f) The operation is repeated at quick succession, at the same flowrate for the required number of passes or runs.

g) It is good practice to record the result of each pass and run in a manner where a running mean, standard deviation and range of results can be calculated. It is also good practice to record the results graphically, hence showing any drift or trend in the results which may indicate instability of the proving. The repeatability of the batch of results is assessed as described in Annex C. If necessary, to obtain acceptable repeatability of the batch, additional passes or runs can be carried out. The minimum number of determinations may be specified by contract or regulation but would not be less than three. If the acceptability criteria for repeatability allows for a variable number of passes or runs, this should be achieved in a reasonable number of attempts (no more than 15 individual passes or runs or 3 batches). If not achieved, work should stop and the cause of the error or instability investigated.

h) The proving operation should be repeated at the required number of flowrates.

i) It is of the utmost importance that the technician(s) carrying out the proving operation are trained and familiar with the techniques of meter proving, assessing the results and generally keeping the measurement system "in control".

12.7 Preliminary assessment of the results

If either the meter or the prover is malfunctioning, this is usually made evident by poor repeatability in the results. It is recommended that the results of each pass, run or batch be monitored and repeatability calculated during the batch. If these repeat passes or runs are in good agreement, this is a fair indication that results are acceptable.

It is important to note that good repeatability does not prove that the results are correct. A systematic error introduces a constant error to all results.

There are various ways of assessing whether the repeatability of a batch of readings is acceptable. In pipe prover operations, it is generally sufficient to use a very simple test, namely to see whether all the results in the batch are within a specified range. This means that the difference between the highest and the lowest results in the batch is less than a specified range criterion. Usually five results would be required to give a definitive result, however two or three give an indication of a problem. A range of less than 0,05 % is often used as a guide. Examining any trend in results with a record of stability of flowrate and temperature may indicate inadequate stability.

It is presupposed that procedures, contract or regulation specify the acceptance for proving a meter. Further guidance is given in Annex C.

If the repeatability exceeds the specified criteria, the reason should be investigated and further runs initiated. If the repeatability of the second batch is within the prescribed criteria, this result may be adopted as the result. Results from the first batch should be retained in the records but are not required to be reported.

If the repeatability remains unacceptable after 15 individual runs (or 3 batches), it is recommended to stop proving and look for a cause.

With a small volume prover, it may sometimes be necessary to increase the number of passes in a run to obtain satisfactory repeatability. Before increasing the number of passes in a run, operators should first obtain the agreement of all the parties concerned with the proving.

The number of passes in a run should be constant for each batch and the number of passes per run should be stated on the proving certificate.

Once repeatability has been obtained, the result should be compared against previous proving results. If the result is significantly different, the most probable cause is a change in the meter performance. However, all practicable checks of the prover instrumentation and the flow circuit should be made to eliminate other potential errors. The monitoring history of proving a meter may indicate wear and give early warning of impending failure.

It is good practice to maintain a record of the magnitude of change in meter performance associated with a prover, especially a mobile prover. Examining any trend or commonality from different meters may indicate a potential change in the prover.

Due to unstable flow conditions, particularly in offshore production facilities, it may not be possible to obtain the required repeatability in a fixed number of runs. In this case, increasing the number of runs following the methods in Annex C may achieve the required result. If the required repeatability cannot be met due to operating conditions, the result should be recorded and the uncertainty estimated based on the measured results.

12.8 Fault finding

To assist in identifying sources or faults and errors, the experience of prover operators has been embodied in Annex D.

13 Safety

13.1 General

It is presupposed that all designers and operators of a pipe prover are aware of applicable international, national and local regulation and safe working practices. In particular, the following specific aspects should be noted.

All provers should be designed to be structurally sound and all supports, supporting structures and lifting points designed, certified and inspected to ensure there is no structural failure.

All provers and associated pipework should be designed and certified to cover the pressure and temperature range for the applications and all internal seals should be compatible with the fluids to be used. This recommendation also includes flexible hoses which may require additional inspection and maintenance. For mobile provers, evidence of conformance may need to be provided to clients and carried with the prover to operational locations.

Access platforms should allow safe operation and inspection of all components of the prover.

All precautions should be taken in advance to prevent spillage, to plan for the safe containment and recovery of any spilled fluids and to prevent risk of ignition or pollution of water courses. This is particularly important if hydrocarbon liquids are being used.

A method for the safe and controlled drainage of liquid, particularly hydrocarbon liquid, from the prover, pipework and associated equipment should be documented.

Electrical safety, earth bonding and procedures for connection should be documented to prevent any electrical shock risk and potential of static electrical spark. The requirements for hazardous area electrical equipment relevant to the location should be observed, with particular regard to temporary instrumentation connections. The continuity of bonding for connecting pipes through flexible hoses should be established and the continuity of flexible hoses tested and recorded at regular intervals.

If a change in liquid between volatile and non-volatile hydrocarbon liquids is required, recognition should be given to the danger of creating an explosive gas mixture within an open tank or volumetric measure (sometimes referred to as “switch loading” hazard).

A means for the safe venting of hydrocarbon vapours, gas and associated entrained liquids from the prover and any associated volumetric measure should be provided.

A mobile prover or associated volumetric measure should be cleaned and purged before transport. Care should be taken to prevent any vapour or fumes entering the cab of the vehicle.

13.2 Permits

When setting up and operating a prover, written authorization in the form of a permit or permits may be required. Site safety regulations give details of any permits required and who is responsible for issuing them. The person granting the permit may wish to ensure that the equipment to be used is safe and suitable for its purpose, to inspect any risk assessments and method statements (RAMS), as well as safety certificates relating to the prover and its ancillary equipment. On fixed installations, permits may be required before operating the prover, and before opening it for inspection or calibration.

13.3 Opening end chambers and removing a displacer

The displacer should be directed into the end chamber (usually the "home" chamber) and the prover isolated from the associated fluid circuit. All pressure should be released across the prover.

It is vital to ensure there is no residual pressure within the prover, on either side of the displacer, prior to opening the end chamber cover. Failure to fully release all pressure may result in the end cover being forcibly opened under pressure once the bolts are loosened. Many designs of enclosure door are fitted with a pressure "tell-tale" or indicator device that must be acknowledged or released before the door itself can be opened.

The prover is now drained. Some designs have the end chambers raised above the level of the main prover pipe. In this case, partial drainage to below the level in the end chamber may be sufficient. Care should be taken to avoid drawing the displacer back into the barrel of the prover from the end chamber when draining.

The correct tool should be used to remove the displacer, e.g. a suction type sphere removal tool. Large spheres are heavy and it is presupposed that users give attention to safe manual, or mechanical, lifting practices and regulations. Suitable mechanical handling appliances may be required.

If a displacer has been drawn back into the pipe or has jammed, and cannot be removed, a specific procedure should be followed. This may, in the first place, require refilling the prover and re-establishing flow to direct the displacer further back into the end chamber. Should the displacer remain jammed, it may be possible to use an auger type device to harpoon or screw into the sphere, to allow it to be pulled out using mechanical means. Extreme care is necessary and it should be understood that the displacer is not usable thereafter.

On no account should compressed gas be used to free or move the displacer. Using compressed gas can eject the displacer in an uncontrolled manner with potentially fatal result.

13.4 Special precautions when proving with LPG

For safety reasons, it is recommended that LPG meters be permanently connected to a dedicated prover. Where this is not possible, and when a mobile prover is used, the following special precautions are essential. Paragraphs c) to f) also apply when dedicated provers are being filled or emptied of LPG.

a) Where a mobile prover is connected to an LPG line, the connection spools to the prover should be fitted with valves. These spools should be fitted with vents on the prover side of the valves.

b) For purging the system, the vent on the inlet may be connected to a nitrogen supply while the vent on the outlet is connected to the flare-stack (or other safe disposal system).

c) Flexible metallic hoses of adequate working pressure should be used to connect the prover to the LPG line and these should not be bent in curves of smaller radius than the manufacturer's specifications permit. If loading arms are used, the seals at the joints should be frequently inspected and maintained in sound condition.

d) After connecting the prover, the air is purged out with low-pressure nitrogen to avoid the formation of an explosive mixture inside the prover during filling.

e) The nitrogen pressure is increased to nearly that of the LPG supply and locked into the prover and associated pipework and hoses. The pressure and all connections are monitored for a period of 10 min to ensure the system is leak tight before starting to fill the prover with LPG. The nitrogen at pressure should prevent rapid expansion, cooling and consequent icing when LPG is first admitted.

f) While filling, the prover vent valve(s) is connected to a flare-stack or other safe disposal system until the prover is completely filled with LPG.

g) At the end of the operation, the prover is drained into a safe disposal system, by admitting nitrogen through the inlet vent valve and allowing it to vent to the flare-stack via the outlet vent valve. This procedure may involve raising and lowering the nitrogen pressure several times before the LPG has dissipated and may well take several hours. It is never permissible to empty a prover of LPG by venting it to atmosphere. Arrangements for emptying the prover should be made in advance, during the planning stage.

h) Finally, during the disconnection of the hoses, extreme care should be exercised to prevent the inhalation of vapours (LPG and/or nitrogen), the use of masks and visors is recommended, as is the use of thermal gloves to prevent freeze burns from handling hoses.

13.5 Fire precautions

Site fire precautions, procedures and instructions may apply and portable fire extinguishers should be located adjacent to the work area.

A safe containment to dispose of waste liquids, oily waste and rags should be provided locally until they are permanently disposed of in a safe manner.

