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Natural gas — Measurement of properties — Volumetric properties: density, pressure, temperature and compression factor

Gaz naturel — Mesurage des caractéristiques — Caractéristiques volumétriques: masse volumique, pression, température et facteur de compression

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. 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.

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.

ISO 15970 was prepared by Technical Committee ISO/TC 193, *Natural gas*.

Introduction

The transmission of natural gas can involve passage across national boundaries; at border stations and elsewhere, knowledge of the physicochemical properties of the fluid is of great operational and economic importance. The energy flow and properties of the gas are required at several stages of the overall production and custody transfer process: production, blending, transmission, metering, distribution and supply.

International standardization of the performance specifications for various types of measuring instruments can facilitate comparison of, and increase confidence in, measurement results for contracting partners. In many cases, it is possible to calculate the properties of natural gas with sufficient accuracy, given the composition. However, it is often also possible to measure the property using techniques that do not require a compositional analysis for their implementation.

This International Standard considers only those methods for determining physical properties of natural gas that do not rely upon a detailed component analysis of the gas. Such measurements consider the “whole” sample of the gas.

This International Standard defines performance characteristics necessary to specify instrumentation for measurement of some natural gas properties. It provides guidelines for the installation, traceable calibration, performance, operation, maintenance and acceptance testing of these measurement instruments.

The principle of measurement of various properties included in this International Standard is typical for a number of applications.

It is required that the calibration of the instruments dealt with in this International Standard be traceable to national standards or International Standards.

It is required that the measuring instruments, including their installation and the devices used for field calibration, verification and maintenance comply with local legal regulations on application in hazardous areas.

Annex A presents general guidelines for instrument selection, instrument test and operational procedures of the instruments considered in this International Standard.

Annex B lists the data of particular importance for the instrument documentation.

Natural gas — Measurement of properties — Volumetric properties: density, pressure, temperature and compression factor

1 Scope

This international Standard gives requirements and procedures for the measurement of the properties of natural gas that are used mainly for volume calculation and volume conversion: density at reference and at operating conditions, pressure, temperature and compression factor.

Only those methods and instruments are considered that are suitable for field operation under the conditions of natural gas transmission and distribution, installed either in-line or on-line, and that do not involve the determination of the gas composition.

This International Standard gives examples for currently used instruments that are available commercially and of interest to the natural gas industry.

NOTE Attention is drawn to requirements for approval of national authorization agencies and to national legal regulations for the use of these devices for commercial or official trade purposes.

The density at reference conditions (sometimes referred to as normal, standard or even base density) is required for conversion of volume data and can be used for other physical properties.

Density at operating conditions is measured for mass-flow measurement and volume conversion using the observed line density and can be used for other physical properties. This International Standard covers density transducers based on vibrating elements, normally suitable for measuring ranges of 5 kg/m^3 to 250 kg/m^3.

Pressure measurement deals with differential, gauge and absolute pressure transmitters. It considers both analogue and smart transmitters (i.e. microprocessor based instruments) and, if not specified otherwise, the corresponding paragraphs refer to differential, absolute and gauge pressure transmitters without distinction.

Temperature measurements in natural gas are performed within the range of conditions under which transmission and distribution are normally carried out (253 K $< T <$ 338 K). In this field of application, resistance thermometer detectors (RTD) are generally used.

The compression factor (also known as the compressibility factor or the real gas factor and given the symbol Z) appears, in particular, in equations governing volumetric metering. Moreover, the conversion of volume at metering conditions to volume at defined reference conditions can properly proceed with an accurate knowledge of Z at both relevant pressure and relevant temperature conditions.

