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Liquid hydrocarbons — Dynamic measurement — Proving systems for volumetric meters —

Part 4:
Guide for operators of pipe provers

Hydrocarbures liquides — Mesurage dynamique — Systèmes d'étalonnage des compteurs volumétriques —

Partie 4: Manuel de référence pour les opérateurs de tubes étalons

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Contents

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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.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 7278-4 was prepared by Technical Committee ISO/TC 28, *Petroleum products and lubricants*, Subcommittee SC 2, *Dynamic petroleum measurement*.

ISO 7278 consists of the following parts, under the general title *Liquid hydrocarbons — Dynamic measurement — Proving systems for volumetric meters:*

— *Part 1: General principles*

— *Part 2: Pipe provers*

— *Part 3: Pulse interpolation techniques*

— *Part 4: Guide for operators of pipe provers*

— *Part 5: Small volume provers*

Annex A of this part of ISO 7278 is for information only.

Introduction

All measuring instruments which have to meet a standard of accuracy need periodic calibration – that is to say, a test or series of tests has to be performed in which readings obtained from the instrument are compared with independent measurements of higher accuracy. Petroleum meters are no exception. Nearly all those used for the purpose of selling or assessing taxes, by national laws, need proving at intervals, and when there is a large amount of money at stake they are likely to be calibrated quite frequently. In the petroleum industry the term 'proving' is used to describe the procedure of calibrating volume meters on crude oil and petroleum products.

The most usual way to prove a meter is to pass a quantity of liquid through it into an accurate device for measuring volume, known as a prover. With very small meters the proving device may be a volumetric flask or similarly shaped vessel of metal with an accurately known volume. There are, for instance, standard measuring vessels which can be used to prove the meters incorporated in gasoline dispensing pumps at roadside filling stations. If the pump dial registers 10,2 litres when enough gasoline has been delivered to fill a 10 litre vessel, it is evident that the meter is over-reading by 2 %.

In a large metering installation, where a single meter can be passing thousands of litres per second, the situation is much more complicated. The measuring elements of the meters generally do not drive mechanical dials graduated in units of volume like a gasoline dispenser, but instead cause a series of electrical pulses to be generated which are registered by electrical counters. With meters of this type the purpose of proving is to determine the relationship between the number of pulses generated/counted and the volume passed through the meter – a relationship which varies with the design and size of the meter and can be affected by flowrate and liquid properties.

Another difficulty is that where the meters are in a pipeline the flow through these large meters usually cannot be stopped and started at will. Consequently, both the meters and the prover have to be capable of being read simultaneously and 'on the fly', that is, while liquid is passing through them at a full flowrate. The proving is complicated still further by the effects of thermal expansion and compressibility on the oil, and that of thermal expansion and elastic distortion under pressure on the steel body of the prover.

This part of ISO 7278 is concerned with only one class of provers, known as pipe provers, which are used very widely where meters for crude oil and petroleum products have to be proved to the highest possible standards of accuracy. In principle, a pipe prover is only a length of pipe or a cylinder whose internal volume has been measured very accurately and having a well-fitted piston (or a tightly-fitted sphere acting like a piston) inside it, so that the volume swept out by the piston or sphere can be compared with the meter readout while a steady flow of liquid is passing through the meter and prover in series. In practice, however, various accessories must be added to the simple pipe-and-piston arrangement to produce a prover that will work effectively.

Liquid hydrocarbons — Dynamic measurement — Proving systems for volumetric meters —

Part 4:
Guide for operators of pipe provers

1 Scope

This part of ISO 7278 provides guidance on operating pipe provers to prove turbine meters and displacement meters. It applies both to the types of pipe prover specified in ISO 7278-2, which are referred to here as “conventional pipe provers”, and to other types referred to here as “compact pipe provers” or “small volume provers”.

It is intended for use as a reference manual for the operation of pipe provers, and also for use in staff training. It does not cover the detailed differences between provers of broadly similar types made by different manufacturers.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 7278. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 7278 are encouraged to investigate the possibility of applying the most recent editions of the International Standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 2714:1980, *Liquid hydrocarbons — Volumetric measurement by displacement meter systems other than dispensing pumps*.