13.6 Miscellaneous safety precautions

It is presupposed that personal protective clothing and equipment is specified and worn according to the site and local conditions. It is expected that safety footwear, fire resistant overalls helmet, eye protection and gloves are required on most sites.

There are special regulations for handling leaded fuels and for avoiding exposure to vapours including carcinogenic vapours such as benzene. The use of personal monitors may be required as a safety precaution.

The brakes, stabilizing jacks and jockey-wheel gear on mobile provers should be inspected and tested at regular intervals. When using jacks and other equipment, it should be ensured the ground is suitable.

13.7 Safety records

Every mobile prover should be accompanied by its own safety log book. A dedicated prover should have its own safety log book, or should share the safety log book of the area in which it is situated. It is the duty of the prover operator to record in the log book all incidents affecting safety. All accidents should be entered, whether they involve personal injury or not, and so should any abnormal events which can have a bearing on the future safe operation of the equipment.

It is recommended that a record is maintained holding the safety certificates, both mechanical and electrical of all equipment and instrumentation associated with the prover. This should include certificates of electrical and mechanical conformance with the appropriate standards, a record of the dates and results of the testing of all equipment which are required under safety regulations or operating procedures.

Annex A
(informative)

Calculations

A.1 Overview

A volumetric prover is calibrated to displace a quantity of fluid. The result of the calibration is given as the standard volume. The standard volume displaced is therefore the volume it would displace at the stated standard condition. During calibration process the prover is calibrated against a reference device and the calibrated volume determined and corrected to a standard, or base, volume. When used, the measured volume displaced is calculated from the standard volume. This measured volume, after further correction for differences in conditions, is the volume passed through the flowmeter under test. These calculations account for the operating temperature and pressure, and any differences in conditions between prover and a meter under test.

The accepted standard temperature used to express volume of liquid petroleum is 15 °C[3)] but may be set to another temperature by agreement. The standard pressure is 101 325 Pa (1,013 25 bar) and, only in rare circumstances, 100 000 Pa (1 bar) or another stated pressure used, such as for high-pressure provers.

The volume of liquid displaced by the prover is normally at a different temperature and pressure to that of the meter under test. The liquid expands or contracts as it passes from one to the other. While this difference is minimized by stabilizing the conditions, the volume is corrected to allow for any difference.

The calculations for particular applications should be specified within the procedures or contract documents either specifically or by reference to standards e.g. ISO 4267-2[8]. The calculations are summarized in this document.

Corrections are usually applied through the application of correction factors. For liquids these are derived from changes in the density with temperature and pressure while, for the materials of construction, they derived from thermal expansion and elasticity.

Formulae for the properties of fluids and for materials may be specified in contract or regulation. The most relevant formulae, particularly those for the density of water, are given in ISO 8222[4] and reproduced in this annex.

Unlike the situation where a quantity of fluid is traded and calculations are carried out by two or more parties and the result agreed, the calibration of a prover or a flowmeter using a prover provides a single certified result from a single calculation and carries an uncertainty. It is therefore not recommended that rounding of values in a prescribed way is applied during the calculation process, unless specifically required by regulation. The final result should however be rounded to significant figures commensurate with the uncertainty of measurement.

A.2 Correction factors

A.2.1 Thermal expansion of a prover

The correction factor C_{ts} for the thermal expansion of the material of a proving tank, pipe prover or other volumetric measure is given by Formula (A.1).

$$C_{ts} = 1 + 3\alpha(t - t_s) \tag{A.1}$$

3) In the US, the standard temperature used for liquid petroleum is 60 °F (15,6 °C).

where

α is the linear expansion coefficient of the prover barrel material (unless otherwise specified, this may be assumed to be 11 × 10^{-6} °C^{-1} for mild steel and 17 × 10^{-6} °C^{-1} for stainless steel);

t is the measured temperature;

t_s is the standard temperature.

For small volume provers with detectors located separate from the prover barrel, the correction factor is given in two parts as shown in Formula (A.2).

$$C_{ts} = 1 + 2\alpha(t - t_s) + \alpha_d(t_d - t_s) \tag{A.2}$$

where

t is temperature of the prover barrel;

t_d is the temperature at the detector bar;

t_s is the standard temperature;

α is the linear thermal expansion coefficient of the prover barrel material (unless otherwise specified, this may be assumed to be 11 × 10^{-6} °C^{-1} for mild steel and 17 × 10^{-6} °C^{-1} for stainless steel);

α_d is the linear thermal expansion of the material separating the detectors.

If the material separating the detectors is chosen with very low thermal coefficient, e.g. invar, the second term may in some instances be omitted as insignificant.

NOTE In Formula (A.1), 3α can be replaced by the volumetric coefficient of expansion of the material. In Formula (A.2), 2α can be replaced by the area coefficient of expansion of the material.

A.2.2 Expansion of pipe prover due to pressure

The correction factor C_{ps} for the expansion of the pipe prover due to internal pressure is given by Formula (A.3) which applies to an unconstrained pipe section:

$$C_{ps} = 1 + \frac{p}{E} \times \frac{D}{w} \tag{A.3}$$

where

p is the gauge pressure (bar);

E is the modulus of elasticity of the steel used (unless otherwise specified, this may be assumed to be approximately 2,1 x 10^6 bar);

D is the pipe prover internal diameter (mm);

w is the pipe prover wall thickness (mm).

For most applications, the uncertainty in the values used should be adequate. Where there is a high operating pressure, the uncertainty in elasticity may be as high as 20 % and a calibration of the prover at elevated pressure may be advised.

NOTE Small volume piston provers with large high pressure flanges relatively close to the calibrated length of pipe do not expand with pressure as is assumed for an unconstrained pipe.

A.3 Thermal expansion of liquid

If the liquid warms or cools between the prover or reference and the device under test, it expands or contracts. While good practice suggests any temperature change is kept to a minimum, it is possible that a temperature difference may give a significant change in volume.

The correction factor C_{tl} for the thermal expansion of liquid is the ratio of its density, ρ_1, at temperature, t_1, to its density, ρ_2, at temperature, t_2, as given as Formula (A.4).

$$C_{tl} = \frac{\rho_1}{\rho_2} \qquad \text{(A.4)}$$

This formula is used for water and any other fluid where the density to temperature relationship is well defined.

For petroleum products covered within standards, such as ISO 91[9], API MPMS:2004, 11.1[10], and API MPMS:1986, 11.2.1[12] (the petroleum measurement tables), volumetric expansion correction factor has been defined by formulae. This provides correction from the operating temperature to a standard temperature (15 °C[4)]). In older editions, pressure and thermal corrections were calculated separately. However, in the newer standards referenced, the corrections are combined in a single computer implementation, inclusive of both thermal and pressure expansion. The computer code uses the formulae given in this annex.

To correct between two conditions, the ratio of the volume correction factors from temperature condition 1 to standard condition and that for condition 2 to standard conditions is applied. This is shown in Formula (A.5)

$$C_{tl,D} = \frac{\rho_1}{\rho_S} / \frac{\rho_2}{\rho_S} = \frac{C_{tl1}}{C_{tl2}} \qquad \text{(A.5)}$$

where ρ_S is the density of the liquid at the standard temperature.

When using correction factors (C_l or C_{tl} and C_{pl}) taken from the petroleum measurement tables, it is usual to correct the volume of both the prover and the second device (flowmeter or reference) to standard conditions separately rather than derive a single correction using temperature difference.

A.4 Compressibility of liquid

If the fluid pressure increases or decreases between the prover, the reference, or the device under test, the volume of the fluid expands or contracts. While good practice recommends that any pressure change should be kept to a minimum, it is potentially significant if calibrating a prover at pressure using a volumetric measure at atmospheric pressure.

The correction factor C_{pl} for the effect of pressure on a liquid is the ratio of the specific volume at a reference condition to the specific volume at another pressure at the same temperature. It may be calculated from the isothermal secant compressibility β of the liquid from Formula (A.6).

$$C_{pl} = \frac{1}{(1 - \beta \cdot p)} \qquad \text{(A.6)}$$

where

β is Isothermal secant compressibility;

p is the measured gauge pressure.

4) In the US, the standard temperature used for liquid petroleum is 60 °F (15,6 °C).

The same unit system to calculate the value of β and that of pressure should be ensured. That is, if β is given in units of bar^{-1}, pressure should also be in bar. Isothermal compressibility is a function of pressure. The value of β selected should be that at the pressure to which the correction is being made. This is usually the standard pressure.

Formulae for calculating β for water and hydrocarbon oils are given in ISO 8222 [4] and in A.6.

C_{pl} may also be derived from Formula (A.4) if the densities are taken from an equation of state relating pressure to density.

The formulae for C_{pl} for hydrocarbon oils has been incorporated into the computer implementation described in ISO 91[9] or API MPMS:2004, 11.1[10], which combine C_{pl} and C_{tl}. This formula is the same as that given in ISO 9770[5] [11]. Compressibility for light hydrocarbons is provided in API MPMS: 1986, 11.2.1[12].