2 Normative references

The following referenced documents are indispensable for the application 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 2186, *Fluid flow in closed conduits — Connections for pressure signal transmissions between primary and secondary elements*

ISO 5167-1, *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full — Part 1: General principals and requirements*

ISO 6976, *Natural gas — Calculation of calorific values, density, relative density and Wobbe index from composition*

ISO 10715, *Natural gas — Sampling guidelines*

ISO 12213-1, *Natural gas — Calculation of compression factor — Part 1: Introduction and guidelines*

IEC 60079-0, *Explosive atmospheres — Part 0: Equipment — General requirements*

IEC 60079-1, *Explosive atmospheres — Part 1: Equipment protection by flameproof enclosures "d"*

IEC 60079-11, *Explosive atmospheres — Part 11: Equipment protection by intrinsic safety "i"*

IEC 60079-14, *Explosive atmospheres — Part 14: Electrical installations design, selection and erection*

IEC/TR 60079-15, *Electrical apparatus for explosive gas atmospheres — Part 15: Construction, test and marking of type of protection 'n' electrical apparatus*

IEC 60381-1, *Analogue signals for process control systems — Part 1: Direct current signals*

IEC 60381-2, *Analogue signals for process control systems — Part 2: Direct voltage signals*

IEC 60751, *Industrial platinum resistance thermometer sensors*

IEC 60770-1, *Transmitters for use in industrial-process control systems — Part 1: Methods for performance evaluation*

3 Terms and definitions

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

3.1 Terms and definitions for density at reference conditions

3.1.1
density at reference conditions
mass of a gas divided by its volume at specified reference conditions of pressure and temperature

3.1.2
relative density at reference conditions
ratio of the mass of a gas, contained within an arbitrary volume, to the mass of dry air of standard composition in accordance with ISO 6976, which would be contained in the same volume at the same references conditions

3.2 Terms and definitions for density at operating conditions

3.2.1
density
mass of a gas divided by its volume at operating conditions of pressure and temperature (operating and reference conditions)

3.2.2
vibrating element density transducer
device that contains a vibrating element that is maintained at its natural frequency, made such that the element contains or is surrounded by gas, the gas and the element forming a system where the density of the gas is the main property of the gas determining the natural frequency of the element

NOTE The natural frequency to the first approximation is determined by the gas density.

3.2.3
main density transducer constants
constants that, to a first approximation, define the relationship between the natural frequency of the vibrating element and the density of the gas

3.2.4
raw density
density as determined by a vibrating-element density transducer from its vibrating frequency by use of the main density transducer constants before any corrections for temperature, pressure and composition are applied

3.2.5
correction density transducer constants
constants applicable to a density transducer to correct for the deviation between the calibration condition under which the main constants were determined and the operating conditions

3.2.6
temperature-corrected density
raw density corrected for difference in temperature to which the vibrating element is exposed in operation and the temperature at which the density transducer was calibrated

3.2.7
compositional-corrected density
temperature-corrected density, corrected for difference in gas properties between gas to which the vibrating element is exposed in operation and the gas properties of the gas used for calibration

NOTE Normally, the gas property relevant for this purpose is velocity of sound, hence this term is often referred to as velocity-of-sound-corrected density.

3.2.8
line density
compositional-corrected density, corrected for difference in operating conditions, e.g. pressure and temperature, to which the vibrating element is exposed and the operating conditions in the line where the density is measured

3.3 Terms and definitions for pressure

3.3.1
pressure transmitter
device that responds to a measured pressure to produce a standard output signal for transmission, which has a prescribed continuous relationship to the value of the measured pressure

3.3.2
lower range value
LRV
lowest value of the pressure that a transmitter is adjusted to measure

3.3.3
upper range value
URV
highest value of the pressure that a transmitter is adjusted to measure

3.3.4
span
algebraic difference between the upper and lower range values

3.3.5
static pressure
pressure that would be measured by a pinpoint observer travelling with a particle of the fluid

3.3.6
absolute static pressure
static pressure of a fluid measured with reference to an absolute vacuum

3.3.7
gauge pressure
difference between the absolute static pressure of a fluid and the atmospheric pressure at the place and time of the measurement

3.4 Terms and definitions for temperature

3.4.1
temperature transmitter
device that responds to a measured temperature to produce a standard output signal for transmission, which has a prescribed continuous relationship to the value of the measured temperature

3.5 Terms and definitions for compression factor

3.5.1
least squares method
method used to compute the coefficients of the equation when a particular form of equation is chosen for fitting a curve data

NOTE The principle of least squares is the minimization of the sum of squares of deviations of the data from the curve.

