INTERNATIONAL STANDARD

ISO 2715

Second edition
2017-11

Liquid hydrocarbons — Volumetric measurement by turbine flowmeter

Hydrocarbures liquides — Mesurage volumétrique au moyen de compteurs à turbine

Reference number
ISO 2715:2017(E)

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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 on 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 the following URL: 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 Technical Committee ISO/TC 30, *Measurement of fluid flow in closed conduits*.

This second edition cancels and replaces the first edition (ISO 2715:1981), which has been technically revised.

Introduction

This document gives recommendations on the design, installation, operation and maintenance of turbine metering systems used for liquid measurement. This widens the application scope from the previous document, which was primarily aimed at hydrocarbon custody transfer applications. The guidance now applies to all suitable liquids measured across different applications and industry sectors.

Turbine meters for liquids are extensively used in general fluid measurement in addition to fiscal, custody transfer and legal metrology applications involving hydrocarbon and non-hydrocarbon products. These can range from the light products such as gasoline, through to higher viscosity fluids and non-hydrocarbon liquids.

The document has an extended scope from the first edition to cover applications for a wider range of liquids and duties and to remove restriction to hydrocarbon liquids. It now provides guidance, rather than mandatory requirements, on performance to allow meters to be specified and verified to meet relevant regulatory, fiscal and custody transfer specifications. The document also now includes additional meter designs. This revision has been achieved through the participation of ISO/TC 30 in the preparation, hence, providing a single standard for the measurement of flowing liquids using turbine flowmeters.

Liquid hydrocarbons — Volumetric measurement by turbine flowmeter

WARNING — The use of this document might 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 describes and discusses the characteristics of turbine flowmeters. Attention is given to the factors to be considered in the application of turbine meters to liquid metering. These include the properties and nature of the liquid to be metered, the correct installation and operation of the meter, environmental effects, and the wide choice of secondary and ancillary equipment. Aspects of meter proving and maintenance are also discussed.

This document is applicable to the metering of any appropriate liquid. Guidance is given on the use of turbine meters in the metering of two-component liquid mixtures such as water and oil.

It is not applicable to two-phase flow when gases or solids are present under metering conditions (i.e. two-phase flow). It can be applied to the many and varied liquids encountered in industry for liquid metering and is not restricted to hydrocarbons.

Guidance on the performance expected for fiscal/custody transfer applications for hydrocarbons is outlined.

This document is not applicable to cryogenic liquids, such as liquefied natural gas (LNG) and refrigerated petroleum gas. It does not cover potable water applications.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC Guide 99, *International vocabulary of basic and general terms in metrology (VIM)*

ISO 4006, *Measurement of fluid flow in closed conduits — Vocabulary and symbols*

3 Terms, definitions, symbols and abbreviated terms

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

ISO and IEC maintain terminological 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 Terms and definitions

3.1.1
accuracy
closeness of the agreement between the 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]

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

EXAMPLE This entails bringing a measuring instrument (meter) into a satisfactory performance and accuracy.

Note 1 to entry: Adjustment can be of zero point, span, linearity or other factors affecting the performance of the meter.

Note 2 to entry: Adjustment should not be confused with calibration, which is a prerequisite for adjustment.

Note 3 to entry: After adjustment, a recalibration is usually required.

[SOURCE: ISO/IEC Guide 99:2007, 3.11]

3.1.3
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.

[SOURCE: ISO/IEC Guide 99:2007, 2.39, modified]

3.1.4
cavitation
phenomenon related to, and following, *flashing* (3.1.6) 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 pipe and meter through erosion.

3.1.5
error
measured value minus a reference 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]

3.1.6
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 reduce 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 will remain for a considerable distance downstream of the meter even if pressure recovers.

3.1.7
flow conditioner
flow straightener
device installed upstream of a turbine meter to reduce swirl and velocity profile distortions

3.1.8
K-factor
ratio of the number of pulses obtained from a meter, and the quantity passed through the meter

3.1.9
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.

3.1.10
lubricity
liquid property which affects friction between moving surfaces

Note 1 to entry: Good lubricity allows the formation of a liquid film between surfaces, and thereby reduces friction. Poor lubricity, where little or no film is formed, can result in accelerated component wear.

3.1.11
meter factor
ratio of the quantity indicated by the reference standard and the quantity indicated by the meter

3.1.12
performance indicator
derived value which may be used to indicate the performance of the meter

EXAMPLE Error, K-factor, or meter factor.

3.1.13
proving
calibration with comparison to defined acceptance criteria

Note 1 to entry: Proving is a term 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 defined by standards, regulation or procedures providing a determination of the errors of a meter and showing (proving) it performs to defined acceptance criteria.

3.1.14
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 latter is the most common method through a double timing technique.

3.1.15
range
measuring range
set of values of flowrate for which the error of a measuring instrument (flowmeter) is intended to lie within specified limits

[SOURCE: ISO Guide 99:1993]

3.1.16
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.

3.1.17
repeatability
a
closeness of agreement between indications or measured quantity values obtained by replicate measurements under specified conditions

Note 1 to entry: Specified conditions normally imply 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 or K-factor. Alternatively, repeatability can be expressed as a function of the standard deviation of the values.

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

[SOURCE: ISO/IEC Guide 99:2007, 2.21, modified]

3.1.18
slip
measure of the fluid which passes through the meter without being directly measured

3.1.18.1
dynamic slip
slip measured when the meter is rotating

3.1.18.2
static slip
slip measured when the meter is not rotating

3.1.19
standard conditions
conditions 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, these are usually 15 °C, 20 °C or 60 °F and 101,325 kPa.

Note 3 to entry: Quantities expressed at standard conditions are shown by prefixing the volume unit by "S", e.g. 4 Sm^3 or 700 kg/Sm^3.

Note 4 to entry: Definition has been adapted from Energy Institute HM 0 and OIML R 117. Some other petroleum standards employ the term "base" conditions.

Note 5 to entry: In some other documents, "standard" conditions are described as "base" conditions and, incorrectly, as "reference" conditions. Reference conditions are conditions of use (influence quantities) prescribed for testing the performance of a measuring instrument.

[SOURCE: ISO Guide 99:1993]

3.1.20
swirl
condition where the liquid flowing through a pipeline rotates with an associated high tangential component of velocity relative to the axial component

3.1.21
uncertainty
non-negative parameter characterizing the dispersion of the quantity values attributed to a measurand based on the information used

Note 1 to entry: 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.

[SOURCE: ISO/IEC Guide 99:2007, 2.26, modified]

3.1.22
velocity profile distortion
deviation from a fully developed velocity profile within a pipeline

3.2 Symbols and units

For the purposes of this document, the symbols given in ISO 4006 and ISO/IEC Guide 99 apply.

NOTE 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.

4 Design and operation of turbine flowmeters

4.1 Basic characteristics and mode of operation

An axial-flow turbine meter comprises a meter body, normally a section of pipe, containing a free-running rotor assembly mounted on an axial central shaft. The shaft is supported on bearings held within hanger assemblies, which align the rotor centrally within the meter body and parallel to the direction of the flow.

The rotor is fitted with multiple straight or curved blades positioned round the rotor and extending outward to the body wall, minimizing blade tip clearance. It is the action of the flowing liquid on the blades which causes rotation of the rotor at a speed proportional to the fluid velocity.

Although rotor speed is proportional to fluid velocity, it is normal to relate rotor speed to volumetric flowrate.

Rotor design varies widely with 2 to 20, or more, blades fitted. These can be straight and angled to the flow, contoured, or helically cut covering up to 180° circumference.

Some designs have a ring around the outside of the blade tips (rimmed rotor).