A.5 Pipe prover calculations

A.5.1 Calibration of a prover by water draw using a volumetric measure

Where a prover is calibrated using a volumetric measure, the prover is the test device and the measure is the reference. The standard volume $V_{S,T}$ is calculated from Formula (A.7).

$$V_{S,T} = V_R \times \frac{C_{tl,R}}{C_{tl,T}} \times \frac{C_{ts,R}}{C_{ts,T}} \times \frac{1}{C_{pl,T}} \times \frac{1}{C_{ps,T}} \quad \text{(A.7)}$$

where

V_R is the indicated volume of liquid in the reference measure at observed temperature and atmospheric pressure;

$C_{tl,R}$ is the correction factor for the liquid temperature in the reference measure;

$C_{tl,T}$ is the correction factor for the liquid temperature in the pipe prover;

$C_{ts,R}$ is the correction factor for the thermal expansion of the reference measure metal;

$C_{ts,T}$ is the correction factor for the thermal expansion of the pipe prover metal;

$C_{pl,T}$ is the correction factor for the liquid compressibility in the pipe prover;

$C_{ps,T}$ is the correction factor for the expansion of the pipe prover metal due to pressure.

NOTE 1 No pressure correction is required for the volumetric measure as it is at atmospheric pressure. Corrections $C_{pl,R}$ and $C_{ps,R}$ are assumed to be 1.

NOTE 2 For multiple tank fills, the temperature correction is applied to each fill. If the pressure remains constant throughout the run, it is possible to apply pressure correction to the total.

NOTE 3 For the water-draw of small volume provers with special adaptions such as a double casing or displacement due to rods in an upstream volume, the calculations can be modified following the manufacturer's guidance.

NOTE 4 The ratio $C_{tl,R}/C_{tl,T}$ can be replaced by a correction based on the difference in temperatures.

NOTE 5 For a bidirectional pipe prover, the base volume reported is usually the sum of the volumes obtained from measurements made in each direction or pass and is referred to as the round-trip volume.

5) Withdrawn.

A.5.2 Calibration of a prover by water draw using a gravimetric reference

For a gravimetric calibration, the volume at the prover is calculated from the mass displaced divided by the density of the liquid at the prover conditions.

The mass of water, m, collected in the tank is given by Formula (A.8).

$$m = W_a + W \rho_a \left(\frac{1}{\rho_t} - \frac{1}{\rho_w} \right) \tag{A.8}$$

where

W_a is the weight (in air) of liquid collected in the weigh-tank (kg);

ρ_a is the density of air during weighing (kg/m^3). May be assumed to be 1,012 kg/m^3;

ρ_w is the conventional density of the weights used to calibrate the weighing machine = 8 000 kg/m^3;

ρ_t is the density of the liquid (water) in the weigh tank (kg/m^3).

For convenience, the density of the water in the prover may be assumed to be that at the weigh tank unless the temperature is significantly different.

The prover base volume, $V_{S,T,}$ at the standard conditions is then calculated using Formula (A.9)

$$V_{S,T} = \frac{m}{\rho_T} \times \frac{1}{C_{ps,T}} \times \frac{1}{C_{ts,T}} \tag{A.9}$$

where

m is the collected mass of water;

ρ_T is the density of the water in the pipe prover during the calibration run at the measured temperature and pressure (kg/m^3);

$C_{ps,T}$ is the correction factor for the pressure expansion of the pipe prover under test;

$C_{ts,T}$ is the correction factor for the thermal expansion of the pipe prover under test.

For a bidirectional pipe prover, the base volume is the sum of the volumes obtained from measurements made in each direction.

A.5.3 Calibration of a flowmeter

A prover is used as the reference to calibrate a flowmeter. The flowmeter may be the working flowmeter for an application or it may be the master meter used in the calibration of a pipe prover.

A master meter used to calibrate a pipe prover may also be calibrated against a volumetric measure. For this purpose, the meter factor, although rarely used, is calculated using Formula (A.10).

$$F = \frac{V_{S,R}}{V_M} \times \frac{C_{tl,R}}{C_{tl,M}} \times \frac{1}{C_{pl,M}} \times C_{ts,R} \tag{A.10}$$

Formula (A.11) is used if a K-factor of a master flowmeter with a pulsed output is calibrated.

$$K = \frac{N}{V_{S,R}} \times \frac{C_{tl,M}}{C_{tl,R}} \times C_{pl,M} \times \frac{1}{C_{ts,R}} \tag{A.11}$$

NOTE No pressure correction is required for the volumetric measure as it is at atmospheric pressure. Corrections $C_{pl,R}$ and $C_{ps,R}$ are assumed to be 1.

To calculate the meter factor for flowmeter using a pipe prover, Formula (A.12) can be used. This is not a commonly required formula since flowmeters normally have a pulsed output.

$$F = \frac{V_{S,R}}{V_M} \times \frac{C_{tl,R}}{C_{tl,M}} \times C_{ts,R} \times C_{ps,R} \tag{A.12}$$

To calculate the K-factor for flowmeter using a pipe prover, Formula (A.13) can be used.

$$K = \frac{N}{V_{S,R}} \times \frac{C_{tl,M}}{C_{tl,R}} \times \frac{C_{pl,M}}{C_{pl,R}} \times \frac{1}{C_{ts,R}} \times \frac{1}{C_{ps,R}} \tag{A.13}$$

Where the following apply to Formulae (A.10) to (A.13):

F is the meter factor;

K is the K-factor;

$V_{S,R}$ is the volume, at standard conditions, of the reference prover or volumetric measure;

V_M is the volume indicated by a flowmeter;

N is the number of pulses generated by the meter during a proving pass or run (if pulse interpolation is used, N is expressed with a decimal fractional part);

$C_{tl,R}$ is the correction factor for the thermal expansion of the liquid in the reference, prover or volumetric measure;

$C_{tl,M}$ is the correction factor for the thermal expansion of the liquid measured by the flowmeter;

$C_{pl,R}$ is the correction factor for the compressibility of the liquid in the reference, prover or volumetric measure;

$C_{pl,M}$ is the correction factor for the compressibility of the liquid in the flowmeter;

$C_{ts,R}$ is the correction factor for the thermal expansion of the steel of the pipe prover or volumetric measure;

$C_{ps,R}$ is the pressure correction factor for the expansion of the steel of the reference pipe prover.

Optional correction factors, $C_{ts\ M}$,and $C_{ps,M}$, to express the meter factor, or K-factor, at standard conditions have not been included in Formulae (A.10) to (A.13), hence are assumed to be 1. These optional corrections account for changes in the meter performance due to temperature or pressure and viscosity. These additional correction corrections or coefficients should be shown on the calibration certificate to allow subsequent users to apply them appropriately in service.

A.5.4 Calibration of prover using a master meter (sequential method)

This calculation method is used where meter factor or K-factor of the master meter is derived then used to derive the volume of the prover under test. The K-factors or meter factors are calculated from the appropriate Formulae (A.10) to (A.13). The mean meter factor, $\overline{F}$ or K–factor, $\overline{K}$, are calculated for both the pre- and post-meter calibrations for a consecutive calibration method or during a concurrent calibration. The volume of the prover under test is calculated from the mean of the pre- and post-meter factor or K-factor however the pre-calibration meter factor or K-factor may be used to assess performance and repeatability before calculating the final result.

The volume of a prover under test is calculated using Formulae (A.14) or (A.15).

When the concurrent master meter method is used, it is not necessary to calculate the K-factor, and so the alternative calculation formula given in A.5.5 may be used Formula (A.14) is used if the meter factor has been determined.

$$V_{\mathrm{S,T}} = V_{\mathrm{M}}^{1} \times \bar{F} \times \frac{C_{\mathrm{tl,M}}^{1}}{C_{\mathrm{tl,T}}^{1}} \times \frac{C_{\mathrm{pl,M}}^{1}}{C_{\mathrm{pl,T}}^{1}} \times \frac{1}{C_{\mathrm{ts,T}}^{1}} \times \frac{1}{C_{\mathrm{ps,T}}^{1}} \quad \text{(A.14)}$$

Formula (A.15) is used if the K-factor has been determined.

$$V_{\mathrm{S,T}} = \frac{N^{1}}{\bar{K}} \times \frac{C_{\mathrm{tl,M}}^{1}}{C_{\mathrm{tl,T}}^{1}} \times \frac{C_{\mathrm{pl,M}}^{1}}{C_{\mathrm{pl,T}}^{1}} \times \frac{1}{C_{\mathrm{ts,T}}^{1}} \times \frac{1}{C_{\mathrm{ps,T}}^{1}} \quad \text{(A.15)}$$

where the following apply to Formulae (A.14) and (A.15):

$\bar{F}$ is the mean meter factor from pre and post determinations;

$\bar{K}$ is the mean K-factor from pre and post determinations;

$V_{\mathrm{S,T}}$ is the standard (base) volume of the pipe prover under test;

V_{M}^{1} is the volume reading from the flowmeter;

N^{1} is the number of pulses counted during calibration of the prover;

$C_{\mathrm{pl,M}}^{1}$ is the correction factor for the compressibility of the liquid in the master meter during prover calibration;

$C_{\mathrm{tl,M}}^{1}$ is the correction factor for the thermal expansion of the liquid in the master meter during prover calibration;

$C_{\mathrm{pl,T}}^{1}$ is the correction factor for the compressibility of the liquid in the prover under test during prover calibration;

$C_{\mathrm{tl,T}}^{1}$ is the correction factor for the thermal expansion of the liquid in the prover under test during prover calibration;

$C_{\mathrm{ts,T}}^{1}$ is the correction factor for the thermal expansion of the steel of the prover under test during prover calibration;

$C_{\mathrm{ps,T}}^{1}$ is the correction factor for the expansion of the steel of the prover under test due to pressure.