4 Symbols and units

4.1 Symbols and subscripts for density at reference conditions

Symbol	Quantity	Unit
k_Z	Ratio of $Z(p, T)$ and Z_n	—
p	Absolute pressure	Pa
ρ	Density	kg/m^3
T	Thermodynamic temperature	K
Z	Compression factor	—

Subscripts	
A	Standard air
m	Measured gas/measuring chamber
n	Reference conditions
r	Reference chamber

4.2 Symbols and subscripts for density at operating conditions

Symbol	Quantity	Unit
C	Velocity of sound	m/s
C_c	Velocity of sound in calibration gas	m/s
C_g	Velocity of sound in gas in density transducer	m/s
F	Frequency	s^{-1}
$K_1\ K_2\ K_N$ [a]	Density transducer constants	[b]
ρ_r	Raw density	kg/m^3
ρ_t	Temperature corrected density	kg/m^3
ρ_c	Compositional corrected density	kg/m^3
ρ_L	Line density	kg/m^3
T_c	Calibration temperature	K
t_c	Calibration temperature	°C
T_d	Temperature in density transducer	K
T_L	Temperature in pipe	K
t_d	Temperature in density transducer	°C
t_L	Temperature in pipe	°C
p_d	Pressure in density transducer	Pa
p_L	Pressure in pipe	Pa

[a] The number of constants (n) can vary for the different types of density transducers. The manufacturers are allowed to use a numbering system for constants different from the one used throughout this International Standard.

[b] The unit of the various constants shall be such that all terms in Equations (4) and (5) come out with unit kg/m^3.

Subscripts	
L	Pipe or line
d	Density transducer

4.3 Symbols and subscripts for compression factor

Symbol	Quantity	Unit
V_1	Volume of the small vessel in the Z-meter	m^3
V_2	Volume of the large vessel in the Z-meter	m^3
V_3	Sum of volumes V_1 and V_2	m^3
p_1	Line pressure	Pa
p_2	Pressure before expansion	Pa
p_3	Pressure after expansion	Pa
Z_1	Compression factor at conditions p_1 and T	—
Z_2	Compression factor at conditions p_2 and T	—

Z_3	Compression factor at conditions p_3 and T	—
k_V	Ratio of volumes V_2 and V_1	—
$B_1(T), B_2(T)$	Coefficients of the polynomial of the compression factor as a function of the pressure	a
T	Temperature of the Z-meter	K
t	Temperature of the Z-meter	°C
Z	Compression factor	—
k_Z	Ratio of $Z(p,T)$ and Z_n	—
a, b	Coefficients in the function for the transfer in temperature	—
e, f, g	Coefficients in the function for the transfer in pressure	b

a The units of $B(T)$ and $C(T)$ shall be such that all resulting terms in Equations (9) and (10) are dimensionless.

b The units of e, f and g shall be such that all resulting terms in Equation (12) are dimensionless.

Subscripts

i	initial conditions
f	final conditions
n	reference conditions

5 Density at reference conditions

5.1 Principle of measurement

5.1.1 General

Two basic principles are used for measuring the density at reference conditions:

a) direct measurement, for example determining the buoyancy force of a defined volume of gas with a balance system;

b) indirect measurement, for example determining the natural frequency of a vibrating element, which is influenced by the density of the medium in which the element vibrates.

5.1.2 Balance system

The apparatus measures the buoyancy force of a closed, gas-filled glass bulb in an atmosphere of gas whose density at reference conditions is being determined (see Figure 1).