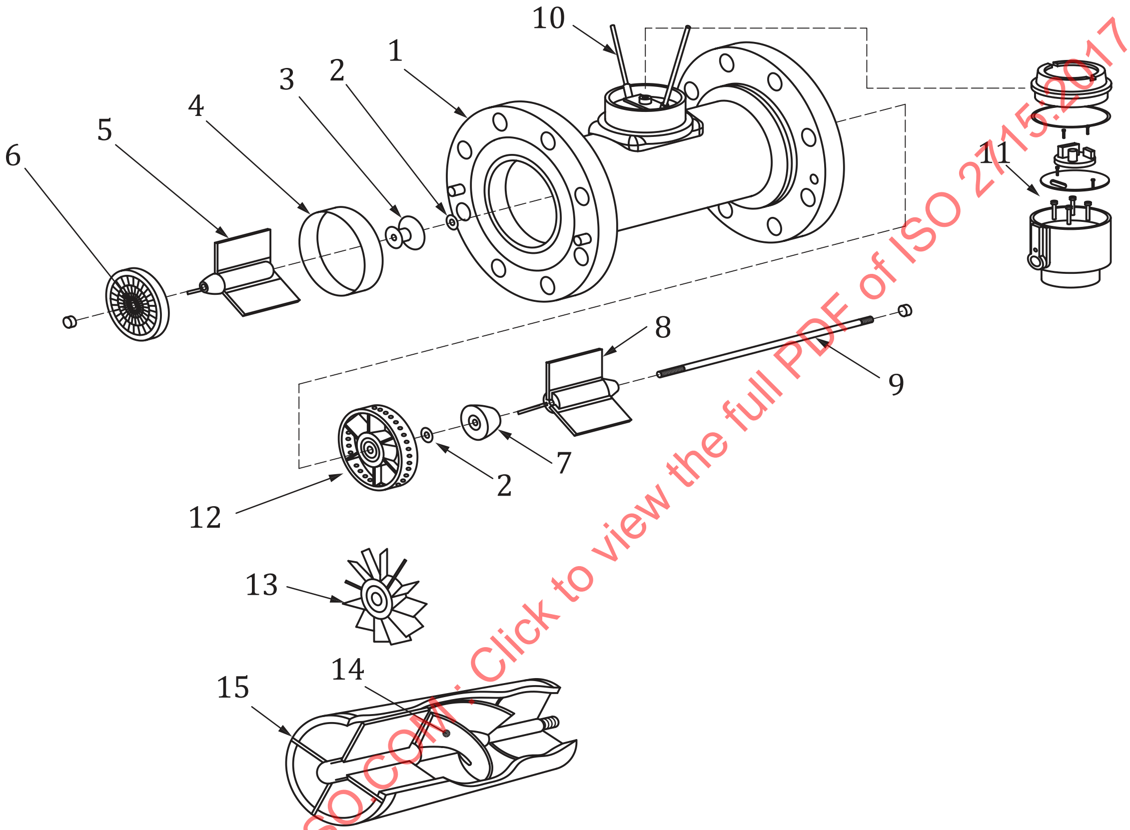
The bearings can be journal or ball bearing type, and chosen to suit the liquid and application. The bearings are housed in the upstream and downstream hangers. Thrust bearings take the force generated by the flow. Many designs have hydro-dynamically designed cones upstream and downstream of the rotor, allowing the rotor to "float" between the bearings, hence, minimizing drag and wear.

Hangers can be flat plates or tube bundles, aligned to the flow direction, and secured to the body. They can assist in conditioning the flow.

The body is a piece of pipe which contains the pressure of the liquid. To provide ease of assembly, and to minimize the pressure effect on the measuring section, a double-case construction can be used, where the rotor is enclosed in a second internal housing. Some designs have such a construction as a replaceable "cartridge" containing the rotor and components, allowing a meter to be pre-calibrated in one body, then used in another.

A further modification allows such a construction to provide a reduced diameter for the rotor assembly through the use of carefully designed cones. This increases the velocity of the fluid in the meter, potentially improving the measurement range.

The major components of typical designs are shown in Figure 1.



Key

1 meter body	9 shaft
2 thrust washer	10 pick-ups A and B
3 upstream cone	11 head pre-amplifier
4 deflector ring	12 rimmed rotor
5 upstream hanger	13 bladed rotor
6 optional flow conditioner (plate/tubes)	14 helical bladed rotor
7 downstream cone	15 cartridge insert
8 downstream hanger	

Figure 1 — Components of a turbine meter

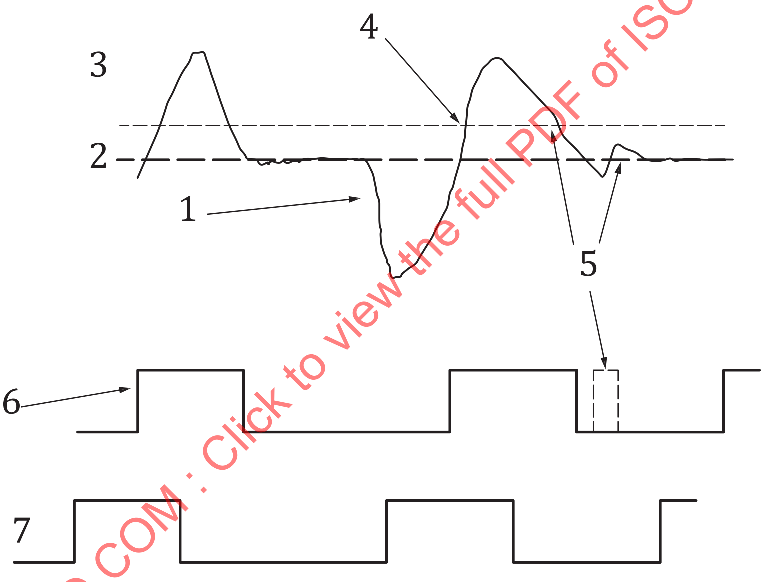
4.2 Output signal

The meter output is in the form of electrical pulses generated by a sensor located in the body wall. This detects the rotation of the rotor through inductive, magnetic, or radio-frequency sensing of the blade tip passage. Alternatively, a rimmed rotor ring can carry magnetic markers or slots, which allow a higher pulse output resolution. More novel detection methods are possible, such as optical sensors.

Pick-ups are normally located in a fitting on the pipe wall, and can sense the rotor through the wall, ensuring pressure integrity of the body. As the sensing is through the wall, it is vital that the pick-up is fully inserted into the fitting, as an increased distance from the pipe wall will lead to a reduced amplitude signal.

By using magnetic/inductive sensing, the signal is generally a modified sine wave with an amplitude, which increases with speed of the rotor. Generally, the amplitude of the pulses is in the range between 10 mV and 1 V, depending on speed and design. Care should be taken to ensure that the detection of pulses allows for this change in amplitude with speed and to avoid the danger of missing pulses at low flowrates or double counting as the amplitude rises. A typical signal is shown in Figure 2.

Pulse output frequency varies with flowrate, but also with rotor design. Straight-bladed turbines normally operate at a maximum frequency of 10 kHz, while helical rotors with two blades operate with a significantly lower frequency output. A low frequency gives rise to issues regarding electronic noise filtering and also a low resolution, especially when proving.



Key

1 typical raw signal from magnetic pick up

2 zero volts

3 maximum voltage increasing with frequency (e.g. 10 mV to 200 mV)

4 pulse counter trigger threshold

5 potential for noise pick up and false pulses

6 amplified signal

7 amplified output from second pick-up

Figure 2 — Typical pulse output signal

Each generated pulse can be related to the passage of a quantity of liquid and, hence, the primary output parameter describing the meter performance indicator is K-factor, expressed as pulses per unit volume.

Where security of measurement is important or a regulatory requirement, the meter pulse pick-up can be sealed, and in some cases, the meter body and associated pipework can also be sealed to prevent misalignment. Two pick-ups are installed for fiscal meters, allowing integrity of pulse counting to be ensured. Suitable spacing of the pick-ups allows direction sensing.

A pre-amplifier can be installed at the meter to provide amplified and square-edged pulses for transmission. Proprietary pre-amplifiers are available from manufacturers to match the potential signal amplitudes, frequencies, and pulse shape from their design. The amplifier may incorporate a digital to analogue converter, allowing a 4 mA to 20 mA signal to be transmitted. However, this would only be recommended for process control applications. Some amplifiers also allow for linearization and digital output in volumetric units.

4.3 Pressure loss

The pressure loss follows a classical relationship, increasing with the square of the flowrate when the flow is turbulent.

In certain applications, too high a pressure loss leads to increased forces being applied to bearings, particularly thrust bearings, leading to component wear and increased linearity.

5 Performance aspects

5.1 General

This clause discusses the general performance of turbine flowmeters and the various factors which can affect the characteristic curve. Performance is normally stated in terms of variation in performance indicator as function of volumetric flowrate through the meter. The performance indicator is usually K-factor (pulses per unit volume). However, meter factor and error are also used.

Meters can have a single value determined and applied across the flow range, or a number of values determined across the range, and by appropriate interpolation, applied to the operating flowrate.

5.2 Factors affecting meter performance

The performance of turbine meters is affected by a number of variables, depending on the metering element design and the geometry of body and measuring chambers. The most important are:

a) liquid flowrate;

b) liquid viscosity;

c) liquid temperature;

d) upstream and downstream flow profile (pipework);

e) liquid pressure and pressure drop through the meter;

f) meter construction and metering element design;

g) blade angle, geometry and tip clearance;

h) lubricating properties of the liquid;

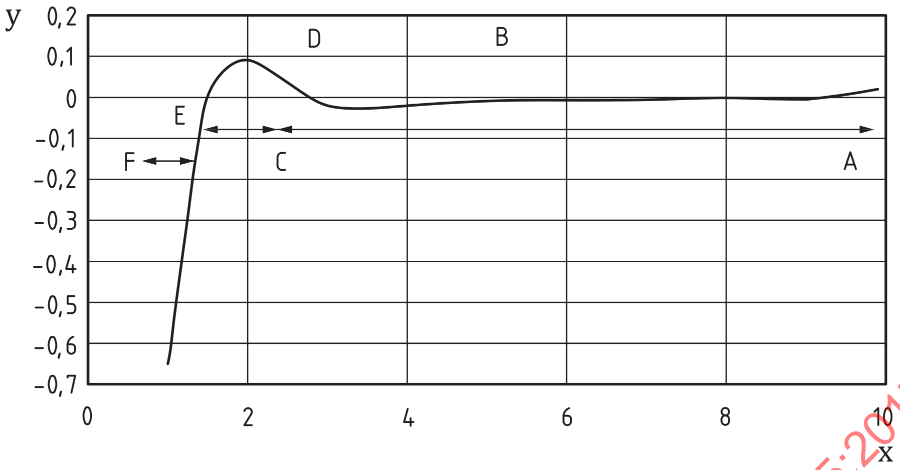
i) debris and deposits;

j) wear characteristics affecting bearings and blade surfaces;

k) secondary components, e.g. solids or gases.