ISO 2715:1981, *Liquid hydrocarbons — Volumetric measurement by turbine meter systems.*

ISO 4124:1994, *Liquid hydrocarbons — Dynamic measurement — Statistical control of volumetric metering systems.*

ISO 4267-2:1988, *Petroleum and liquid petroleum products — Calculation of oil quantities — Part 2: Dynamic measurement.*

ISO 7278-2:1988, *Liquid hydrocarbons — Dynamic measurement — Proving systems for volumetric meters — Part 2: Pipe provers.*

ISO 7278-3:1998, *Liquid hydrocarbons — Dynamic measurement — Proving systems for volumetric meters — Part 3: Pulse interpolation techniques.*

3 Principles

3.1 Ways of expressing a meter’s performance

The object of proving meters with a pipe prover is to provide a number with (usually) four or five significant digits – such as 1,002 9, 0,999 8, or 21 586 which can afterwards be used to convert the readout of the meter into an accurate value of the volume passed through the meter.

There are several different forms that this numerical expression of a meter's performance can take, but only three of them are of importance to the pipe prover operator. They are discussed below.

3.1.1 Meter factor

The earliest petroleum meters were of the displacement type (see 4.1) with dials reading directly in units of volume such as litres or cubic metres. Readings on the display are usually approximate values. These values may be corrected to reflect a more accurate number by either changing the gear ratio in the display mechanism or through the use of a meter factor. Since difficulty can arise in attempting to achieve a given volume through changing the gears, the meter factor is more commonly used.

The meter factor, MF, is defined as the ratio of the actual volume of liquid passed through the meter (V) to the volume indicated on the dial of the meter (V_m). That is:

$$\mathrm{MF} = V / V_\mathrm{m} \tag{1}$$

In a proving operation the value of V is derived from the prover while V_m is read directly from the meter. Afterwards, when the meter is being used to measure throughput, readings can be multiplied by MF to give the corrected values of the volumes delivered.

Meter factor is a non-dimensional quantity, a pure number. This means that its value does not vary with a change in units used to measure volume.

3.1.2 K factor

During the past quarter of a century, turbine meters (see 4.1) have come into widespread use in the petroleum industry. They do not usually have a dial reading in units of volume, because their primary readout is simply a train of electrical pulses. These are collected in an electronic counter, and the number of pulses counted (n) is proportional to the volume passed by the meter.

The object of proving such a meter is to establish the relationship between n and V. One way of expressing this relationship is through a quantity called K factor, which is defined as the number of pulses emitted by the meter while one unit volume is delivered. That is:

$$K = n/V \tag{2}$$

When a meter is being proved it is necessary to obtain simultaneous values of n and V, with n coming from the meter and V from the prover. In subsequent use of the meter, the procedure is to *divide* the K factor into the number of pulses emitted by the meter in order to obtain the volume delivered.

The K factor is not a pure number. It has the dimensions of reciprocal volume ($1/V$) and so its value depends upon the units used to measure volume. A value of K factor expressed as pulses per cubic metre, for instance, is a thousand times the value expressed as pulses per litre.

3.1.3 One pulse volume

Because it is easier to multiply than to divide, the reciprocal of the K factor is a more useful quantity for field use when hand calculations are employed (but not when computers are used). This reciprocal is called the "one-pulse volume" (q) because it indicates the volume delivered by the meter (on average) while one pulse is emitted. It is defined by the equation:

$$q = 1/K = V/n \tag{3}$$

q has the dimensions of volume per pulse. When it is multiplied by the number of pulses emitted by the meter, the result is the volume delivered through the meter.

3.1.4 Alternative uses of meter factor, K factor and one pulse volume

It is shown in the previous subclauses how meter factor was originally used with displacement meters. With readout in units of volume, K factor and its reciprocal q are used with turbine meters, with the readout being a number indicated on a pulse-counter. Nowadays however, this distinction has largely disappeared. On the one hand, displacement meters intended for use with pipe provers are always fitted with electrical pulse-generators, so that for the purposes of proving they behave like turbine meters and the results can be expressed as a value of K factor or one pulse volume. On the other hand, some modern large-scale turbine metering systems incorporate a data processing module, sometimes known as a “scaler”, which converts the number of pulses emitted into a nominal value of the volume delivered; with such systems the earlier notion of meter factor again becomes useful in certain circumstances.