Formulae (A.14) and (A.15) assume the master meter is proved with same conditions of liquid, flowrate, temperature and pressure as when used to calibrate the prover. Corrections to standard conditions for the meter ($C^{1}{}_{\mathrm{ts,M}}$ and $C^{1}{}_{\mathrm{pt,M}}$) are not required and are assumed to be 1. If conditions are significantly different, it is possible that additional corrections factors are required to account for changes in meter performance with temperature or pressure.

A.5.5 Calibration of prover using a master meter (concurrent method)

When the concurrent master meter method is used there are two methods of calculating the volume of the prover under test.

The calculations may use the Formula (A.13) to calculate the K-factor for each pass of the master prover, the mean being used along with Formula (A.15) to calculate the volume of each pass of the prover under test.

Alternatively, it is not necessary to calculate the master meter K-factor except to determine acceptability of the meter performance. Using this option, Formula (A.16) may be used to effectively transfer the volume of the master prover to that of the prover under test.

$$V_{S,T} = V_{S,R} \times \frac{N_T}{\bar{N}_R} \times \frac{C_{tl,R}}{C_{tl,T}} \times \frac{C_{ts,R}}{C_{ts,T}} \times \frac{C_{pl,R}}{C_{pl,T}} \times \frac{C_{ps,R}}{C_{ps,T}} \quad (A.16)$$

where

$V_{S,T}$ is the standard (base) volume of the pipe prover under test;

$V_{S,R}$ is the standard (base) volume of the master prover;

N_T is the number of pulses from the reference meter for the pass/run of the prover under test;

$\bar{N}_R$ is the average number of pulses from the reference meter for passes of the master prover;

$C_{tl,R}$ is the correction factor for the thermal expansion of the liquid in the master prover during prover calibration;

$C_{tl,T}$ is the correction factor for the thermal expansion of the liquid in the prover under test during prover calibration;

$C_{ts,R}$ is the correction factor for the thermal expansion of the steel of the master prover during prover calibration;

$C_{ts,T}$ is the is the correction factor for the thermal expansion of the steel of the prover under test during prover calibration;

$C_{pl,R}$ is the correction factor for the compressibility of the liquid in the master prover during prover calibration;

$C_{pl,T}$ is the correction factor for the compressibility of the liquid in the prover under test during prover calibration;

$C_{ps,R}$ is the correction factor for the expansion of the steel of the master prover due to pressure;

$C_{ps,T}$ is the correction factor for the expansion of the steel of the prover under test due to pressure.

A.6 Liquid property formulae

A.6.1 Density of water

It is possible to calculate the density of pure water satisfactorily from a number of sources. An overview of the different water property formulae are given in ISO 8222 [4].

From 2001, the Formula (A.17) for the density of pure water was accepted by the International committee for weights and measures (CIPM) for use in metrology is that developed by Tanaka. This is the recommended formula to be used when calibrating volume measures and provers.

$$\rho_{Tanaka} = a_0 \times \left[1 - \frac{(t + a_1)^2 (t + a_2)}{a_3 (t + a_4)} \right] \quad (A.17)$$

where

ρ_{Tanaka} is the density of pure water from Tanaka formula (kg/m^3);

t is the temperature (°C).

and the coefficients are:

a_0 = 999,974 950 a_1 = −3,983 035 a_2 = 301,797 a_3 = 522 528,9 a_4 = 69,348 81

This formula gives a range of applicability for the density of pure water.

The older Formula (A.18) for density of water is that of Patterson and Morris. Although no longer recommended by CIPM, this formula gives satisfactory results and is often prescribed in existing procedures and regulations. This again has a range of applicability for the density of pure water between 0 °C and 40 °C.

$$\rho_{\text{P\&M}} = \rho_0 \left\{ 1 - [c_1(t-t_0) + c_2(t-t_0)^2 + c_3(t-t_0)^3 + c_4(t-t_0)^4 + c_5(t-t_0)^5] \right\} \quad \text{(A.18)}$$

where

$\rho_{\text{P\&M}}$ is the density of pure water from the Patterson and Morris formula (kg/m^3);

t is the temperature (°C);

t_0 is the temperature of maximum density (°C);

t_0 = 3,981 8;

ρ_0 is the maximum density of water (kg/m^3);

ρ_0 = 999,973 58;

c_1 = 7,013 4 × 10^{-8};

c_2 = 7,926 504 × 10^{-6};

c_3 = −7,575 677 × 10^{-8};

c_4 = 7,314 894 × 10^{-10};

c_5 = −3,596 458 × 10^{-12};

For the calibration of volumetric measuring devices, the difference between Tanaka and Patterson and Morris is unlikely to be significant except at the lowest uncertainty levels.

If the temperature range is above 40 °C, the recognized density formulation is the equation of state given by the International Association for the Properties of Water and Steam as release IAPWS 95[13]. This is a complex equation of state however a polynomial Formula (A.19) has been fitted to IAPWS data and is given in ISO 8222 [4]. This provides the density of pure water to an uncertainty less than 0,01 % at temperatures between 5 °C and 90 °C.

$$\rho_{\text{IAPWS}} = c_0 \cdot \left(\frac{1 + c_1 t_n + c_2 t_n^2 + c_3 t_n^3}{1 + c_4 t_n + c_5 t_n^2} \right) \quad \text{(A.19)}$$

where

ρ_{IAPWS} is the density of pure water from formula fit to IAPWS 95 (kg/m^3);

t_n is the normalized temperature, t /100;

t is the temperature (°C);

c_0 = 999,843 82;

c_1 = 1,463 938 6;

c_2 = −0,015 505;

c_3 = −0,030 977 7;

c_4 = 1,457 209 9;

c_5 = 0,064 893 1.

Guidance is given in ISO 8222[4] as to the formulae to use for impure water. Impure water is classified as ranging from potable (drinking) water through brackish water, sea water and further extended to highly saline water.

It is generally assumed that, although the densities are significantly different, the expansion factors for impure water are not significantly different from that of pure water up to and including poor quality potable (drinking) water. If the salinity of the water used for the calibration increases due the use of brackish, saline or sea water, the advice and Formulae given in ISO 8222[4] should be followed.

A.6.2 Compressibility of water

Compressibility (B) for pure water may be determined from an equation of state, e.g. IAPWS 95.

ISO 8222[4] provides Formula (A.20) shown below, for the compressibility of water at atmospheric pressure:

$$\beta = \frac{1}{\left(19{,}69 + 0{,}141\,8 \cdot t - 1{,}934 \times 10^{-3} \cdot t^2 + 5{,}866 \times 10^{-6} \cdot t^3\right)} \times 10^{-3} \quad \text{(A.20)}$$

where

β is isothermal compressibility at atmospheric pressure (bar^{-1});

t is temperature (°C).

API MPMS:2010, 4.9.4 [14] suggests the use of a constant value for water compressibility, at 15 °C and 1 bar, may be acceptable taking regard of the uncertainty required for the particular application. This is given by:

$\beta = 4{,}64 \times 10^{-5}$ bar^{-1}

A.6.3 Compressibility of oil

The accepted Formula (A.21) provides compressibility of oil given in ISO 9770[11] 6).

$$\beta = \mathrm{EXP}\left(-1{,}620\,8 + 2{,}159\,2 \times 10^{-4} \cdot t + 0{,}870\,96 \cdot \rho_{15}{}^{-2} + 4{,}209\,2 \times 10^{-3} \cdot t \cdot \rho_{15}{}^{-2}\right) \times 10^{-4} \quad \text{(A.21)}$$

where

β is isothermal compressibility of oil at atmospheric pressure (bar^{-1});

t is the temperature, expressed in °C;

ρ_{15} is the density, in kg/l, at 15 °C and 1,013 25 bar.

NOTE 1 The density is input as kg/l not kg/m^3 as elsewhere in this document.

6) Withdrawn.

NOTE 2 API MPMS:2004, 11.1[10] and ISO 91 [9] include the pressure correction within the implementation to provide a combined C_{tl} and C_{pl} correction factor.

Annex B
(informative)

Selecting a prover volume for a flowmeter

B.1 Historical selection

API STD 2531[15] had design guidance for a pipe (displacement) prover. It recommended that a pipe prover should have a minimum volume of 0,005 times the maximum hourly flowrate of the meters to be proved. This gives the time for a measured volume to be a minimum of 18 seconds. The reasoning behind the guidance provided little theoretical justification and seemed to be based on an assumption of 0,5 % of the hourly throughput of the associated flowmeters.

A second criteria was to allow for the collection of a minimum of 10 000 pulses for a pass to provide an uncertainty on pulse resolution of less than 0,01 %.

The guidance given in API STD 2531 had been specified at a time when conventional pipe provers were the norm and were used with multi-bladed turbine flowmeters. This early guidance retains some validity to provide a timing and volume relationship however does not recognize the different technologies and flowmeters which are now being used. It is noted that a multi-bladed turbine may have around 2 000 revolutions of the rotor during a pass when following this guidance.

It was found when preparing the subsequent API, EI and ISO standards that installations in service met the design guidance associated with the pulse count limit alone and hence the time guidance of 0,5 % of hourly flowrate was not required.

B.2 Introduction of pulse interpolation

The development of twin-bladed turbine flowmeters provided meters which, while giving a high number of revolutions in a proving pass volume, were only giving two pulses per revolution. In many cases, this did not allow a minimum of 10 000 pulses per proving volume. Pulse interpolation was introduced to increase the resolution of the pulse output of these meters during proving.