5.3 General performance characteristics

While turbine meters are supplied with a nominal K-factor and performance characteristic, to achieve accurate measurement, all turbine meters would need calibration. This establishes the meter K-factor and general performance characteristics, such as the sensor output signal and pressure drop. Typical characteristics of the variation in meter performance as a function of flowrate through the meter for low-viscosity hydrocarbon usage are shown in Figure 3. This illustrates the performance, as relative error from a nominal K-factor, as a function of normalized flowrate.



Key

x normalized flowrate

y relative error

Figure 3 — Classical performance curve

The illustrative curve can be divided into distinct parts. However, this curve is not for a particular meter, and different designs show different characteristics.

In a classic meter performance curve, there is a linear section B, from flowrate A to flowrate C, where the meter has a predictable and stable K-factor. A constant value of K-factor can be used, or if a predictable curve shape is identified, reliable linearization can be applied. The flowrate range of the linear portion of the characteristic curve for a turbine meter depends on the meter size, the blade design and the viscosity of the fluid. To a lesser extent, the density of the liquid can have an effect. If the meter is always operated within this portion of its range, the use of an arithmetic or weighted mean value of the meter factor (or the meter K-factor) will cause only a small measurement error. This practice can be acceptable in situations where the flowrate is fairly constant for extended periods, such as in pipeline operations. If there is a change in properties of the liquid, for example, in the batch transfer of liquids in a multi-product pipeline, then establishing a K-factor through re-proving at each liquid batch can be necessary.

The linear part of the curve can be followed by a “hump”, D. The height, flowrate range and position of the “hump” are very dependent on the meter design, size and fluid viscosity. It varies from being almost non-existent in some designs and in higher viscosity liquids, to a very sharp peak in some meter designs.

This non-linear section of the curve across the “hump”, from flowrate C to flowrate E, provides a less reliable K-factor curve, and one where linearization can or cannot be applied successfully. This is a flowrate range where the meter should be used only with a knowledge of the performance of the particular meter, design, and size.

Data collected below the linear flow range E to F is considered to be inaccurate, since the non-repeatability due to the steep slope of the characteristic causes unacceptable errors.

At very low flowrates, the retarding torque of the bearings overcomes the driving torque and the rotor stops, even though a small flow is still passing through the meter.

Provided there is sufficient back-pressure to suppress cavitation within the meter, the turbine can be run for short periods above the rated maximum flowrate. However, the characteristic curve shows a drop in K-factor as the blade tip drag increases, effectively slowing the rotor. Continuous running at high speed can be detrimental to bearing life and can affect meter performance.

Generally, a measurement range of 10:1 can be achieved within a linearity band of 0,2 % for fluids with viscosity less than 20 cSt. However, this might reduce to 2:1 for higher viscosity liquids. Using a meter in the non-linear portion of the range might be invalid, since the non-repeatability, which is present in this portion of the characteristic, causes unacceptable errors.

An assessment of meter performance can be best made through calibration in different fluids at different viscosities and subsequent use of a meter control chart (see ISO 4124) to record performance with time and fluid. The control chart plots successive meter factors (or meter K-factors) obtained over a period of time and calibrations. It enables changes in meter factor (or meter K-factor) to be identified over short or long periods and gives confidence in the reproducibility of the meter. Further guidance is given in 11.4.

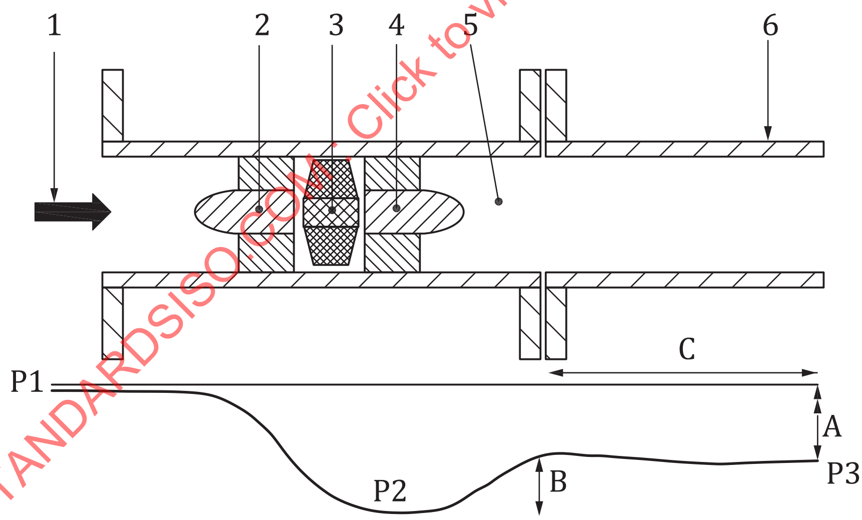
5.4 Pressure drop and back-pressure considerations

5.4.1 Pressure loss

The pressure loss through a meter is proportional to the square of the flowrate when the meter is operated in the turbulent flow regime. For a constant inlet pressure, there is a maximum flowrate at which a turbine meter can be operated within acceptable error limits before performance deteriorates due to the differential pressure across the meter.

Since there are many different designs of turbine meter, each manufacturer should be able to provide the pressure drop characteristics for different viscosities, hence, defining the maximum flowrate (velocity).

Figure 4 shows a typical pressure drop profile (which is design dependent) along the axial length of the meter. This simplified plot does not show the possibility of local pressure drop and recovery which can occur within the meter.



Key

Meter

1 inlet

2 upstream hub and support

3 rotor

4 downstream hub and support

5 outlet

6 downstream pressure point

Pressure profile

P1 inlet pressure

P2 lowest pressure

P3 downstream pressure

A pressure loss

B recovered pressure

C approximately 4 diameters

Figure 4 — Pressure profile through a turbine meter

Pressure loss should be measured from immediately upstream of the meter to a point around 4 pipe diameters downstream of the outlet, which is where the back pressure is also measured.

High differential pressure increases the loads applied to the bearings of the meter, causing wear and, potentially, a drop in meter K-factor through increased friction. The maximum recommended flowrate for continuous running or for extended limited time running should not be exceeded. If utilizing the extended range, the meter calibration should include these flowrates.

5.4.2 Flashing and cavitation

"Flashing" occurs when the fluid, or a component in the fluid, "flashes" (boils) to gas or when gas comes out of solution. Flashing occurs when the temperature rises or the pressure drops below the boiling point (or saturation point) of the fluid.

Figure 4 illustrates that the pressure within a meter reduces to the lowest value at, or just downstream of, the smallest internal area where the velocity is highest. The pressure then recovers downstream.

The complex internal design of a flowmeter provides different points where low pressure occurs: the meter hub, the downstream hangers and at the blade tips. At the blade tips, low pressure can be influenced by the velocity of the blade and the blade tip to body gap. This suggests flashing might occur at different points within the meter and not just at the smallest cross sectional area.

Free gas from solution is not generally re-absorbed as the pressure recovers until some distance downstream of the meter.

Cavitation can follow flashing when the released gas bubbles from boiling implode as the pressure recovers. This can happen immediately after a pressure reduction or further downstream. This implosion can be violent, and might lead to meter damage through erosion of components within the meter. Cavitation can sometimes be detected acoustically. However, this requires some experience, and lack of discernible sound does not indicate that no cavitation is present.

Cavitation and flashing within, or downstream of, the meter should be avoided at all times. Both give rise to measurement inaccuracies and might possibly damage key components with the meter. The onset of both flashing and cavitation creates a sharp change in the value of the K-factor. Usually, this results in a sharp rise in K-factor. However, it has been reported in a few designs that the K-factor drops.

Flashing is most likely to occur with a high-vapour-pressure hydrocarbon operating with a low system pressure. However, both effects can be readily created in low-vapour-pressure fluids such as water.

Flashing is avoided by keeping the pressure above the vapour pressure of the fluid, keeping in mind the operating temperature.

It is difficult to provide guidelines recommending a minimum downstream absolute pressure (back pressure) above the vapour pressure within the meter. Manufacturers' guidance should be sought for particular meters and duties.

Experience has suggested the numerical value of the minimum back pressure required, P_b, may be estimated from Formula (1):

$$P_b = 2\Delta P + 1{,}25 P_v \tag{1}$$

where

ΔP is the pressure loss across the meter at the maximum rated flow;

P_v is the absolute vapour pressure at the maximum operating temperature;

P_b is the absolute downstream pressure (measured around 4 diameters downstream).

NOTE The units used have to be consistent and by expressing P_v as absolute pressure as is conventional, P_b is also expressed as absolute pressure. This requirement is not made clear in some earlier documents.

This guidance is given in a number of documents, guidance documents and some manufacturer's guides. It is generally accepted that Formula (1) overestimates the required back pressure for high-vapour-pressure liquids, and the coefficient of 1,25 can be reduced. For very low-vapour-pressure liquids, it might underestimate the back pressure and the coefficient should be increased.