Detailed instructions for the use of meter factor, K factor and one pulse volume are given in ISO 4267-2.

3.2 How meter performance varies

Manufacturers’ literature often states that the K factor of a certain meter is such-and-such, as if it were a constant value. But this is only approximately correct. K factor is affected to some extent by a number of variables, some of which are considered in 3.2.1 to 3.2.6.

3.2.1 Effect of flowrate

Meters are designed so that their factors are almost constant over a fairly wide range of flowrates. The ratio between flowrates at the top and bottom of this range is called the “rangeability”, or the “turndown ratio”, of the meter. Rangeabilities of the turbine and displacement meters widely used for hydrocarbon measurement generally do not exceed ten to one although some special meters may have considerably greater rangeabilities. Within this effective working range the K factor should not vary from its mean value by more than a small amount, and the extent to which it actually does vary – such as ± 0,25 % or ± 0,5 % – is known as the “linearity” of the meter. When complete information about the meter’s performance is needed it has to be proved at several different flowrates, so that its rangeability and linearity can be established. Above and below the effective working range of a meter its K factor is liable to vary so greatly with flowrate that it is no longer practical to use the meter for accurate measurement.

3.2.2 Effect of viscosity

Meters of all types are affected to some degree by changes in the viscosity of the liquid being metered, although those of certain type and design are affected more seriously than others. When the viscosity of the liquid being metered changes it may be necessary for the meter to be re-proved. Whether it is necessary or not will depend upon:

- the amount by which the viscosity has changed;
- the extent to which the K factor of the meter concerned is affected by changes in viscosity;
- the accuracy required.

3.2.3 Effect of temperature

Temperature changes affect K factor in two ways. Thermal expansion in the meter causes dimensions and clearances to alter; and temperature changes cause the viscosity of the liquid to change, and thus produce the effect mentioned in 3.2.2. The thermal expansion effect is often negligible in turbine meters, except where large temperature changes occur. With displacement meters the thermal expansion effect is more significant because dissimilar metals are frequently used in the measuring chamber so clearances are changed.

3.2.4 Effect of pressure

Pressure affects K factor both by producing dimensional changes in the meter and by causing viscosity changes in the liquid. The effect of pressure on viscosity however, is too small to be significant in most metering applications. The dimensional effect is usually small in some designs of meters for operation at high pressures, but can be significant in some meters. Pressure changes will not often have enough effect on K factor to justify re-proving.

3.2.5 Effect of wear, damage and deposits

As a meter wears, its K factor will gradually change and so a meter used for custody transfer purposes should be re-proved at regular intervals to take account of this, even if re-proving because of changes in viscosity and temperature is not necessary. Deposits of wax and dirt can cause similar effects.

Accidental damage to a meter is likely to alter its K factor considerably. If a meter is stripped for repairs it should be proved after it has been reassembled.

3.2.6 Frequency of proving

The necessary frequency of proving varies enormously, from several times a day to once a year, or longer. Very frequent proving is often justified where the total value of the metered liquid is high – for instance, where crude oil is being metered for fiscal purposes, or in major pipeline installations – and in these circumstances, it is usual for a large pipe prover to be 'dedicated' (permanently connected and stationary) to the metering system. The meters can easily be re-proved whenever the flowrate, temperature or viscosity change enough to warrant it, or whenever a new type of crude or product is being pumped. In some circumstances there may be a specified interval of time or a specified increment of throughput, after which the meter should be proved again.

In situations where not quite such a high accuracy is required, and where viscosity and temperature do not vary too widely, it is often sufficient for meters to be re-proved at specified intervals, such as every month or two when the metering system is new, extending to once in six or perhaps twelve months when the reliability of the meter system has been established. Master meters and portable proving tanks are still frequently used for this purpose, but the use of portable pipe provers is now quite common and this part of ISO 7278 therefore covers their operation as well as that of stationary pipe provers.

