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Second edition

Petroleum measurement systems — Metering of viscous and high temperature liquids

Systèmes de mesurage des produits pétroliers — Comptage des liquides visqueux et à haute température

PROOF/ÉPREUVE

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Contents

Page

Foreword

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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 document 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).

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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*.

This second edition cancels and replaces the first edition (ISO 9200:1993), which has been technically revised.

The main changes are as follows:

— mass and volumetric metering is now covered;

— a description and definition of viscosity has been added along with a clarification of high viscosity and high temperature;

— the emphasis on positive displacement meters has been replaced by descriptions of other meter types including ultrasonic, Coriolis and differential pressure devices.

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

This document is intended to guide users in the design, installation, operation, and proving of flowmeters, and their auxiliary equipment, used in the dynamic metering of viscous liquids. It also provides guidance when elevated operating temperatures are used to reduce viscosity. The document applies to Newtonian, hydrocarbon and petroleum liquids. Extra consideration should be given when using other liquids and non-Newtonian liquids.

The objective of this document is to highlight the considerations to be taken into account when metering high viscosity liquids at normal and elevated temperatures, in addition to the normal application of metering less viscous liquids at ambient temperatures.

As the viscosity of a liquid increases, the resistance to flow increases. In a fluid transfer system, this generally means that the maximum flowrate achievable for any given conduit size is reduced to avoid excessive pressure loss. This generally results in lower velocities within the measurement system than would be found in lower viscosity applications. As most flow sensors and meters require a minimum velocity to provide reasonable resolution of measurement, the operational range of the flowmeter chosen can be reduced.

Each flowmeter type and design has different limitations on the viscosity and flow range across which it operates at an acceptable accuracy. For higher viscosities and low velocities, it is probable that for many applications the flow regime is laminar rather than turbulent which again affects the performance of flowmeters.

To provide efficient transport of the fluid within a pipe, viscous liquids are often heated to reduce the viscosity. Measuring systems and the associated flowmeters are therefore selected and operated to suit the chosen operating temperature, taking into account changes in temperature and viscosity from ambient conditions.

The behaviour of the fluid should be considered carefully to recognize the potential for the liquid to solidify during idle periods and also to manage the potential for air, gas, solids, and wax content from damaging or affecting the metering system.

This document supplements the guidance documents applicable to different flowmeter designs and proving methods in the relevant ISO standards referenced in the bibliography.

Petroleum measurement systems — Metering of viscous and high temperature liquids

1 Scope

This document gives guidance for measuring a quantity of primarily viscous hydrocarbon liquid using flowmeters at ambient or elevated operating temperatures.

This document describes the effects of high viscosities and potentially high temperatures, which can induce additional errors in measurement. It also gives guidance on how to overcome or mitigate difficulties.

2 Normative references

There are no normative references in this document.

3 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
density
mass in a given volume

3.2
performance indicator
derived value which relates the meter output to the quantity measured and can be used to indicate the performance of the meter

EXAMPLE Error, meter factor, K-factor, and discharge coefficient.

3.3
pipe prover
displacement prover
device where the volume of a fluid is displaced from the calibrated length of a pipe and used to provide a calibration reference for flowmeters

3.4
pour point
lowest temperature at which a liquid product loses its flow characteristics and, under specified conditions, ceases to flow

Note 1 to entry: The temperature at which a liquid ceases to flow is based on a standard test.

3.5
Reynolds number
dimensionless number expressing the ratio between the inertia forces and viscous forces within a flowing fluid

Note 1 to entry: The Reynolds number can provide an indication of the flow profile within a pipe. Generally, numbers below 2 000 indicate a laminar flow, while a number higher than 5 000 indicates a turbulent flow.

Note 2 to entry: The Reynolds number and performance indicator for some flowmeters provides a single relationship which accounts for variations in viscosity as well as flowrate.

3.6
viscosity
measure of resistance to flow

3.7
dynamic viscosity
viscosity dynamic
viscosity absolute
ratio of shear stress to shear rate within the fluid, hence the force needed to overcome internal friction

Note 1 to entry: The unit of absolute viscosity is Pascal second (Pa s). The unit of centipoise (cP) is commonly used in practice. 1cP = (1×10^{-3} Pa s).

3.8
kinematic viscosity
viscosity kinematic
ratio of *dynamic viscosity* (3.7) to *density* (3.1)

Note 1 to entry: The unit of kinematic viscosity is metre square per second ($m^2\ s^{-1}$). The unit centistoke (cSt) is commonly used in practice. 1cSt = ($10^{-6}\ m^2\ s^{-1}$) = ($1\ mm^2\ s^{-1}$). The unit $mm^2\ s^{-1}$ is used throughout this document when giving examples of fluid viscosity.

3.9
performance indicator
derived value which may be used to indicate the performance of the meter

EXAMPLE Error, K-factor, meter factor or discharge coefficient.

3.10
volumetric measure
measure used to provide an accurate measurement of volume to provide a reference for other volume measuring devices

3.11
wax point
cloud point
wax precipitation point
temperature at which wax precipitates from a hydrocarbon liquid

4 Properties of high viscosity liquids

4.1 Viscosity

In this document a viscous liquid is any liquid that requires special treatment or equipment in its handling or storage because of its resistance to flow at either ambient or operating temperature. The liquid is assumed to be Newtonian. If the fluid is non-Newtonian, additional influences on metering should be considered.

Viscosity is typically expressed as being either dynamic or kinematic.