It is noted that for liquid petroleum gas (LPG) liquids (applicable between −10 °C and +55 °C), the minimum back pressure can be estimated from Formula (2):

$$P_b = P_v + 200 \tag{2}$$

where pressures P_b and P_v are absolute in units kPa(a).

As the required back pressure is highly dependent on the meter design, the blade tip velocity, and the fluid composition, vapour pressure and properties, it is stressed that the two formulae are given as guidance.

5.5 Flow profile

Turbine meter rotor speed is proportional to the mean fluid velocity. Any variation in the velocity across the meter pipe diameter or deviation in the directional vector of the velocity has an effect on the speed of rotation.

Turbine meters are, therefore, affected by the flow profile entering the meter in terms of both asymmetry and swirl components.

Every effort should be made to ensure that the flow profile entering the meter approaches that of a fully developed profile, particularly in terms of swirl. This can be achieved by installing an adequate length of straight pipe upstream, or utilizing flow straighteners or conditioners.

6 Liquid property effects

6.1 General

This clause discusses the more important liquid property effects. The performance of any turbine meter is likely to change as the liquid conditions change. To ensure the lowest metering uncertainty, it is recommended that the meter be proved with a liquid having the same physical properties as the liquid it is intended to measure. If there are differences between the physical properties of the operational liquid and the liquid on which the meter is proved, then changes in meter factor should be expected between proving and operation.

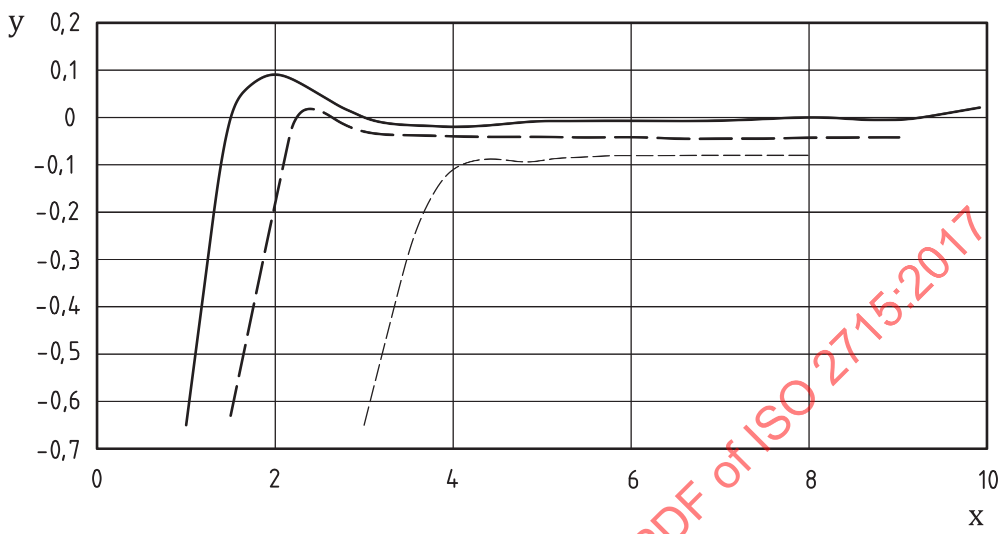
6.2 Effect of viscosity

General guidance for the metering of viscous hydrocarbons is given in ISO 9200.

Turbine meters are sensitive to the liquid viscosity. Blade shape, meter size, and blade number are all influential in determining the actual variations in meter factor with viscosity. Blade tip clearance to the body and the use of a rimmed rotor all contribute to the effect of viscosity on performance. Figure 5 shows typical changes in meter error (K-factor) with kinematic viscosity for straight- and helical-bladed designs. These curves shown in Figure 5 are illustrative only, and should not be construed as representing the actual performance of a given model or size. Helical-bladed meters are generally less sensitive to viscosity than straight-bladed meters. It is suggested that some designs of rimmed rotor reduce the sensitivity to viscosity. Helical-bladed rotors with two blades show the lowest sensitivity to viscosity and have found widespread use in the more viscous hydrocarbon applications.

Due to the wide range of designs, no firm guidance on viscosity limits can be defined. For general guidance, bladed and rimmed types of rotor can maintain a linearity band of 0,2 %, for a 10:1 turndown up to 20 cSt, dropping to 8:1 at 50 cSt. The linearity degrades rapidly with increasing viscosity after this limit. This applies to larger sizes (>150 mm) as smaller sizes have a more limited viscosity range. Helical-bladed turbines have a significantly wider viscosity range, operating up to 100 cSt in some cases.

In general, increasing viscosity reduces the linear range of the meter as shown in Figure 5. (The effect reduces the “hump”, effectively moving the non-linear part of the curve to the right in Figure 3).



Key

x normalized flowrate

y relative error

——— low viscosity

— — — mid viscosity

– – – – – high viscosity

Figure 5 — Typical viscosity effects on turbine meters

As fluid viscosity changes significantly with temperature, changes in temperature have a significant effect on the meter characteristic through changing viscosity. Generally, changes in viscosity follow an exponential relationship with temperature, so changes in viscosity are greater at higher temperatures. Higher density hydrocarbons exhibit a high viscosity sensitivity and, hence, larger changes in K-factor. Low density hydrocarbons (such as gasoline) generally exhibit small changes in viscosity with temperature.

6.3 Universal viscosity curve

The “universal viscosity curve” is a commonly used method of presenting the data when a turbine meter is specified for use over a wide range of operational viscosities or is to be calibrated with a different viscosity fluid form the operating condition.

It can be shown that the K-factor characteristics of turbine meters approximate to a function of flowrate and kinematic viscosity. For any particular meter, plotting K-factor against a parameter related to flowrate and viscosity shows that the results of different viscosity calibrations start to overlap to form a continuous curve.

The simplest function is to plot K-factor (or meter factor or error) against a “viscosity index” number as shown in Formula (3):

$$Iv = \frac{q_V}{\upsilon} \quad \text{or} \quad \frac{F}{\upsilon} \tag{3}$$

where

Iv is the viscosity index;

q_V is the volumetric flowrate (m^3/s);

F is the frequency (Hz);

υ is the viscosity (kinematic) (m^2s^{-1}) (10^6 cSt = 1 m^2s^{-1}).

Relating K-factor to Reynolds number (Re) provides an applicable viscosity related performance curve for many turbine meter designs as shown in Formula (4):

$$Iv = Re = \frac{4 \times q_V}{\pi \times D \times \upsilon} \tag{4}$$

where

Iv is the viscosity index;

q_V is the volumetric flowrate (m^3/s);

υ is the viscosity (Kinematic) (m^2s^{-1}), (10^6 cSt = 1 m^2s^{-1});

D is the pipe diameter (m).

Another index used relates K-factor to Roshko number.

$$Iv = Rosh. = \frac{F \times D^2}{\upsilon}$$

where

Iv is the viscosity index;

$Rosh.$ is the Roshko number;

F is the frequency (Hz);

υ is the viscosity (Kinematic) (m^2s^{-1}) (10^6 cSt = 1 m^2s^{-1});

D is the pipe diameter (m).

This is sometimes used in conjunction with replacing K-factor (K) with Strouhal number.

$$Stro = K.D^3$$

where

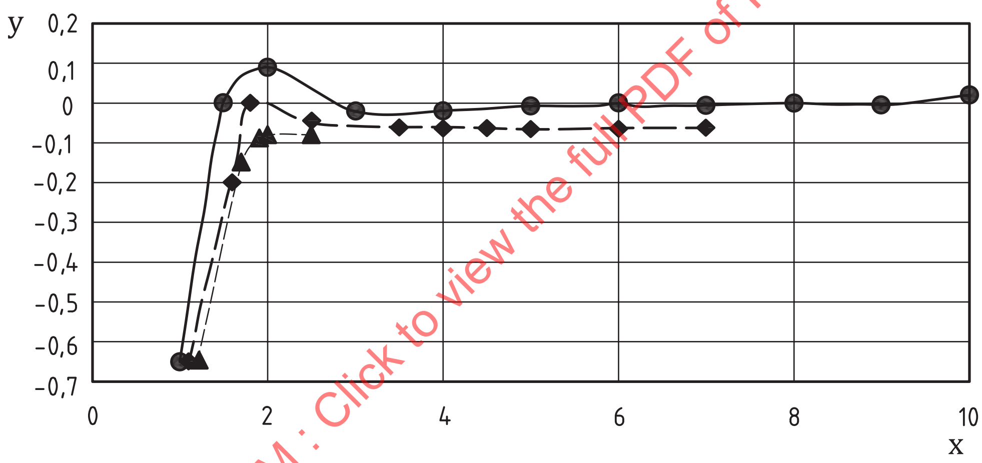
$Stro$ is the Strouhal number;

K is the K-factor (P/m^3);

D is the pipe diameter (m).

These two implementations provide little advantage over using Reynolds number or the simple flowrate viscosity relationship.

Figure 6 illustrates how the performance curves shown in Figure 5 are replotted against a normalized Reynolds number. It can be seen that the data roughly fall on a single curve.