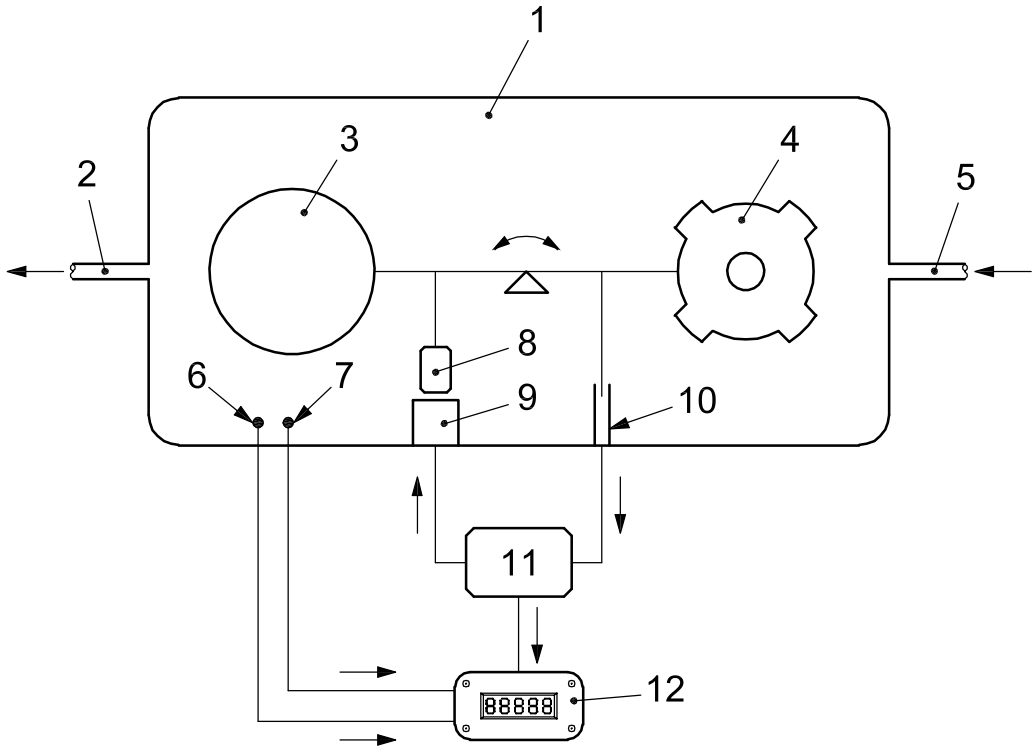
The glass bulb is fitted to a balance beam with an open glass bulb as a counterweight. This weighing system is mounted in a chamber through which the gas being tested is passed. Either the displacement of the balance beam or the force that is necessary to compensate the displacement can be taken as a measure for the density.

A correcting system compensates for the temperature and pressure fluctuations of the measuring chamber.

5.1.3 Vibrating element system

Two different systems are commonly used. Each consists of two chambers. One chamber is filled with a reference gas that is similar to the gas being measured and sealed from the atmosphere. The gas being tested is continuously passed through the other chamber. A pressure equalizer ensures that the pressure in