3.3 Correction factors

The volume of liquid pipe prover changes with both pressure and temperature; so does the specific volume of a liquid. To allow for these changes four correction factors are employed. These may either be used by the operator in manual calculations, or programmed into the data processor associated with the prover.

3.3.1 Corrections for change in volume of prover

For every pipe prover there is an important figure known as its base prover volume, V_b. This is determined through a calibration procedure which is carried out when the prover is built and subsequently at required intervals. It represents the volume within the calibrated section of the prover at some specified pressure and temperature, usually zero gauge pressure and 15 °C or 20 °C.

However, what the prover operator needs to know each time he carries out a proving run is the volume of the prover at the actual gauge pressure and temperature during that run. The gauge pressure will almost always be above zero, and this excess pressure will cause the prover to expand slightly. The temperature may be higher or lower than the reference temperature, and so its effect will be to cause the prover either to expand or contract.

To obtain the corrected volume of the prover at the appropriate pressure and temperature, the factors C_{ps} (or CPS) [correction for pressure on steel] and C_{ts} (or CTS) [correction for temperature on steel] are used. Detailed instructions for the use of these correction factors are given in ISO 4267-2.

3.3.2 Correction changes in specific volume of liquid

The corresponding factors to compensate for the effect of pressure and temperature upon the specific volume (the reciprocal of density) of the liquid are C_{pl} (or CPL) [correction for pressure on liquid] and C_{tl} or (CTL) [correction for temperature on liquid]. Their function is to convert a volume of oil, which has been measured at the observed pressure and temperature, to what is known as the “standard volume”, which is the volume that the oil would occupy at an absolute pressure of one standard atmosphere (approximately 101 kPa) and some specified temperature such as 15 °C or 20 °C. Detailed instructions for the use of these correction factors are given in ISO 4267-2.

NOTE The correction factors referred to in 3.3.1 and 3.3.2 are functions of the type of liquid, its density, pressure, temperature and the standard pressure and temperature. A numerical value of one of these factors should never be used without checking that it is the right value for the conditions occurring at the time.

4 Meters and provers

4.1 Pulse-generating meters

Currently only two basic types of pulse-generating meter are commonly used for high-accuracy liquid metering in the petroleum industry.

One of these is the turbine meter. This consists essentially of a freely spinning propeller or “turbine” mounted on axial bearings inside a short length of pipe. When liquid flows along the pipe, the turbine rotates at a speed which is almost proportional to the flowrate and generates a series of electrical pulses. The pulses are fed into an electronic counter, from which the total volume passed through the meter is deduced. Refer to ISO 2715 for additional information.

The other meter type is the displacement meter, which was formerly known as the positive displacement or “PD” meter. Many types of these are in use and are discussed in ISO 2714. They may be thought of as devices resembling reciprocating or rotary piston pumps or perhaps gear or vane pumps which are driven by the liquid instead of by an external motor. The number of revolutions of the meter is essentially proportional to the total volume passing the meter, and this is normally displayed on a mechanical counter driven by a gear train. If an electrical pulse-generator is installed on the displacement meter, its output signal can be treated as if it were that of a turbine meter. In particular, such meters can be proved directly with a pipe prover, whereas displacement meters without an electrical output cannot.

4.2 Sources of error in operating meters

For a pulse-generating meter to give accurate results, the following three requirements shall be met:

- it shall be in good condition, both mechanically and electrically;
- conditions of the flowing fluid shall be suitable for metering and proving;
- the system shall be arranged so that the counter registers the same number of pulses as are generated by the meter – no more, no less.

The first of these is too obvious to need elaboration, but the other two involve some rather subtle difficulties which are explained in 4.2.1 and 4.2.2

4.2.1 Flow conditions

The four main problems involving the flowing liquid are entrained solids, entrained air, cavitation and swirl.

Adequate filtration should be provided upstream of the meter.