Key

x normalized Reynolds number

y relative error

low viscosity

mid viscosity

high viscosity

Figure 6 — Universal viscosity curve

It is important that

a) the selection of calibration liquid and viscosity enables the full range of Reynolds number to be covered,

b) the viscosity is measured accurately, and the viscosity at the operating condition is used,

c) the number of liquids used to establish the final calibration curve network is sufficient to ensure overlap between consecutive curves,

d) care is taken to ensure consistency of the units used to define the relationship, and

e) performance is not extrapolated.

The relationships have limitations, and departure from a common performance curve is likely to be seen at both the low and the high extremes of the relationship. It should also be proved that the relationship holds for any particular design and size of meter.

6.4 Effect of temperature

In addition to property changes of the liquid being measured, temperature can alter the dimensions of the meter body, bearings, and rotor clearances in a complex way that cannot be accurately predicted. Changes in physical dimensions can be estimated from the mechanical properties of the construction materials. Commonly, meters are proved at actual operating temperature, thereby avoiding the need for temperature corrections.

The complexity of different temperature effects makes it very difficult to predict performance with temperature changes, particularly when two apparently similar meters do not react in the same way to a given set of flow operational conditions.

Where temperature correction to the meter is thought appropriate, and no knowledge of the exact correction for a particular meter is available, the cubical expansion for the body material can provide an initial approximation. The correction is applied as a temperature correction factor for the material of the body (C_{ts}) as part of a fiscal metering or proving calculation process.

It is important to run turbine meters prior to proving, or use, to ensure thermal equilibrium. Thermal lagging should be used where necessary to minimize ambient temperature effects and to help ensure thermal stability across the meter(s) and associated instrumentation.

Temperature effects on the liquid being metered are discussed in Clause 7.

6.5 Effect of pressure

Fluid pressure changes the dimensions of the meter body, hence, change the cross-sectional area of the meter and the blade tip clearance. If there are variations between the proving pressure and operating pressure, this would have to be accounted for. The effect of the meter area can be corrected through application of a standard mechanical expansion calculation for the meter body generating a pressure correction factor (C_{ps}). The use of an area or volume correction makes insignificant difference. Predicting effect of changing tip clearance is design-dependent and no guidance can be given.

There are some designs which utilize a double-case, where the rotor is located in an insert with pressure balanced between the meter and the outside of the case. For such designs, the effect is extremely small.

Pressure effects on the liquid being metered are discussed in Clause 7.

6.6 Lubricity and liquid cleanliness

The lubricity of the liquid can affect meter linearity, measurement range, repeatability, and reproducibility. With dry liquids (such as LPG), friction between moving surfaces can be large, as the liquid film, normally present with oils and similar liquids, is absent. Therefore, accelerated wear, increased friction, and more leakage can be present with non-lubricating liquids. Similarly, the presence of solid particles can also accelerate component wear, increase friction and, in extreme cases, block the meter. This occurs when particles become trapped between moving components and the meter seizes. Attention should be paid to the lubricating nature of the liquid and the presence of particles, since these can affect the choice of metering element and materials of construction.

The choice of both the type and materials for the turbine bearings is particularly important to ensure compatibility with the fluid.

Adequate filtration should normally be provided upstream of the meter so that critical dimensions and components are not affected through abrasion or mechanical damage from solid particles or pipeline rouge; however, this depends on the application. Failure to protect in this manner can result in meter seizure. The strainer should be positioned upstream of the air eliminator.

6.7 Two-phase flow

The document does not cover the use of turbine meters for measurement where two-phase flow is present. The following has been included to describe the potential effect of such two-phase fluids on the meter behaviour and performance.

Two-phase flow covers the presence of gas in the liquid or solids in the liquid. Both have an effect on the performance and life of the meter.

All turbine meters are affected by the presence of gas in the flow. This can be a situation where gas is entrained in the fluid entering the meter, or be due to gas flashing from the liquid due to a pressure drop within the meter or in an upstream component, such as a filter.

The presence of gas has an unpredictable effect on the K-factor and can cause damage to the meter, particularly if there are "slugs" of free gas entering the meter. This document covers the use of meters for single-phase liquid metering only; hence, any gas should be removed before entering the meter through the use of gas separators or eliminators.

Flashing should be avoided by raising the system pressure or reducing pressure loss.

Turbine meters are sensitive to the presence of solid particles such as pipeline rouge, scale and other particulate matter. These can cause bearing wear to be accelerated, can cause rounding of the blade edge or, in extreme cases, can cause a change in blade surface. Such effects lead to the loss of meter linearity, an increase in non-repeatability, or possibly both effects together.

6.8 Two-component operation

Two-component operation is the situation where two immiscible liquids are present (e.g. oil and water). Such mixtures provide unpredictable viscosity in the fluid and can, in the case of hydrocarbons and water forming an emulsion, create a high viscosity mixture. The presence of water in a mixture can also promote corrosion of key surfaces or components within the meter, unless it has been designed for water duty. Regular inspections are recommended in these cases. This document covers such applications where the component mixture is homogeneous, the properties of the mixture are predictable and fall within the performance specification of the meter.

6.9 Pulsating and fluctuating flow

Pulsations in the flowing fluid can affect the performance of a turbine meter. There is extensive information that indicates that high-frequency pulsations cause a meter to over-read. Most of this is related to gas turbines and pulsations at relatively high frequencies related to pumps and other rotating machinery in the flow stream. There is little information to quantify the magnitude of the effect. It is almost certainly affected by amplitude, frequency, distance and viscosity. The flowmeter should be installed as far from sources of pulsation as possible and the potential for over-reading assessed.

There is another source of pulsation that is more accurately described as fluctuating flow. This can be caused by inadequate stability of flow control valves or a process fluctuation.

Turbine meters that experience low frequency symmetrical fluctuations in flowrate are found to accurately follow changes in flowrate at frequencies of 0,025 Hz (period 40 s), and flowrate changes with amplitudes of up to 66 % of the mean flow. These measurements apply to flow fluctuations that are symmetrical around a mean value as reported in Reference.[23] It is probable that asymmetric fluctuations also do not provide a significant error, as long as the frequency remains within the frequency range investigated. The effect observed applies only to the behaviour of the meters and bias effects can be introduced by subsequent pulse counting and calculation processes.

7 System design

7.1 Design considerations

The installation should be capable of handling the complete range of flowrates (minimum to maximum), the maximum working pressure over the specified temperature range, and the liquid (or range of different liquids) to be measured. Protective devices should be installed where necessary to ensure the meter operates within design limits. Where large flow ranges are required, meters should be installed in parallel. The installation should provide facilities for the proving of each meter (see 10.4). Where reliability is important, the meter system design often includes a spare or standby meter run.

The installation should be designed to ensure maximum and reliable operating life. Filters, strainers, vapour/air eliminators or other devices should be provided upstream of the meter so that any debris or vapours which are present do not affect volumetric measurement uncertainty. The system operating pressure should be adequate to ensure that the liquid being metered is in the liquid state at all times.

If the installation operates with flow in both directions, ancillary equipment, such as filters, need to be installed at both ends of the metering section. All materials of construction in contact with the liquid(s) should neither be affected by, nor affect, the metered liquid(s).

Factors that should be included in the design are listed in Table 1. These parameters are not in order of importance and are for general guidance only.

Table 1 — Factors affecting the selection of turbine meter type

	Category	Items for consideration
1	Performance considerations	Desired level of overall performance Desired level of linearity Desired level of repeatability/reproducibility Range of operating flowrates Maximum pressure drop allowed Response time Output characteristics
2	Installation considerations	Pipework orientation Line size Provision of ancillaries Presence of pulsation/vibration Location access for servicing Electrical power and connection requirements
3	Liquid property considerations	Pressure range Temperature and viscosity range Lubricity Compressibility effects Liquid abrasiveness Corrosive nature Presence of other phases
4	Environmental considerations	Ambient temperature effects Effect of humidity Electrical interference Presence of hazardous atmospheres External corrosive effects

7.2 Selection of turbine meter

The type of turbine meter selected should meet the specified accuracy limits over the range of flows and liquid property changes. The potential effect on the measurement from each of the conditions listed in Table 1 should be examined. Any, or all, of these can influence the performance of the meter system. In addition, the meter manufacturer's advice should be sought to ensure the correct selection of metering element design, bearing material, pulse generating and collection system, flange rating, etc. In addition, the following factors should be addressed:

a) operating flowrate, uni-directional or bi-directional, continuous, intermittent or fluctuating;

b) fidelity and security of pulse data transmission systems (see ISO 6551);

c) existing space and method by which a bank of meters can be put online, or taken offline;

d) the method used to prove that meter *in situ* or by removal;

e) types of readout, computer or print devices to be used;

f) the signal amplification and conditioning system;

g) the use of automatic temperature compensation equipment and linearization.

The turbine meter should generate sufficient pulse resolution that overall metering uncertainty is not impaired. This can be achieved through having a rotor with a fixed number of blades, and with multiple pick-ups, a rimmed rotor with the appropriate number of slots or studs, or the application of pulse interpolation techniques (see ISO 7278-3). Two of these options are shown in Figure 1.