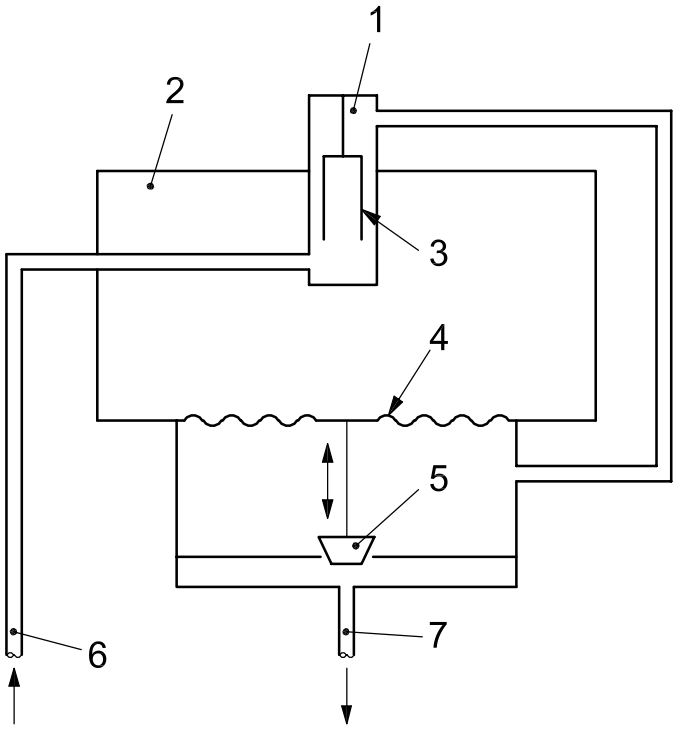
the measuring chamber is equal to the pressure in the reference chamber. The housings of the systems are designed in such a way that both gas chambers have the same temperature (see Figures 2 and 3).



Key

1 instrument housing
2 gas outlet
3 closed glass bulb
4 open glass bulb
5 gas inlet
6 pressure sensor
7 temperature sensor
8 magnet
9 compensation coil
10 photo sensor
11 PID regulator
12 display

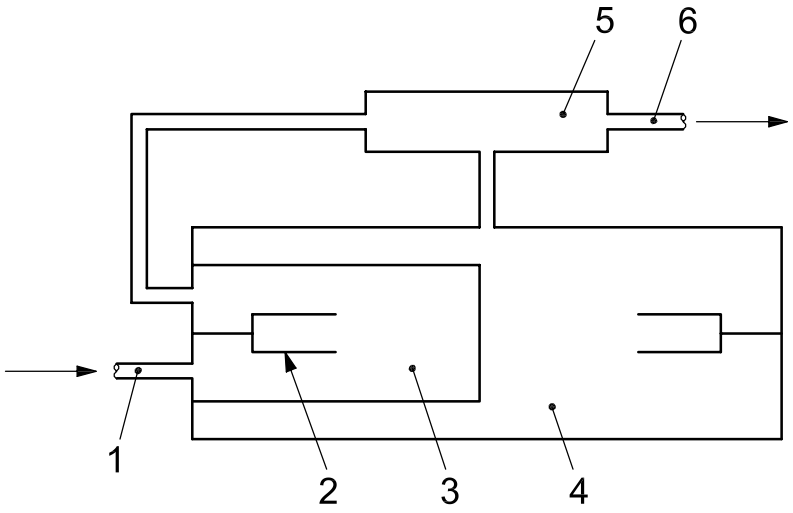
Figure 1 — Gas density balance system



Key

1 measuring chamber
2 reference chamber
3 vibrating element
4 diaphragm
5 pressure control valve
6 gas inlet
7 gas outlet

Figure 2 — Gas densitometer with one vibrating element



Key

1 gas inlet
2 vibrating element
3 measuring chamber
4 reference chamber
5 pressure equalizer
6 gas outlet

Figure 3 — Gas densitometer with two vibrating elements

Generally, the density, ρ, is as given by Equation (1):

$$\rho = \rho_{\mathrm{n}} \frac{T_{\mathrm{n}}}{p_{\mathrm{n}}} \frac{p}{T} \frac{1}{k_{\mathrm{Z}}} \tag{1}$$

where

p is the pressure;

T is the thermodynamic temperature;

k_{Z} is the ratio (Z/Z_{n}) of the compression factors;

n is the subscript indicating that the values are at reference conditions.