Introduction of small volume provers, both in operation and design, showed that the stability of the pulse period from a meter had a significant effect on a result. Instability, or variation in pulse spacing or period, does not allow for accurate pulse interpolation result and hence poor repeatability. Some flowmeters with a high instability were shown to have unacceptable repeatability when pulse interpolation was applied even when a large number of raw pulses were counted. The stability of the pulse period is a function of both inter-rotational and intra-rotational nonlinearity. It is also found that there is a relationship between the stability of the proving result and the number of revolutions of the meter rotor being tested. The volume for a proving run is therefore a function of the number of pulses, the resolution improvement through pulse interpolation, and the number of revolutions of the meter rotor.

In recognition of this, ISO 7278-3[6] recommends a minimum of 100 raw pulses be collected in a pass before interpolation is applied. It also recommends that each pass corresponds to more than one complete meter revolution, or intra-rotational cycle.

At this time, it was recognized that the effective volume of a prover is increased by averaging the results of multiple passes of the prover to provide one reportable result.

B.3 Issues with electronic based flowmeters

The introduction of electronic-based flowmeters, such as Coriolis and ultrasonic meters, provide pulsed outputs where the output frequency is not related to the physical behaviour of the meter but is set or scaled by the user. The K-factor, and hence frequency, is calculated internally and then determines the frequency of the output based on the calculated flowrate. The flowrate is measured from internal averaging of a large number of low-resolution measurements. The calculated frequency may then be set or scaled to provide a high frequency, hence a large number of pulses for a proving pass. This has allowed the 1-pulse-in-10 000 guidance to be achieved with small volumes. In these meters, there is no rotational effect. Pulse frequency however varies as flowrate changes. The stability and response time of the output frequency to changes in flowrate is based on the computational time, delays and smoothing within the design of the microprocessor. The time base for this process is very short but not usually available to the user.

Intelligent amplifiers fitted to turbine, displacement or vortex meters may behave in a similar way and transmit pulses at a frequency calculated from the input pulses. This allows the introduction of scaling, calibration correction factors and increased resolution.

Both the revolutions of a mechanical meter and the internal averaging stability of an electronic-based meter are described as the "internal resolution" of the meter. This is separate from the external (or output) resolution based on the pulse frequency.

A delay in the output frequency to reflect changes in flowrate may be introduced. While rarely being of significance to a meter in service, it may impact on the short time periods involved in proving. The run-in lengths of a pipe prover, particularly a small volume piston prover, should be carefully considered to ensure the output frequency has stabilized after the drop-in flowrate due to the launch of the displacer. Larger run-in lengths may be required to be larger than would be expected for those required by turbine meters.

Difficulty in achieving a stable average within the flowmeter is due to the inherent low resolution of the primary measurement or, for ultrasonic meters, the internal turbulence in the flowing fluid. In either case the meters provide an accurate volume measurement when averaging is taken over a long enough period. It can however give rise to poor repeatability over small volumes and times. This results in the requirement for a larger proving volume than that expected from a similar turbine flowmeter. Increasing the pulse numbers or resolution does not improve the repeatability from this source.

B.4 Summary

Minimum volume required to prove flowmeters is a combination of the internal and external resolution of the meter under test. Minimum volume is defined as the volume of a pass, or a run where the run provides the mean value of multiple passes.

There is a minimum volume or minimum time between detector actuations that is required for a single pass. This value is critical when sizing certain prover types when used with certain meter technologies, e.g. proving Coriolis meters using small volume piston provers. These minimum values can be provided by the by the meter manufacturer.

Conventionally five runs were specified as the maximum to establish a criterion for repeatability based on the range of the results. It is now suggested that a larger number of runs, or passes are used and the repeatability calculated from the standard deviation of the results.

Annex C
(informative)

Acceptance criteria and performance specification

C.1 General

The purpose of proving a device or system is threefold:

— to establish the performance indicator of the device;

— to provide an uncertainty for the performance indicator and hence uncertainty of the final measurement;

— to test and confirm the performance of the device against specified acceptance criteria.

The performance indicator for a flowmeter is usually expressed as error, meter factor or K-factor, and is determined by calibration or proving. It may be a single value or a number of values across the range of the device.

The uncertainty of the calibration is a combination of the uncertainty of the reference device, the uncertainties of the instrumentation associated with the calibration method and the uncertainty associated with the results of the calibration.

Any change in performance indicator or the variation in performance indicator across the flowrange provides a measure of performance of the device. The repeatability of the results at a single condition provides an additional indicator of performance.

The concept of proving a device infers that a calibration is performed and then the results obtained are compared against criteria for acceptance. Acceptance criteria should be specified prior to the calibration and normally specified in company procedures, contracts, regulations or standards.

Reference to and comparison with the acceptance criteria is usually carried out during the calibration, with uncertainty being finally assessed retrospectively.

Three acceptability criteria are usually referenced: linearity, repeatability and comparison of the result with previous, or expected, values.

C.2 Linearity

C.2.1 General

Linearity is a measure of the deviation of a flowmeter characteristic, or performance indicator, from a defined functional relationship to flowrate. The functional relationship provides a nominal value at any flowrate across the measurement range of the meter. The nominal value may be calculated from a linear relationship or a more complex function to give different nominal values at different flowrates. The relationship may be theoretical for example the manufacturers specification, or derived from a calibration data. In practice, it is usually a constant value (linear relationship with slope = 0).

Linearity is expressed as the range of deviation from a chosen “nominal” value, i.e. the maximum (most positive deviation) to the minimum (most negative deviation) as shown in Formula (C.1).

$$lin_r = \Delta_{max} - \Delta_{min} \tag{C.1}$$

where

lin_r is the linearity range of values;

Δ_{max} is the most positive deviation from the nominal value at that flowrate;

Δ_{min} is the most negative deviation from the nominal value at that flowrate.

When multiple test points are taken at any one flowrate, usually to determine repeatability, the mean of each batch of results represents the value at that flowrate. This method provides a realistic estimate of the linearity.

Where single points are taken at multiple flowrates across the measurement range of the meter, Δ_{max} and Δ_{min} may be estimated by using a "best fit" line placed through the points and taking the deviations of the line from the nominal value(s).

Linearity is usually expressed as relative to a nominal value and expressed as a ± percentage value as given in Formula (C.2).

$$lin = \pm \frac{\Delta_{max} - \Delta_{min}}{2 \times N} \quad \text{(C.2)}$$

where

lin is the linearity range of values relative to the chosen nominal value;

Δ_{max} is the largest (most positive) deviation from the nominal value at that flowrate;

Δ_{min} is the smallest (most negative) deviation from the nominal value at that flowrate;

N is the chosen nominal value.

It is the choice of the nominal value that is ill-defined in standards and is defined differently in different practices. The nominal value can also differ from the nominal value used to define Δ_{max} and Δ_{min}.

There are a number of conventions used and three have been outlined in C.2.1, C.2.2 and C.2.3.

If Δ_{max} and Δ_{min} are based on a function, and not a constant, they should be recalculated as values relative to the nominal value at the appropriate flowrate.

C.2.2 Mid-range method

The convention advised in this document is the mid-range method. This is an implementation of the independent linearity method given in ISO 11631.

The nominal value is calculated by dividing the range of deviations by two, then adding the result to the minimum value.

$$N = \pm \frac{\Delta_{max} - \Delta_{min}}{2} + \Delta_{min} \quad \text{(C.3)}$$

To calculate linearity, Formula (C.3) is shown to reduce to:

$$lin = \pm \frac{\Delta_{max} - \Delta_{min}}{\Delta_{max} + \Delta_{min}} \quad \text{(C.4)}$$

where

lin is the relative linearity;

Δ_{max} is the largest (positive) deviation value;

Δ_{min} is the lowest (most negative) deviation value.

It is then conventional to express this as a percentage by multiplying by 100 unless the relative percentage values of Δ_{max} and Δ_{min} are used as the values.

C.2.3 Average method

This method is only applicable when a constant nominal value is used. The nominal value is defined as the mean of all points. This is a simple definition and easy to understand; however, it does not fully represent an uneven slope of a meter characteristic across the flow measurement range.

C.2.4 Defined value method

The nominal value is taken as a defined or specified value. This can be the theoretical value (e.g. meter factor = 1, error = 0) or the measured value at a specified flowrate, such as mid-range or maximum flowrate. It is possible to use a theoretical function describing the meter performance as the basis for a variable nominal value to be calculated across the flow measurement range.

This option does encompass the whole performance of the meter; however, it produces significant misrepresentation of the true definition of linearity if the meter has a systematic offset or bias.

The use of a value at a specified flowrate, usually the highest or mid-range flowrate also does not represent the linearity across the complete flow measurement range of the meter. It is described here as the method is specified in some contracts and regulations. Using a nominal value chosen at the normal operating (or duty) flowrate of the meter, if there is one, does have some merit.

C.3 Repeatability

C.3.1 General

When establishing the performance of a device, it is usually the mean of a number of calibration results at a single flowrate which provides the final reportable result. This may be at one flowrate or different results reported at multiple flowrates.

By taking a number of determinations a mean value is determined and the repeatability of that value established. The expanded uncertainty of this mean, attributed to the repeatability, can be calculated as shown in Formula (C.5).

$$U_r = \frac{\sigma t}{\sqrt{n}} \quad (C.5)$$

where

n is the number of measurements;

σ is the standard deviation of the measurements;

t is the value from the Student's t-distribution for a half range and with (n-1) degrees of freedom at the chosen confidence level. The values for t at 95 % confidence are given in Table C.1.