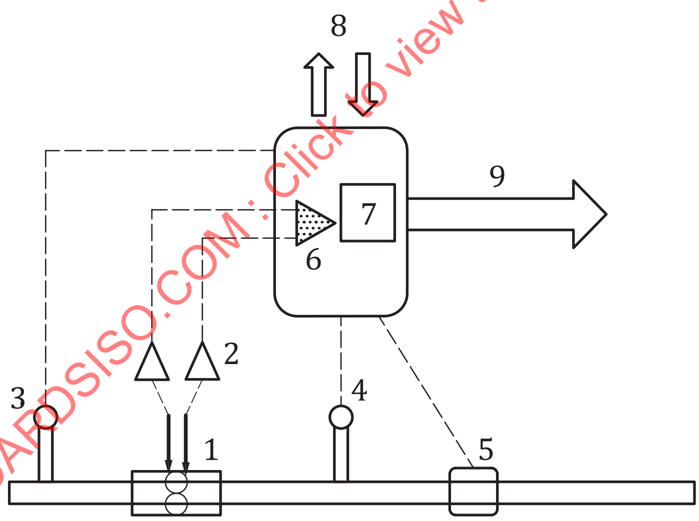
Experience has shown that certain types of meter are selected based on the liquid type. For example, in low viscosity service, and in smaller sizes, the straight-bladed meter design is usually selected. Where the viscosity is high, a helical-bladed design is generally specified. Rimmed rotors are generally only available for larger diameter meters.

7.3 Ancillary equipment

7.3.1 General

There is a large selection of ancillary equipment which can be used with turbine meters. Some of these are shown in Figure 7. Computers and controllers enable on-site monitoring, on-line computation to the required standard conditions and system control, thereby removing most human error and allowing online compensation to be performed effectively and economically. Secondary equipment should also be examined and fully specified to prevent difficulties arising from environmental, layout and electrical incompatibility effects.

Environmental considerations include electrical safety, weather-proofing, corrosion protection and changes in ambient temperature. Layout considerations include stand-by power supplies, alternative or back-up devices, and access for maintenance. Electrical compatibility includes all devices and cabling associated with the turbine meter, particularly the input/output characteristics of all elements in the data transmission/reading system.



Key

1 two sensors on flowmeter
2 amplifiers
3 pressure sensor
4 temperature sensor
5 densitometer
6 pulse comparator circuit
7 flow computer
8 input and output to flow control valves and meter prover
9 output: flowrate, total volume, standard volume, and mass: transmission to storage, displays, printers and reporting

Figure 7 — Ancillary equipment for use with turbine meters

7.3.2 Mechanical accessories

It is unusual to have any mechanical drive or accessories fitted to a turbine. However, there are some low-performance turbine meters with external drive shafts that are used to drive mechanical counters and registers. The torque needed to drive a shaft via a gear and sealing gland places an unacceptable drag on the rotor for most accurate measurement purposes.

7.3.3 Secondary electronic instrumentation

The choice of secondary electronic equipment is very wide. Pre-amplifiers are usually used to amplify and create a clean square pulse from the raw pick-up signal. The pulses are then the input to simple pulse frequency, totalizing counters, or scalable counters, which display the output in terms of flowrate from the known K-factor. The flow computers, or “intelligent head amplifiers”, also allow linearization by interpolating the K-factor from the given calibration data at different flowrates and, hence, calculating the volume at any flowrate within the range. Flow computers can also compensate/correct the flow data, control several streams, and sometimes, also control the flow stream valves and an on-line prover associated with the installation.

7.4 Flow algorithms

Considerable measurement discrepancies can be introduced into the measurement for trade of hydrocarbons, unless the volume metered is converted to a standard volume at defined (standard) temperature and pressure. Alternatively, the volume can be used to calculate mass using the liquid density. It is recommended that the appropriate conversions be made to minimize this error whenever the liquid volume changes significantly with temperature and pressure, and that the standard volume is clearly defined on any meter documentation. Changes in product volume are sometimes corrected to an accepted standard temperature with automatic temperature compensations. Temperature correction factors, C_{tlm}, are calculated to provide volume correction. A variation in liquid pressure also results in a change in the liquid volume due to compressibility. Compressibility factors can be applied to correct for pressure. Standard conditions and correction factors for hydrocarbons are available from ISO 91 and ISO 9770. The standard volume through a meter can be determined using Formula (5):

$$V_{\text{ref}} = V_{\text{m}} \times MF \times C_{\text{tlm}} \times C_{\text{plm}} \times C_{\text{tsm}} \times C_{\text{psm}} \quad (5)$$

where

V_{ref} is the volume at standard conditions;

V_{m} is the meter registration during a proving or measurement time interval;

MF is the meter factor at line reference conditions, or that obtained from calculation;

C_{tlm} is the correction factor for the liquid temperature;

C_{plm} is the correction factor for pressure on the liquid;

C_{tsm} is the correction factor for the temperature effect on the meter body;

C_{psm} is the correction factor for liquid pressure effect on the meter body.

Corrections for the effect of temperature and pressure on the meter body, C_{tsm} and C_{psm}, although used in some countries, are no longer recommended. These two additional terms are only used when meters are not re-proved when significant changes in temperature and pressure occur between the provings. Local operating practice should be followed to determine which constants are acceptable.

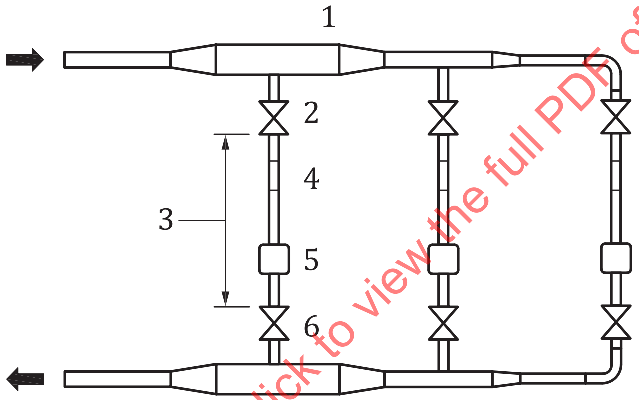
Common methods for calculation and rounding of the calculations should be applied where required. Further guidance is given ISO 4267-2.

8 Installation aspects

8.1 General

Turbine meters are normally installed in horizontal pipe runs so that they are full of liquid at all times. The meter(s) should be installed in such a manner that it (they) will not be subjected to undue stress or strain. In most metering stations, the design of the pipework can be influenced by the requirement to provide adequate upstream flow conditioning, and the need to ensure flow is evenly distributed among the meters.

Where multiple meter runs are employed, correct header design is essential to ensure an even flow distribution (to avoid excess flowrates through individual meters) with the minimum inducement of swirl. Figure 8 shows a recommended layout where the requirement for flow control is minimized. Each meter run has a similar path length and the inlet and outlet headers are hydraulically balanced. Installations with zero velocity zones at the end of the inlet or outlet headers should be avoided. Pressure and temperature are normally measured on each meter run. However, if they are measured at the header, locations should be chosen to ensure that the measurements reflect the conditions at the meter(s).



Key

1 hydraulically balanced header (diameter reducing to maintain constant velocity)

2 meter run inlet isolating valve

3 straight pipe lengths before straightener, upstream and downstream of the meter

4 flow straightener

5 flow meter

6 downstream valve(s) — double block and bleed and flow balancing valves

Figure 8 — Hydraulically balanced inlet header

8.2 Installation pipework

8.2.1 Effect of bends

Single bends of all kinds produce asymmetric distortions of the profile. Generally, the sharper the bend, the worse the effect, with major profile distortion being produced by mitre bends. As the radius of the bend increases, the distortion is reduced. It is recommended that large-radius swept bends are used wherever possible.

Two or more close coupled bends in different planes can generate severe swirl within the liquid. This can persist for long distances (more than 100 pipe diameters has been reported) and is difficult to correct. Even flow straighteners are not totally successful in removing this influence. The effect on K-factor can be minimized by moving the bends further apart from each other. The magnitude of the error can be positive or negative, depending on the direction of the swirl relative to the blades.

8.2.2 Effect of valves

The effect of valves is variable and depends on the valve type and the degree of opening. Partly closed valves cause asymmetry in the profile and can cause swirl.

8.2.3 Reducers and expanders

Reducers and expanders produce profile distortion. The conical reducer has the effect of flattening the profile, whereas the expander can cause reverse flow close to the walls due to possible separation of the boundary layer. The former effect causes the meter to read high, whereas the latter usually appears as a drop in K-factor from the reference calibration conditions. Where an eccentric reducer or expander is used, asymmetric profile distortion results and a bias is introduced into the K-factor, depending on the amount of distortion present. Where reducers are located close to and downstream of bends or valves, the reducer acts as an amplifier and can increase the severity (circumferential velocity) of the swirl. This causes measurement error depending on the direction of the swirl relative to the blades.

Many installations incorporate reducers to allow smaller turbine meters to be mounted in existing pipework. In such situations, the reducer should be installed well upstream of the meter, 10 to 20 pipe diameters being recommended.

Where reduced line sizes are introduced by a metering leg, the product velocity should be recalculated to ensure that it is below the safety threshold for the generation and accumulation of static electricity, and/or that there is sufficient relaxation time downstream of the reduced diameter line section. If necessary, expert advice should be sought.

8.2.4 Step in the pipe

Axisymmetric disturbances can also be caused by mismatch in the bore of the pipe or the protrusion of a gasket just upstream of the meter inlet. This results in a change in the meter factor.