Dynamic viscosity (μ) and kinematic viscosity (υ) are related through density (ρ) by Formula (1).

$$\mu = v\rho \tag{1}$$

where

μ is the dynamic viscosity, expressed in Pascal seconds (Pa s);

ρ is the density, expressed in kilograms per cubic metre (kg m^{-3});

v is the kinematic viscosity, expressed in metre square per second (m^2 s^{-1}).

When applying this conversion, or any other use of a viscosity relationship, consistent and matching units should be used. Using the relevant SI unit as given in Formula (1) helps to avoid error.

4.2 Reynolds number and flow profile

The Reynolds number provides a scale to represent the turbulence within a flowing fluid, hence providing a guide to the velocity profile within a pipe. The Reynolds number is calculated from Formula (2).

$$Re = \frac{VD\rho}{\mu} = \frac{VD}{\upsilon} \tag{2}$$

where

D is the pipe internal diameter, expressed in metres (m);

V is the mean pipe velocity, expressed in m^2 s^{-1};

ρ is the density, expressed in kg m^{-3};

μ is the dynamic viscosity, expressed in Pa s;

v is the kinematic viscosity, expressed in m^2 s^{-1}.

When calculating the Reynolds number, it is important to ensure the units used are consistent. Using the relevant SI unit as given in Formula (2) helps to avoid error.

Generally, laminar flow is present at Reynolds numbers below 2 000 and turbulent flow at Reynolds numbers above 5 000. Between 2 000 and 5 000, a transitional condition is found where either laminar or turbulent or a changing flow condition exists. Within the transitional range, the condition can switch between regimes. These values are indicative and the Reynolds numbers at which the transition between laminar and turbulent flow occurs is variable and depends on of a variety of factors. These include, but are not limited to, pipe configuration, pipe roughness, temperature, orientation and vibration. Typically, turbulent conditions cannot easily exist below Reynolds number of 2 000, but the transition from laminar to turbulent can easily extend to Reynolds numbers approaching 10 000 and sometimes above.

Increasing viscosity results in a lower Reynolds number for a given velocity. Although most industrial flows of liquids are at a velocity leading to a Reynolds number above 5 000, with higher viscosity liquids a low velocity is often chosen to reduce the pressure losses. Many applications can therefore operate at Reynolds numbers within the transition or laminar region.

Laminar flow results in a parabolic or peaked velocity profile across the pipe, with the highest velocity being at the centre and reducing either side towards the wall. Turbulent flow results in a profile which is essentially flat, or equal, across most of the pipe diameter, and then reduces rapidly to the pipe wall. The flow profile can also be changed due to the viscosity reducing additives or contaminants within the fluid or on the pipe wall. The flow regime and velocity profile have a significant effect on various types of flowmeters.

A stable, predictable and fully developed flow profile (turbulent or laminar) is disturbed by bends and changes in diameter and devices (valves, filters etc.) in the pipe resulting in a swirling or asymmetric flow profile. It takes time and distance to return to a fully developed profile. While a turbulent flow profile can be mostly re-established after a distance of approximately 20 to 30 pipe diameters, a laminar flow profile takes significantly longer to re-establish and in some applications, can take a distance of up to 100 pipe diameters. In laminar flow regimes, temperature difference across a pipe due to sun or wind can modify the profile.

Many flowmeters are designed to perform most effectively with a relatively high flow velocity, resulting in a turbulent flow regime and flat velocity profile. These flowmeters are also significantly affected by a distorted flow profile. Consideration should be given when such flowmeters are used in conditions where there is a laminar flow profile.

When characterizing a meter’s performance over its operating range, the Reynolds number can provide an alternative to volumetric flowrate. In some cases, the Reynolds number can be more suitable than the flowrate in providing a single relationship for the performance indicator across the range of the device.

The Reynolds number is not measured directly, however there are techniques available to predict the operational Reynolds number by measuring pressure loss in a straight length of pipe upstream of the flowmeter.

4.3 Density

Density is related to viscosity insofar as high-density hydrocarbon liquids typically also have high viscosity. This is not a linear relationship and can differ between different liquids.

Density should not be used to predict viscosity except when used as a very rough guide.

4.4 Effect of temperature on viscosity

The density of a hydrocarbon liquid varies with temperature in an approximately linear relationship, reducing as the temperature increases. The density and hence volumetric expansion of many hydrocarbon liquids has been defined and the relationship standardized for measurement purposes.

The viscosity of a hydrocarbon liquid also varies with temperature but follows an exponential relationship with viscosity, reducing as the temperature increases. As temperature decreases, the change in viscosity becomes increasingly significant at the lower temperatures.

Viscosity is not required to define the quantity of fluid being measured. It does however, play a significant role in the performance of flowmeters. To specify the viscosity of a liquid, it is common practice to state the dynamic or kinematic viscosity at one specific temperature. It is noted that this temperature is not usually the standard temperature chosen to calculate standard volume. Typically, 20 °C is used to specify viscosity for lower viscosity fluids. For higher viscosity fluids, significantly higher temperatures are used, such as 30 °C, 40 °C or 60 °C, to ensure they are fully liquid when characterized.

There are no common standard formulae relating viscosity to temperature for hydrocarbon liquids. A number of formulae exist, most of which relate kinematic viscosity to temperature. The commonly used formulae all take a similar form and the most common is given in Formula (3).

$$\log\log(\upsilon + A) \cong \log(T) \tag{3}$$

where

log	is logarithm to base 10;
υ	is kinematic viscosity, expressed in $mm^2\ s^{-1}$;
A	is a constant derived from the viscosity measured at two temperatures;
T	is temperature, expressed in degrees Celsius (°C).

NOTE The constant, A, can be derived from measurements using different units from those shown above. In this case, it is expected that units used are carefully recorded and that consistency is ensured when using the formula.