The standard deviation is a measure of the spread of the results around the mean value. This uncertainty pre-supposes the results approximate to a normal distribution and the number of results is adequate to determine a reliable standard deviation.

To give a reliable, statistical result many (>20) measurements, should be taken however generally U_r converges within 10 measurements to a representative value for flow and volume applications.

It is recognized that the time taken to obtain a large number of measurements may be impractical due to time, cost and the ability to maintain stable conditions. Different methodologies have been established to provide acceptability criteria and uncertainty estimates. These have become accepted practice based on experience and knowledge of the proving process and devices.

One acceptance criterion is based on the repeatability based on the range or spread of results calculated by subtracting the smallest result from the largest result. This difference is then be divided by the mean of the results and then this may be expressed as percentage of the mean as shown in Formula (C.6).

$$R = \frac{(K_{max} - K_{min})}{\bar{K}} \quad (C.6)$$

Where K_{max} and K_{min} are the largest and smallest values respectively and $\bar{K}$ is the mean value

Some standards and procedures, notably API MPMS documents, define range as the difference divided by the smallest value rather than the mean. For fluid measurement this is unlikely to provide a significant difference but in circumstances where acceptance is marginal, it may be important. For this reason, the definition of the convention used should be stated in specifications, certificates and reports.

C.3.2 Repeatability from consecutive results

Acceptability criterion is defined as being the range or spread of a specified number of results. Conventionally this is a relatively small number, three or five, consecutive results depending on the application.

The advantage of this method is simplicity. By applying well-known and established technologies a quick and easy measure of acceptable performance is defined. Experience and established procedures have shown that the required number of results give confidence that the device is performing as expected. It is recognized that some results, particularly the first result(s) of a calibration, may not meet the requirements due to instability in the proving conditions. It is therefore accepted that some results preceding the acceptable set are discarded. The number of such results allowed, should be specified to reduce the chance of disguising a non-repeatable meter, i.e. continuing testing until acceptance is achieved by chance.

The number of these preliminary results should be indicated on the proving report and the results retained in the operator records. The preliminary results are not normally required to be reported in full on the certificate.

The acceptability of the method assumes a prior knowledge, based on experience and history, of both the proving procedure and the anticipated meter performance.

The acceptance criteria is specified by the application. It is industry practice to define acceptability in regulation or contract agreement. Generally the expectations are:

— Custody transfer and fiscal meters - range of 0,05 % (±0,025 %) over 5 repeat runs.

— Prover base volume by master meter – range of 0,02 % over 5 repeat runs

— Prover base volume by water draw - range of 0,02 % over 3 repeat runs.

Formula (C.5) gives an unrealistically large estimated uncertainty which does not reflect what is expected. This large uncertainty is resultant from the small sample size giving a large standard deviation and value for the Student's *t*-distribution. Formula (C.5) usually gives an overestimate of uncertainty but may also give a significant underestimate if, by chance, the results have a very small range.

Recognizing that the acceptance criteria has been derived from significant knowledge of the expected performance of these devices when they are proved using specified methods and if the consecutive runs method is employed, the expanded uncertainty of the mean is calculated from the acceptability range (criterion) rather than the measured range when the acceptance criterion has been met. Formula (C.7) expresses the calculation of expanded uncertainty.

$$U_r = \frac{R_a}{2\sqrt{n}} \tag{C.7}$$

where

U_r is the expanded uncertainty;

R_a is the acceptability criterion value for the range for n measurements.

This is based on two assumptions. Firstly, the acceptance criteria have been met without a significant number of rejected results. Secondly, the method and the meter have significant history, which would give confidence that meeting the criteria shows acceptable performance.

The probability distribution would be assumed to be rectangular, hence the standard uncertainty would be calculated by dividing by $\sqrt{3}$.

C.3.3 Consecutive results from multiple measurements

Unidirectional pipe provers use each pass of the displacer to establish the volume – each pass being one reportable result (run).

Bidirectional pipe provers use two passes to establish the volume to make one reportable result effectively increasing the volume used to provide that result.

Small volume provers may be operated as conventional or reduced volume provers for smaller flowmeters with stable pulsed outputs. When used to calibrate flowmeters with a larger volumetric flowrate, they often do not provide a repeatable result based on individual passes (measurements) but instead rely on a much larger number of passes, to provide a single reportable result (run). This effectively increases the measurement volume of the prover. Repeatability is then calculated by repeating that number of runs. The acceptance and uncertainty are then taken as described for the consecutive results method but using the results from multi-pass runs.

The number of passes required may be determined by examining the standard deviation of the results within a run and is generally established during a preliminary run or from previous experience. The number of passes is then fixed and used for all subsequent runs. Acceptability of the number of passes is usually achieved for between 5 and 10 passes and, only after investigation of possible faults, up to 20 passes may be allowable.

The number of passes used should be reported on the certificate along with the mean result from each run. The individual pass results are not required to be reported; however, the standard deviation calculated for each run may be reported as an option.

Uncertainty is calculated as for the consecutive results method using Formula (C.7).

The method has the disadvantage that much of the information provided by the individual pass results is not utilized. Either taking the standard deviation of all passes or combining the standard deviations of each run would provide a more satisfactory analysis.

C.3.4 Statistical methods

C.3.4.1 General

The acceptance criteria may be expressed as an uncertainty rather than a range. This allows for the number of runs used to derive the result to be variable.

Although it is acceptable for more traditional flowmeters to use a range-based criteria, a statistical approach is recommended to establish repeatability. This is particularly recommended for flowmeters based on electronically calculated outputs requiring larger volumes to establish repeatable measurements when calibrated using the limited volume available from a prover. It is also useful when a small volume prover is used. The approach allows for more measurements to be utilized without the restriction of requiring a relatively small number of consecutive results to be within the acceptable range. The method is described, with examples, in NORSOK I106 [17] and NORSOK I105:2007[7]), Annex F [16] which provides examples.

The acceptance criterion is specified as the repeatability uncertainty of the mean, as given in Formula (C.5) and is specified by regulation, contract or procedures. The value specified is often coincident with the uncertainty criterion matching to that traditionally attributed to the range of consecutive results.

There are two statistical methods employed: the uncertainty test method, where tests are repeated until the uncertainty meets the criterion, and the uncertainty range method, where a criterion is the range of the results and is variable depending on the number of runs used.

C.3.4.2 Uncertainty test method

The acceptance criterion is specified as an uncertainty. Test points or proving runs are repeated until the uncertainty is less than the specified acceptance criterion. These runs would be single passes of a unidirectional prover or two passes (round-trip) of a bidirectional prover.

Uncertainty for each batch is calculated as described in Formula (C.5) and expressed as a percentage of the mean value.

A minimum of three runs would be the minimum required. Fiscal and custody transfer meter regulations normally specify a minimum of five valid runs to be completed before the acceptance criterion is examined. A minimum of 6 to 10 would be advised to provide a better statistical sample and reduce the probability of an atypical result.

The results should show a clear reducing trend in the uncertainty value across the set of runs. It is recommended that 10 runs are the maximum used before investigation is carried out and an understanding of why the criterion has not been met. The total maximum number of runs should not exceed 20.

The use of established outlier testing can be used to identify and remove unrepresentative results. Dixon’s Q-test or Grubbs' extreme outlier tests are recommended.

To use this method, it is recommended that one preliminary result is taken and discarded if required. The result and the uncertainty is calculated from the remaining results.

There is a danger in this method that, by chance, an acceptable result is obtained after the minimum number of runs. This may be unrepresentative with the uncertainty increasing if more runs are taken. It is good practice to take at least one additional run after acceptance is achieved to ensure that stability of the result has been achieved.

The individual run results are reported along with the mean, standard deviation and uncertainty. A preliminary run should be recorded and reported as having been carried out, but it is not necessary to report the result. Results removed after application of outlier testing should be reported in full and marked accordingly.

C.3.4.3 Uncertainty range test

Although a mean is as simple to calculate as a running average, standard deviation is not such a trivial calculation. It is easier, in the field, to utilize a range criterion based on an unknown number of runs. This method follows the same procedure as the uncertainty test method, the difference being the criterion is based on a range required to obtain an acceptable uncertainty.

7) Withdrawn.

API MPMS:1985, 13.1[18], API MPMS:2018, 13.2[19] and API MPMS:2013, 4.8[20] suggest factors to provide the range required to meet an uncertainty criterion. The factors were taken from standard statistical methods in References [21], [22] and [23].

The standard statistical technique applies to larger sample sets and to the mean range of a number of sample sets (sized between 6 and 10), each having a number of measurements (sized between 6 and 12).

The API standards[18]-[20] suggest the factors can be used with enough confidence applicable to flow measurement applications with fewer measurements than would be required by the standard statistical methods.

Using these methods, a range can be calculated for any specified uncertainty criteria and for any given number of runs. For a given uncertainty acceptance criteria, a table of range criteria can therefore be constructed with increasing numbers of runs. This table can then be consulted during a proving operation and the number of runs increased until the criteria is met. If the estimated uncertainty is subsequently required to be calculated, this would be determined based on the results and Formula (C.5).

To calculate the range values, the relationship between standard deviation is defined in Formula (C.8) as.

$$\sigma = \frac{R}{d} \tag{C.8}$$

where

d is the factor to estimate standard deviation from range of values;

R is the range.