8.2.5 Minimizing installation effects

It is generally accepted that the effects of the various fittings described in 8.2.2 to 8.2.4 can be minimized if a flow conditioner is used upstream of the turbine meter. Such a conditioner comprises a straight pipe section with the tube bundle or conditioning plate at least three to five pipe diameters upstream of the meter inlet. Experimental work indicates that some fittings, in the absence of a flow conditioner, can still produce an effect on the meter even when located at a distance of 20 pipe diameters upstream. Even so, a minimum upstream length of 20 pipe diameters is generally recommended, unless other piping systems are locally approved for custody transfer metering.

Generally, if fittings are moved at least five pipe diameters from each other, the interaction effect is small. If fittings are located directly next to each other in any combination, then laboratory data obtained without flow conditioners show that errors of ±2 % or more can be introduced. There is no clear pattern to the published installation effect data, and the only reliable way to allow for these effects is to prove the meter *in situ* against a reliable standard, such as a master meter or meter prover. Alternatively, a flow conditioning device can be used to minimize the effect of upstream disturbances in the meter. However, in extreme cases, these installation effects can also cause poor repeatability, preventing acceptable proving. In these rare cases, the pipework needs to be redesigned.

8.3 Valves

The flow can be controlled by a valve installed downstream of each meter (fitting a control valve upstream would reduce the line pressure at the meter giving potential for flashing, cavitation, or even a part filled pipe). Control valves allow the required flow to be controlled and flow balanced between streams. The sizing of control valves should take into account the range of expected flowrates, including any seasonal or liquid-property effects. Inlet isolation valves should be fitted in each meter run.

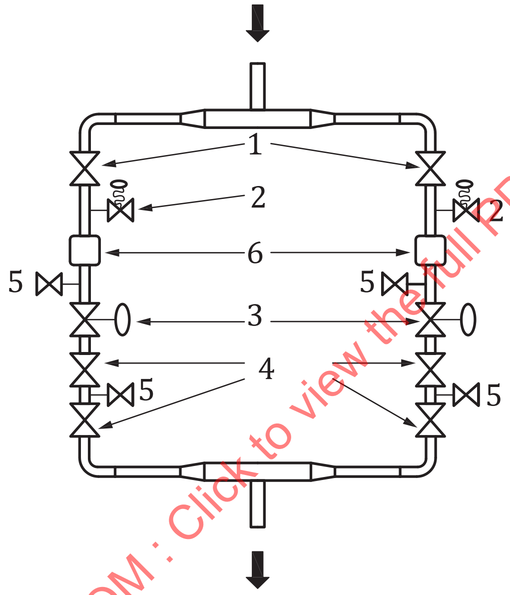
Where meters are to be proved *in situ*, it is recommended that each meter run be fitted with flow control since the addition of the meter prover into the system changes the resistance, and hence, affects flowrate. Individual valves allow the flows to be adjusted to compensate for this effect.

Control valves cannot be relied on to provide a leak-tight seal. Where meters are removed for servicing, or where a stream has to be shown not to pass liquid when not in service, an additional downstream valve, possibly a double block and bleed valve, should be installed downstream of the control valve. An upstream isolator valve might be required to allow removal of a meter for maintenance. This is usually a requirement for fiscal and custody-transfer meter installations.

Installation of valves in a parallel meter installation is shown in Figure 9.

When operating, any valve on the inlet to the meter run should be fully open.

When a run is closed down and isolated, both inlet and outlet valves should be fully closed, and the pressure in the run reduced so that any leakage can be detected through a line pressure rise.



Key

1 inlet isolating valve; full-bore ball valve

2 pressure relief bleed valve

3 flow control/balancing valve

4 double block isolating valves

5 air vent/bleed and drain valves

6 flowmeters

Figure 9 — Parallel meter runs and valves

Vent valves should be fitted to remove air/gas prior to filling the pipe and starting the flow. Drain valves should allow the meter run to be emptied for maintenance. Where a meter run is isolated, a pressure relief valve should be fitted to prevent pressure rise if the fluid warms up in the closed pipe section.

8.4 Flow pulsation

Pulsating flows should be avoided as they can cause the meter to over-read and can also cause mechanical damage. Common sources of flow pulsation are oscillating valves and regulators, reciprocating pumps or hydraulic oscillation caused by poor pipework design. Pulsation effects can be reduced through the use of pulsation dampers, or by long lengths of pipe between the pulsation source and the meter. Alternative equipment includes surge tanks, expansion chambers or pressure-limiting valves.

8.5 Electrical installation

All electrical or electronic equipment that can be installed in potentially hazardous areas should be selected and applied in accordance with the manufacturer's guidelines and existing safety standards. Installation, earthing and maintenance procedures should be strictly followed for each component in the system. Where portable electronic or electrical calibration is required, the following subjects should be addessed:

a) safe system of work, including permits;

b) power supply and earthing requirements;

c) sequence of connection and disconnection;

d) specific installation operating procedures.

8.6 Pulse security

Where appropriate, the pulse security system should be designed in accordance with ISO 6551. Care should be exercised in the data transmission system so that the signal amplitude can be maintained at the highest level whilst reducing the magnitude and influence of the noise. This can be attained by:

a) limiting the length of the transmission line between the meter and data readout or acquisition system;

b) use of the recommended cable with suitable impedance;

c) use of a pre-amplifier at the meter;

d) ensuring the correct supply voltage to the pre-amplifier and not introducing an unacceptable ripple characteristic;

e) attention to the presence of potential differences in the electrical system due to the lack of earthing or through earthing at two points.

9 Environmental considerations

9.1 General

The ambient conditions and possible variations expected around the meter should be taken into account in the design of each turbine meter system used for liquid measurement. This clause discusses some of the more important parameters.

It is usual to locate the electronics away from the meter in those cases where ambient temperature effects are severe. In cases where electronics cannot be mounted remotely, the use of temperature-controlled housings is recommended.

9.2 Electrical interference

Output signals from turbine meters fitted with pulse generators and remote electronics can be susceptible to the presence of large power sources. These power sources (e.g. cables, electric motors or switchgear) can produce surges in the cables that are detected as additional unwanted pulses from the meter.

The use of short-wave radio transmitters near the meter causes similar problems. Signal cables should be routed well away from power sources to minimize electromagnetic and radio-frequency interface (commonly called EMI or RFI) effects. Shielding is also recommended.

9.3 Humidity

High humidity can accelerate atmospheric and electrolytic corrosion and can also lower electrical insulation. Low humidity can induce static electricity. Problems with humidity can be caused by rapid ambient or process temperature changes. The user should be aware of the range of expected humidity variations and check that this does not lead to operational difficulties.

9.4 Safety

In applications within hazardous environments, meters should be selected with regard to electrical area classification, atmospheric compatibility, and other safety regulations, local or standard, which can apply. Of these, the area classification is the most important and all equipment will be expected to conform exactly to the appropriate hazardous area rating. The use of explosion-proof, intrinsically safe or other types of equipment might be appropriate.

10 Calibration

10.1 Proving and verification

The term “proving” refers to a calibration resulting in a determination of the performance indicator of a meter under test and showing (proving) that it performs to defined acceptance criteria. For turbine meters, the K-factor is usually used as the performance indicator. Proving is a term used in the petroleum industry, particularly. The procedures, measurement range and requirements for proving are usually defined in regulation, contracts, local procedures or standards. Proving is usually carried out using the operating fluid or a close substitute. It is good practice to ensure that a proving or proving method produces a result with an uncertainty defined. Verification has a similar definition, and is usually associated with meters complying with trade regulation.

Guidance regarding how to interpret the results of a calibration or proving, and examples of acceptability for fiscal/custody transfer operations, are given in Annex A.

10.2 General considerations

Proving consists of passing liquid through the meter under test and comparing the reading with a reference volume measurement, with a specified maximum uncertainty related to the final use of the meter under test. The reference should be traceable to appropriate national measurement standards. It is preferred that proving systems, calibration laboratories or service providers be accredited to ISO/IEC 17025. The resultant proving or calibration certificates for the flowmeter should include information regarding the test, traceability and the estimated uncertainty. Where repeated proving is carried, out this information should be referenced separately. The reference can be of the volumetric or gravimetric type and either open or closed to the atmosphere, depending on the application and the liquid vapour pressure.

10.3 Proving conditions

Any turbine meter should be proved, *in situ*, in a central proving facility, or in an accredited laboratory, within the range of flowrates for the duty. The properties of the liquid used in the proving should be as close as possible to that expected in normal operation over the range of temperatures, pressures and viscosities to be encountered. The orientation of the meter should be the same during the proving as during operation.

10.4 Proving methods

Proving in the laboratory can be carried out using volumetric start–stop methods, dynamic methods as described in ISO 4185, or by using master meters which have been proven against accepted reference standards. In the first of these methods, the flow is zero at the start and end of each run. The reading of the meter is simply compared with the reading from the reference to determine the error at each proving flowrate. In the dynamic method, liquid passes through the meter at the desired flowrate at all stages of the proving.