Entrained air or gas affects every type of meter but the effects are usually more severe and less predictable with turbine meters than with displacement meters. Air or gas can get into the metered liquid in several ways. When a system is being filled with liquid, the air initially present should be vented. If the venting is not properly carried out, air pockets can be left in the line which will subsequently be swept through the meter. If a pump is drawing liquid from a tank where the surface level has been allowed to fall too low, it is likely that a “bath-tub” type of vortex will form and draw air into the pump. Where there is a danger of this occurring, a device known as a “gas separator”, “air separator” or “air eliminator” is often installed upstream of the meter to remove any air or gas which would otherwise enter the meter. Likewise, air or gas may enter a system under vacuum conditions.

Air or gas bubbles can also be formed right inside the liquid by a process known as “cavitation”. This occurs whenever there are local areas of low pressure, which can cause dissolved air or gas to be drawn out of solution in the liquid. This form of cavitation always produces a great number of very small bubbles. These minute bubbles cannot be removed by a separator and so there is no cure for cavitation — it simply has to be prevented from occurring. To achieve this, the pressure downstream of the meter shall not be less than the minimum specified by the manufacturer of the meter for the fluids being metered.

Another form of cavitation can affect volatile liquids such as crude oil, natural gas liquids, gasoline, liquefied petroleum gas, etc. If the pressure inside the meter falls momentarily to the vapour pressure of the liquid, then the liquid will boil. When this happens the liquid is said to “flash” within the meter. To prevent flashing, the line pressure immediately downstream of the meter shall be kept well above the vapour pressure of the liquid. Most meter manufacturers provide rules for the amount by which the back pressure at the meter shall exceed the vapour pressure. General rules for back pressure in turbine meters are also given in ISO 2715.

Immediately downstream of a partially opened valve, a bend or many types of pipe fitting, the liquid in the pipe can be subject to “swirl”. In other words, instead of following a straight path along the pipe the liquid may be moving in a corkscrew fashion. Swirl has little or no effect on the performance of displacement meters, but it seriously affects the performance of turbine meters. To suppress any swirl which can occur, it is usual for a device known as a flow straightener to be installed upstream of a turbine meter.

4.2.2 Electrical disturbances

A counter can miss some of the pulses generated by the meter, in which case it will read low. Or it can count some pulses that the meter has not generated, in which case it will read high.

If too few pulses are counted, this will usually be because the sensitivity control is improperly set, or because an electrical fault has developed. By adjusting the sensitivity control, or by rectifying any electrical fault that may exist, this trouble can usually be cured completely.

The counting of spurious pulses, however, is liable to be a more serious problem. It is dealt with at length in ISO 6551 and only a brief outline of the subject is given here.

Spurious pulses can originate in two ways:

- from surges in the electrical mains supplying the counter;
- from electromagnetic radiation.

The former is often referred to as “supply-borne noise”, and the latter as “airborne noise”. Electrical welding equipment and radio transmitters are common sources of airborne noise. Manufacturers are well aware of these problems, and normally build metering systems that are fairly well defended against spurious pulses.

The defences will usually include:

- filters on power mains designed to exclude supply-borne noise;
- preamplifiers at the meters, which will ensure a high signal-to-noise in the transmission line and thus make it less likely for airborne noise to be picked up;
- appropriately screened signal transmission cables earthed at only one point to avoid the occurrence of ground loops.

The route followed by signal transmission cable is of crucial importance. It should be kept as far away from AC power cables as possible, and if it has to cross a power cable it should do so at right angles. Spurious pulse counting is often caused by operators making unauthorized alterations to the wiring of their systems and inadvertently breaking these rules in the process.

Metering systems are sometimes fitted with a dual system of generating, transmitting and counting pulses to provide an indication that spurious pulses are not being counted. These are not infallible, but are a useful supplement to the operator’s own vigilance.

4.3 Pulse interpolators

Pulse interpolators are electronic devices that enable pulses from a meter to be counted to a fraction of a pulse, thus reducing the rounding-off error which occurs when pulses from a short proving run are counted to the nearest whole number. They perform best on meters with pulses emitted at regular intervals.