From the Formulae (C.1) and (C.5) the acceptable range (R_a) can therefore be calculated from Formula (C.9).

$$R_a = \frac{U_a d_n \sqrt{n}}{t_{(n-1),P}} \tag{C.9}$$

By re-arranging (C.9) uncertainty is given by Formula (C.10)

$$U_a = \frac{R_a t_{n-1}}{d_n \sqrt{n}} \tag{C.10}$$

Formula (C.8) can be reduced to provide a range-to-uncertainty conversion factor using Formula (C.11).

$$J = \frac{U_a}{R_a} = \frac{t_{(n-1),P}}{d_n \sqrt{n}} \tag{C.11}$$

where

J is the Range to uncertainty conversion factor;

U_a is the acceptable uncertainty;

d_n is the factor for n measurements;

$t_{(n-1),P}$ is the Student's t-value for n–1 measurements and the chosen probability, P, (95 %).

To calculate the allowable range, or spread, of values for a given number of runs, it is simply a case of dividing the required uncertainty by the appropriate value of J.

Where the range of values for a specified number of consecutive runs has been specified as the acceptability criterion, in earlier standards or specifications, the equivalent uncertainty can be calculated from Formula (C.12).

$$U_a = \frac{R_a t_{n-1}}{d_n \sqrt{n}} \tag{C.12}$$

For fiscal and custody transfer meters the range has been traditionally specified as being five runs falling within a range of 0,05 % (±0,025 %). From Formula (C.10), the acceptable uncertainty is calculated as 0,027 %. For lower accuracy flowmeters a traditional acceptance based on three consecutive runs is 0,05 %. This gives and uncertainty criterion of 0,073 %.

Table C.1 provides a summary of the uncertainty criteria for 0,027 %, 0,035 %, 0,05 % and 0,10 %, and the number of runs used to provide the calibration. The values correspond to the consecutive range criteria formally used.

Table C.1 — Uncertainty and range table

No. of runs *n*	*t* (*n*−1) *P* (95 %) 0,05 *t*	**Range to SD factor** *d*	**Range to uncertainty factor** *J*	**SD** *U* = 0,027 *σ* %	**Range** *U* = 0,027 *R* %	**Range** *U* = 0,035 *R* %	**Range** *U* = 0,05 *R* %	**Range** *U* = 0,073 *R* %	**Range** *U* = 0,1 *R* %
2		1,128							
3	4,302 7	1,693	1,467	0,010 9	0,018	0,024	0,034	0,050	0,068
4	3,182 4	2,059	0,773	0,017 0	0,035	0,045	0,065	0,094	0,129
5	2,776 4	2,326	0,534	0,021 7	0,051	0,066	0,094	0,137	0,187
6	2,570 6	2,534	0,414	0,025 7	0,065	0,085	0,121	0,176	0,241
7	2,446 9	2,704	0,342	0,029 2	0,079	0,102	0,146	0,213	0,292
8	2,364 6	2,847	0,294	0,032 3	0,092	0,119	0,170	0,249	0,341
9	2,306 0	2,970	0,259	0,035 1	0,104	0,135	0,193	0,282	0,386
10	2,262 2	3,078	0,232	0,037 7	0,116	0,151	0,215	0,314	0,430
11	2,228 1	3,173	0,212	0,040 2	0,128	0,165	0,236	0,345	0,472
12	2,201 0	3,258	0,195	0,042 5	0,138	0,179	0,256	0,374	0,513
13	2,178 8	3,336	0,181	0,044 7	0,149	0,193	0,276	0,403	0,552
14	2,160 4	3,407	0,169	0,046 8	0,159	0,207	0,295	0,431	0,590
15	2,144 8	3,472	0,159	0,048 8	0,169	0,219	0,313	0,458	0,627
16	2,131 4	3,532	0,151	0,050 7	0,179	0,232	0,331	0,484	0,663
17	2,119 9	3,588	0,143	0,052 5	0,188	0,244	0,349	0,509	0,698
18	2,109 8	3,640	0,137	0,054 3	0,198	0,256	0,366	0,534	0,732
19	2,100 9	3,689	0,131	0,056 0	0,207	0,268	0,383	0,559	0,765
20	2,093 0	3,735	0,125	0,057 7	0,215	0,279	0,399	0,583	0,798
21	2,086 0	3,778	0,120	0,059 3	0,224	0,290	0,415	0,606	0,830

Key

t Student's *t*- value

P probability

SD standard deviation

U expanded uncertainty at 95 % probability

R range of values

NOTE This table has been extended from *n* = 20 to *n* = 25 for information.

Table C.1 *(continued)*

No. of runs *n*	*t* (*n*−1) *P* (95 %) 0,05 *t*	Range to SD factor *d*	Range to uncertainty factor *J*	SD *U* = 0,027 *σ* %	Range *U* = 0,027 *R* %	Range *U* = 0,035 *R* %	Range *U* = 0,05 *R* %	Range *U* = 0,073 *R* %	Range *U* = 0,1 *R* %
22	2,079 6	3,819	0,116	0,060 9	0,233	0,301	0,431	0,629	0,861
23	2,073 9	3,858	0,112	0,062 4	0,241	0,312	0,446	0,651	0,892
24	2,068 7	3,895	0,108	0,063 9	0,249	0,323	0,461	0,673	0,922
25	2,063 9	3,931	0,105	0,065 4	0,257	0,333	0,476	0,695	0,952

Key

t Student's *t*- value

P probability

SD standard deviation

U expanded uncertainty at 95 % probability

R range of values

NOTE This table has been extended from *n* = 20 to *n* = 25 for information.

C.4 Acceptance criteria

C.4.1 General

The acceptance criteria for any particular proving operation are specified by regulation, contract or company procedures. There are however some common expectations used across the Petroleum industry, particularly for fiscal and custody transfer applications, which are given for guidance.

C.4.2 Acceptance criteria for the calibration of a pipe prover

Table C.2 gives a summary of the acceptance criteria expected from industry practice and alternative standards.

Table C.2 — Acceptance criteria for prover calibrations

Calibration methodology	Total expanded uncertainty U %	Repeatability		Shift from previous calibration [g] %
		No of runs [a]	Range [b] %	
Conventional prover by water draw	0,035 [c]	3	0,02	0,05
Small volume prover by water draw		5		
Conventional prover; sequential master meter method [d] (pre-post factors) Conventional prover; Concurrent master meter method [e] (simultaneous factors)	0,05	5 [f]		

[a] For all methods, one run or batch of runs may be required to be at a minimum flowrate of 20 % different from the others.

[b] Prover calibration criteria is almost exclusively specified as being the range of consecutive results. This does not preclude uncertainty being the criteria specified. Achieving 3 runs within 0,02 % range usually results in an uncertainty greater than 0,01 % as described in C.3.2.

[c] The expected total uncertainty in determining the base volume is usually in the range 0,03 % to 0,04 % depending on the equipment used and the conditions under which the calibration is carried out.

[d] When the sequential master meter method is used to calibrate a prover, the meter factors are determined pre- and post-prover calibration. Each determination would be taken from a minimum of 5 tests with repeatability within a range of 0,02 %. The mean pre- and post-values of meter factor should also agree to within 0,02 %.

[e] When the concurrent master meter method is used to calibrate a prover, the mean meter factor is determined by a minimum of 5 measurements in each pass of the prover under test, with a repeatability range of 0,02 % or U_r 0,01 %. In some cases it is specified as acceptable that a pre-calibration verification of repeatability is carried out based on a minimum of 5 determinations of meter factor, falling within a repeatability range of 0,02 % or U_r 0,01 %. No further monitoring of repeatability is then carried out. For the simultaneous method, no criteria are given for the repeatability of mean factors between calibration passes or runs of the prover.

[f] Some standards require 3 batches of 3 runs each, with one batch being at a different flowrate. The overall mean provides the result. The repeatability range of both runs and batch means are to be within 0,02 %.

[g] The change in base volume from previous calibration may be specified as an indicator of the stability of the prover. Ideally, any change in base volume should not be greater than the expected uncertainty of each reported value. Conventionally, a shift in base volume of greater than 0,05 % results in suspension of the calibration while possible causes are investigated. Once all parties are satisfied that all practical remedial actions have been taken, the calibration may be continued or repeated, usually at a different set of flowing conditions (usually a change in flowrate of 25 %). Providing this calibration agrees with the first calibration to within 0,02 %. The second calibration may be considered to be the measured value reflecting a genuine change in base volume. The certificate issued should show the change in volume from the previous and an explanation of the remedial actions taken.

C.4.3 Acceptance criteria for the calibration of flowmeters using a pipe prover

The acceptability criteria for the calibration of flowmeters using a pipe prover as reference are summarized in Table C.3.

Table C.3 — Acceptance criteria for flowmeters

Standard	Range	Linearity	Repeat. consecutive	Repeat. uncertainty
OIML R117[a] class 0.3	10:1/5:1	±0,3 %	±0,12 %	
OIML R 117 class 0.5	10:1/5:1	±0,5 %	±0,20 %	
API MPMS Chapter 4 (superseded) [b]			±0,025 %	
ISO 7278-2:1988			±0,025 %	
EI HM12			±0,025 %	
NORSOK I105 [c e]	10:1/5:1	0,25 %/0,15 %	±0,025 %	±0,027 %
NORSOK I106 [c]			±0,025 %	±0,027 %
API MPMS chapter 4 (current) [d]			±0,025 %	±0,027 %

a OIML does not specify linearity however requires all test points to be within a range ±0,3 % or ±0,5 % of the "true" value. Repeatability is specified as $^2/_5$ of the class value.

b The repeatability value in API MPMS chapter 4 is now superseded. It applies to the calibration of meters by pipe prover at one flowrate.

c NORSOK I105[15] specifies range and linearity values however these are no longer specified in NORSOK I106[16].

d API have adopted the statistical range specification for repeatability.

e Withdrawn.