For field proving, volumetric start-stop methods, master meters or pipe provers can be used. Pipe prover devices can be the conventional sphere provers (either folded or straight pipe), or small volume (compact) provers. Small volume provers can be used to prove turbine meters, but, in a few cases, can give rise to poor repeatability. To prove correctly, the pulses generated from the meter revolutions should give an even pulse period, provided from a stable flow and even blade spacing, with little or no cyclic variations. Some designs, however, do not provide this. Several rotations of the measuring element should be completed in each proving pass.

A master meter that is used to prove a turbine meter should have its meter factor or meter K-factor determined with the liquid and operating conditions as close as possible to those normally encountered. Master meters are normally installed downstream of the meter to be proved. Volumetric tanks are not recommended for proving if the liquid has a high vapour pressure at line temperature, since this can result in a significant loss due to evaporation.

10.5 Proving frequency

There are no fixed guidelines on the frequency of either laboratory or field proving, both of which depend on the required uncertainty and acceptance of risk for the measurement. Local, company, regulatory or contractual guidelines on the frequency of proving might be in force. A risk-based approach can be employed where the additional financial exposure caused by meter drift over time is compared with the cost of calibrating or proving the meter. A judgement can then be made on the calibration frequency.

This can be combined with a meter-performance-based approach, where the history of the meter is monitored and the proving frequency can be adjusted, prolonged or reduced, based on the expectation of potential change.

In those cases where liquid density, viscosity, temperature or pressure might change rapidly and often, it can be necessary to prove for each transaction or at daily or weekly intervals, depending on the magnitude of the changes.

For a new metering installation, when *in-situ* proving is used, frequent (daily or weekly) proving can be necessary to establish meter factors for use in control charts (see 11.4). Further guidance is given in ISO 4124, which can be used to establish proving frequency.

For installations where flowrate and liquid properties are constant, proving might only need to be performed at three, six, twelve month or longer intervals, after confidence in the meter stability has been developed.

In those cases where meter maintenance has been performed, the meter should be proved over the operating range before being returned to service. The fixed proving frequency can then be progressively reduced depending on the experience of the installation.

Monitoring of a process mass balance or comparison with other measurement points in the process can also be used as an indication that a meter might have changed performance, indicating that additional proving is required.

11 Operation and maintenance

11.1 General

This clause covers recommended operating and maintenance practices for turbine meter installations. All operating data pertaining to both measurement and proving should be accessible to interested parties.

11.2 Initial start-up

When placing a new meter in service, means should be provided to protect the meter from damage and malfunction arising from over-speeding or the influence of foreign matter such as thread cuttings, pipe debris, weld spatter or similar material arising from the construction. Means of accomplishing mechanical protection are the use of a temporary by-pass, temporary spool pieces, or the installation of a protective device upstream to collect the debris.

Over-speeding can damage either the bearing, or the measuring element, unless care is exercised during start-up. The line should be filled slowly by allowing line pressure to rise slowly with the downstream valve being closed. Any gas that is present should be vented. Once the pressure is stable and gas is removed, the downstream valve can be opened slowly to allow flow to start.

11.3 Meter maintenance

Meters should be maintained in accordance with the manufacturer's instructions. A full maintenance policy should be established in conjunction with all interested parties, where the key components can be identified. Normally, turbine meters can be expected to perform well for long periods if operated within agreed limits. Indiscriminate adjustment or disassembly is neither necessary nor recommended.

Because of the many different designs, the variety of ancillary equipment and the range of liquid properties that can be metered, it is difficult (and often inadvisable) to establish a maintenance schedule for all installations. It is best to determine when to inspect or repair the meter from control chart data for each liquid and for each meter in the system. If the change in meter factor (or meter K-factor) exceeds three times the standard deviation on the control chart (see 11.4), the reasons should be investigated.

NOTE The suggested "trigger" value of three times the standard deviation (3σ) is a practical balance between triggering an investigation based on an insignificant change and a value where a real problem is being observed. Further guidance can be found in ISO 4124.

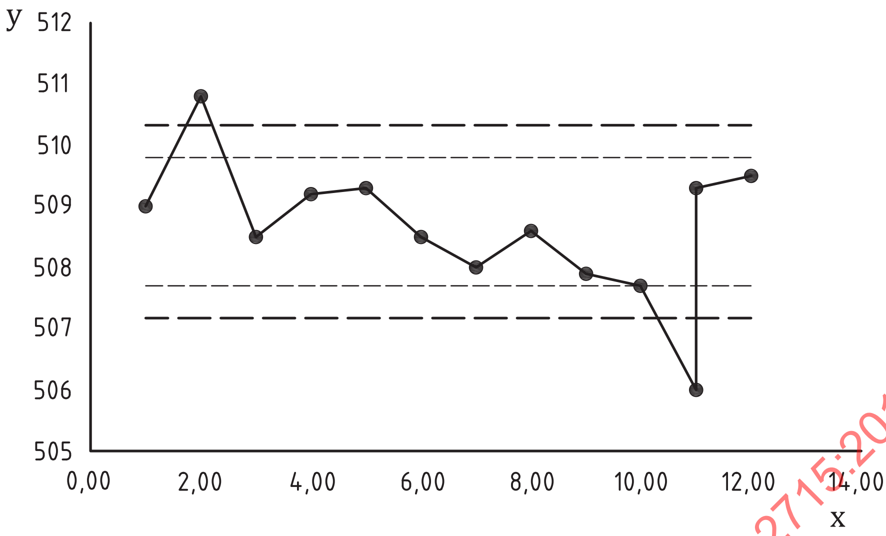
Correct performance of ancillary equipment should only be checked and maintained by personnel with suitable training in the particular item of equipment.

To ensure the metering system retains its design performance, regular inspections should be carried out in accordance with agreed procedures at regular intervals. *In-situ* provings are regarded as part of the inspection procedures. In those installations where off-site proving is used, the frequency of inspections depends on the demonstrated long-term repeatability of the meters and any significant change in operating parameter or conditions that have occurred since the last proving.

11.4 System diagnostics and control charts

A meter control chart is an adaptation of the statistical method described in ISO 4124. These charts are plots of meter factor or meter K-factor obtained at the same operating conditions against time and flowrate. An example is shown in Figure 10.

The charts can be used as a warning signal for problem diagnostics by showing deviations from the predetermined limits. They can be used to determine whether problems are present, but not the nature of the fault. When faults are diagnosed from the chart, a systematic check of the complete system is strongly recommended. The primary fault causes are changes in product composition, temperature, fouling of the meter, meter-bearing failure, and physical damage to the rotor assembly or other internal components of the meter. Debris left in new installations, or liquid-borne solid particles, are particularly significant. After these influences have been eliminated and no defects are noted, the following items should be checked: all valves, ancillary equipment (such as strainers or separators), counters, pre-amplifiers, cabling, prover spheres, sphere detectors and temperature-measuring, pressure-measuring, or density-measuring equipment.



Key

x month

y K-factor

Figure 10 — Example of control charts for fault diagnosis

In Figure 10, the first two points show the system "settling down". Subsequently, there is a downward trend, perhaps, indicating wear. In month 11, there is a significant drop in K-factor, suggesting a fault. The meter was repaired/adjusted and the K-factor returned to the early value. The dashed lines indicate the chosen "trigger" levels where an action is required. The inside lines are twice the standard deviation (2σ) of the results around the mean taken in month 10. This would be a warning and, perhaps, lead to resetting of the K-factor in use. The outer two lines are three times the standard deviation (3σ) around the mean showing there was a fault and action is required.

Annex A
(informative)

Specification of performance

A.1 General

The performance specification, or expectation, is normally defined by regulation, contract agreements, or the user for a particular application. A manufacturer can also provide a specification to detail the expected performance of the product.

To be accepted for trade, a meter has to be approved by the national trading standards authority. This is usually through a "type approval" followed by a system verification. Type approval of the meter type, pattern, or model is granted through testing by the national authority, or by acceptance of an approval granted by another authority. The specification for the testing usually follows the international guidance given in the appropriate OIML recommendation (e.g. R117[14] covering type approval and verification and a wide range of characteristics of the meter from design and labelling to mechanical and EMC performance including the flow metering performance).

For fiscal or custody transfer applications, particularly for hydrocarbon transactions, the regulator or appropriate contract agreements specify the expected performance. Both initial (factory acceptance testing) and subsequent verification (site acceptance testing) are generally required, followed by ongoing verification at defined intervals. The specification might or might not require a trade-approved meter to be used.

It is important that for any application, the verification or approval covers the conditions of temperature, pressure and viscosity for the duty.

While the document covers many aspects of the meter performance, there are only a few aspects which relate to flow measurement, and these are summarized within this annex. The normal performance expectations specified for most trade, fiscal and custody transfer meters in the hydrocarbon industry are illustrated as a guide to expectations.

A.2 Performance criteria

A.2.1 Measurement range (flowrate)

The meter should have a specified measurement range of flowrates across which it remains within the specified linearity. This can vary with viscosity or a specified linearity. It would be expected that a meter would have a measurement range (ratio of maximum to minimum flowrate) of not less than 5:1. However, 10:1 would be the norm for lower viscosity hydrocarbons.

A.2.2 Linearity

A.2.2.1 General

Linearity is a measure of the deviation of the meter characteristic, or performance indicator, from a defined functional relationship. 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 in practice is usually a constant value (linear relationship with slope = 0).