With equal pressure and temperature in the reference chamber (subscript r) and measuring chamber (subscript m), the ratio of the respective densities is given by Equation (2):

$$\frac{\rho_{\mathrm{m}}}{\rho_{\mathrm{r}}} = \frac{\rho_{\mathrm{n,m}}}{\rho_{\mathrm{n,r}}} \frac{k_{\mathrm{r}}}{k_{\mathrm{m}}} \tag{2}$$

Assuming that $k_{\mathrm{r}}/k_{\mathrm{m}}$ is a constant, which is a good approximation for low pressures and means that the gases are similar, the quotient of the densities of the gas to be measured and of the reference gas is directly proportional to the density at reference conditions, as given in Equation (3):

$$\rho_{\mathrm{n,m}} = \frac{\rho_{\mathrm{m}}}{\rho_{\mathrm{r}}} \frac{k_{\mathrm{m}}}{k_{\mathrm{r}}} \rho_{\mathrm{n,r}} = k \cdot \frac{\rho_{\mathrm{m}}}{\rho_{\mathrm{r}}} \tag{3}$$

where k is a constant.

The difference between the two systems is that one uses two vibrating elements to measure the density, one in the reference chamber and one in the measuring chamber, whereas the other system has one vibrating element system inside the measuring chamber and uses the fact that the design of the system ensures that the density of the sealed reference gas is constant. The function of a vibrating element system is discussed in 6.1.

5.2 Performance assessment and acceptance tests

5.2.1 Requirements

The necessary requirements depend on the purpose of the measurement. The requirements affect several characteristics of the instrument such as

a) accuracy, sensitivity,

b) safety,

c) reliability, long-term reproducibility,

d) insensitiveness to disturbances,

e) installation and calibration features,

f) response time,

g) robustness,

h) handling and maintenance features,

i) data handling, connections,

j) costs.

5.2.2 Performance tests

The manufacturer shall perform extensive laboratory tests on a selected number of instruments to verify the performance of the instrument type and to ensure that its own and the purchasers' requirements are met. Guidance and recommendations are given in IEC 60770-2.

The tests shall be carried out by connecting the instrument to reference gases with appropriate densities at reference conditions and varying the parameter of interest to establish the influence on the instrument being tested. The parameter can be, for example

a) the temperature of the sample gas,

b) the operating pressure,

c) the ambient temperature and pressure,

d) the flow rate through the instrument and back-pressure effects,

e) the humidity of the sample gas,

f) the supply voltage,

g) the mounting position,

h) the magnetic and electric fields,

i) contaminents within the gas sample.

To check for effects due to gas composition, tests should be carried out using reference gases with different compositions but similar densities at reference conditions. Tests for checking repeatability and long-term drift shall be performed under field conditions also.

The results of all tests shall be properly reported and made available to the user of the instrument.

Prior to delivery, the manufacturer shall carry out a metrologically traceable factory acceptance test to ensure proper operation for each instrument yielding individual test certificates. An example of a scheme for the factory acceptance testing is given in Annex A. During this test, the vibrating element systems may be calibrated whereas the balance systems shall be calibrated and carefully tested additionally on site.

NOTE As most of the tests recommended in 5.2 for density at reference conditions are also valid for density at operating conditions, refer to 6.2 for a more extensive description.

5.3 Sampling and installation guidelines

The installation guidelines of the manufacturer shall be observed. Since the instruments are sensitive to fluctuations in temperature, special care shall be taken to meet the temperature-fluctuation requirements for operation, calibration and verification.

In order to minimize the reaction time of the measurement, pressure reduction shall be close to the sampling point and the whole piping shall be as short as possible. Another instrument (for example a calorimeter) may be connected to the same sampling line but each instrument shall have a separate vent.

Depending on the sample gas condition, additional filters shall be installed to protect the instrument from contamination. Precautions shall be taken to prevent a change in the gas composition due to a temperature drop caused by a reduction in pressure.

The sample flow rate shall be controlled.