Annex D
(informative)

Troubleshooting

D.1 General

One of the keys to successful troubleshooting is the availability of records of past calibrations of the prover and the calibrations of meters using the prover. Changes from a previous result, indications of drift in results, or a common change in the calibration of different meters all give indication of where potential problems are to be found. For this reason, full records of all calibrations should be kept in a systematic way.

The main indication of problems is manifested through abnormal results being obtained. This may be individual measurements, results within a batch of measurements, or results significantly different from those previously recorded.

Most of the sources of problems are common to both the calibration of provers and/or their use in the field. However, considerably more effort is required for the elimination of faults during prover calibration due to the tighter tolerances involved and the risk of an incorrect result being used for a considerable time thereafter.

Fault finding is rarely straightforward and if a fault is detected or suspected, it is not always immediately clear if it is with the prover, the reference system used to calibrate, or the meter being calibrated.

The first manifestation of a problem is often a failure to obtain the expected repeatability. The reasons for a lack of repeatability should be rectified first. Secondly an unexpected change prover volume or flowmeter K-factor may be evident. Potential causes to be considered are listed.

D.2 Air in the system

Many repeatability problems can be overcome by ensuring that all the air/gas in the system has been removed.

Troubleshooting actions include the following:

— Establishing flow through the system and cycle the displacer around the prover several times before opening each of the vents, in turn allowing sufficient time for air to escape. The end chambers are often natural traps for pockets of gas and should be completely vented, along with any other natural traps for gas between prover and meter (or prover and master prover).

— If problems persist, it can be due to other forms of air/gas entering the system. Entrained air can be drawn into a system through poor pump gland seals or through the misalignment of inlet/outlet hoses in a reservoir. Flashing due to cavitation can result in gaseous bubbles passing through a meter after a partially open valve or other fitting causing a local drop in pressure.

D.3 Instability of temperature and/or pressure within the system

Results that drift upwards or downwards as the exercise proceeds are usually a result of gradually changing flowing conditions, the most prevalent being a drift in temperature or viscosity.

Troubleshooting actions include:

— Running fluid for longer to obtain temperature stability.

— Insulating and /or protecting the entire system to protect it from direct sun, wind or frost.

— Reducing the interface inventory i.e. pipe length, between prover and meter (or master prover).

— Requesting the site operations team keep flowing conditions as steady as possible.

— Scheduling a better time to perform the work, for example early morning or early evening when the sun is not directly heating the fluid and pipework.

— When running from storage tanks, ensuring there is sufficient time to complete the exercise before a tank changeover is scheduled.

D.4 Instability of pressure within the system

Fluctuating pressure can result in inconsistent displacer movement and/or inconsistent line packing in the interface inventory.

Troubleshooting actions include:

— Examining supply pumps and control valves to improve stability, avoid situations where the flow control system is constantly "hunting" up and down trying to achieve stability.

— Monitoring flowrate in the system as the displacer travels through the pipe to ensure no stiction or juddering. This can often be "felt" in the pipework rather more readily than it can be observed on a display.

— For a water calibration of a sphere prover, it is common practise to apply a thin layer of heavy grade grease or lubricant to the sphere in order to smooth its passage around the barrel.

D.5 Error in tank volume measurement

Any change in the volumetric measure which would affect the calibrated volume of the tank is passed directly to the determination of the prover volume resulting in a change in the base volume of the prover, or reference meter.

Troubleshooting actions include:

— Prior to use, checking the tank for external damage, internal damage, leakage, scale adjustment, spirit level alignment and contamination.

— When top loading into a prover tank, considering the potential for liquid to splash out of the neck due to backdraught. This can be a limiting factor in the calibration flowrate.

D.6 Error in temperature, pressure and density measurement

Errors in secondary instrumentation directly affect the results of proving, the higher the thermal expansion and compressibility coefficients of the fluid, the greater the potential error.

Troubleshooting actions include:

— Ensuring instrumentation has a valid calibration, correctly located in the flowing stream and connections are correct.

— Checking thermometers and thermowells have adequate immersion depths and that thermowells have adequate heat transfer paste/liquid.

— Performing spot checks against a reference thermometer. This is done by using a reference thermometer in a spare thermowell with flow passing through the system. If a spare thermowell is not available, the thermometer would be removed and placed in a vacuum flask with the reference thermometer.

— Checking pressure instruments and pressure tappings for leakage, or vent impulse lines blocked.

— Performing spot checks against a reference gauge or calibrator.

— For volumetric calibrations, density is a second order effect but should be measured by in-line densitometer or by lab analysis of a representative sample taken at the time.

D.7 Malfunction of critical valves

Four-way valves, interchange valves and piston poppet valve seals should be fitted with a means to establish they function correctly and should be observed to be leak tight, e.g. through an established internal leak check.

All other valves deemed to be critical in the system, such as vents, drains, valves between prover stubs, isolation valves, pressure relief valves and sample points, should either be fitted with a leak check device (e.g. a tell-tale sight glass) or have some other means to positively isolate the line (e.g. a spectacle blind fitted downstream of the valve) or run to a visibly "open tundish" device.

Valve leakage can be repeatable and therefore not immediately obvious during the calibration but does result in a change in base volume from previous calibration results.

Troubleshooting actions include:

— Checking all critical valves periodically by site personnel, especially when preparing for a calibration. Leaking valves inevitably leads to delays while repairs/modifications are undertaken.

— It is possible to cure a leak in a motorised valve by resetting the "torque" or "limit" setting rather than replacing the seals.

— It can be necessary to check hydraulically operated valves to see if pressure is applied constantly (not ebbing away over time) or can require the hydraulic power to be increased.

— Block and bleed (twin seal) valves should be checked in the open position (to ensure the vent valve/ vent line are not blocked) and then again in the closed position (to ensure the valve is sealing correctly).

— Four-way valves should be checked in both sealing positions.

— Critical valves should be monitored periodically throughout the calibration.

— Where a critical valve is not fitted with a leak check system, and it is not possible to fit a blank, it is possible to isolate a portion of the line by closing a valve further downstream and opening a vent in between the two closed valves to monitor there is no build-up of pressure.

— In circumstances where a valve cannot be checked, rather than abort the operation, it is possible, with the agreement of all parties, to continue with the calibration and if acceptable results are obtained annotate the final certificate highlighting the deficiency. However, it is not acceptable to carry on with a calibration in the knowledge that a critical valve is leaking.

D.8 Malfunction of solenoid valves

In a water draw calibration the solenoid valve is a critical valve and should be leak tight. It should also shut off flow rapidly and in a repeatable manner.

Troubleshooting actions include:

— Before the calibration commences, running the sphere past the detector (or manually gate the detector switch) several times and checking the solenoid valve for valve chatter, leakage and a repeatable delay time from switch actuation.

D.9 Damage or under-inflation/ over-inflation of sphere displacers

A sphere type displacer in good condition provides a good seal and runs smoothly through the calibrated section of a prover, especially around the bends where the pipe cross section may not be perfectly round or where sections of the internal lining may have been lost.

A damaged, distorted or under inflated sphere may allow slippage of liquid past its "sealing band". It may also affect the repeatable triggering of the detector switch.

The surface of a sphere left immersed in product for a long period may be affected by the liquid and have gone "soft". This may well have an adverse effect on its ability to seal correctly and also trigger detectors correctly.

A sphere that has been over-inflated, possibly in order to try and get a good seal, may not run smoothly around the prover and "judder" at the detector causing poor trigger point repeatability.

An over inflated sphere may not seal correctly as it can be too rigid to "mould" into the ovality of a pipework bend. Again, this may be felt as juddering while the sphere travels around the bend.

Troubleshooting actions include:

— The sphere should be removed and checked for damage, distortion, hardness and size before the calibration.

— While removed, the sphere may be checked for a burst or leak by temporarily overinflating and looking for leakage. Over inflation of a sphere is usually only to 1 % to 2 % above the design inflation. The sphere is then deflated to the required diameter before reinstallation.

— Where slippage past the sphere is suspected, a number of runs at several different flowrates may be performed to see if the volume changes as flowrate is changed.

— Where poor repeatability is an issue, over inflating the sphere by a percent or two above design during the calibration may improve performance however it would be most unusual to keep increasing the size past 6 % oversize.

— A larger diameter prover may well require a sphere that is oversized by a larger percentage to maintain an adequate sealing band.

— On occasions, a softer polychloroprene (neoprene) sphere can help the calibration repeatability, but once the prover calibration is complete, it is replaced by a harder polyurethane sphere of the same size for normal operational use. The softer sphere is stored appropriately for future use.

D.10 Displacer is frequently found to be damaged, degraded or burst

The specification of the sphere material should be reviewed in conjunction with the fluid product(s) specification, to ensure it is compatible.

The prover may be poorly finished, with intrusive pipe fittings, pipe welds not ground down flush with the barrel or misaligned flanges. Wear corrosion or damage to the lining may also cause sphere wear or leakage.

The velocity of the sphere may have been at some time above the design specification of the prover, damage being done as the sphere arrives at the end chamber.

Over inflation increases the internal pressure and allow leakage or failure of the inflation valve resulting in the sphere deflating. A larger (deflated) size sphere should be ordered.