It shall be possible to test and calibrate the system by connecting reference gases to it. It shall be ensured, for example by the use of a double block and bleed valve design, that valve leaks do not lead to a mixing of the gases.

5.4 Calibration

The technical manuals and manufacturers' instructions for calibration and recalibration and the requirements of the authorities stipulated in the approvals of the instruments shall be observed.

The systems shall be calibrated by connecting them to reference gases. These gases shall be either one-component gases of high purity ($>$ 99,95 %) or reference gas mixtures.

One of the gases shall have a density at reference conditions which is in the range of that of the operating gas and, for vibrating elements, the same applies for Z_n/Z and the velocity of sound.

Balance systems, which are very sensitive to environmental influences, shall be carefully tested and calibrated on site. Vibrating element systems, which are relatively robust, may be calibrated in a laboratory or on site. However, as the calibration curve constants for vibrating elements depend on the gas in the reference chamber, for those reference chambers that are refilled on site, a recalibration on site is required.

A minimum calibration interval is one year, but shall not exceed five years. The user shall consider the instrument's accuracy during operations and its financial impact on the results.

5.5 Verification

Verification of the correct operation and accuracy shall be performed at regular intervals by connecting the system to a reference gas that has operating properties similar to those of the operating gas. In particular, for all instruments, the reference gas shall have a density at reference conditions that is similar and in addition, for vibrating elements, the same applies for Z_n/Z and the velocity of sound properties should be similar.

This procedure may be performed automatically.

The acceptable limits of the deviation shall be established on the basis of, for example, the manufacturer's recommendations using control charts or parties' agreements.

If the deviations are within these limits, a correction may be applied to the measured values without recalibrating the system; if the deviations are outside the limits, the system shall be recalibrated.

5.6 Maintenance

Filters shall be checked and replaced at regular intervals. The condition of the operating gas governs the length of time between the checks.

5.7 Quality control

If there are two density-measuring systems at one station, the results should be compared continuously and an alarm should be given if the deviation exceeds predetermined limits.

Alternatively, the proper functioning of the measurement system may be ensured by comparing, at regular intervals, the measured density with that calculated from a component analysis of a gas sample taken from the line, either on-line or off-line.

6 Density at operating conditions

6.1 Principle of measurement

6.1.1 Vibrating element

This principle utilizes the fact that an element in a fluid is excited to vibrate at its natural frequency which depends on the density of the fluid. Hence, by measuring the natural frequency, the density can be determined.

The basic correlation between density, ρ_r, and the natural frequency, f, is represented by the second order equation as given in Equation (4):

$$\rho_r = K_0 + K_1\left(\frac{1}{f}\right) + K_2\left(\frac{1}{f}\right)^2 \tag{4}$$

6.1.2 Temperature and pressure correction

The relationship between the density and the frequency is, in principle, also affected by temperature and pressure. This requires the introduction of pressure and temperature correction terms.

The main reason for the temperature and pressure correction is that the material properties, such as elasticity, of the vibrating element are affected by temperature and pressure. Normally, the pressure effect is negligible.

The temperature effects can influence both the zero and the span. The correction can normally be expressed as a first-order correction term as given in Equation (5):

$$\rho_t = \rho_r\left[1 + K_3\left(T_d - T_c\right)\right] + K_4\left(T_d - T_c\right) \tag{5}$$

6.1.3 Velocity of sound (VOS) correction

The densitometer constants K_0, K_1 and K_2 in Equation (4) also depend on the type of gas with which the vibrating element is in contact.

The gas quality parameter that best describes this dependence is the velocity of sound in the gas at operating conditions.

K_0, K_1 and K_2 in Equation (4) are determined by calibration using a particular gas. If the velocity of sound in the gas for which the density is being determined is different from the velocity of sound in the calibration gas, the density resulting from the simple relation in Equation (4) shall be corrected.

Equation (6) describes the correction:

$$\rho_c = \rho_t \left[\frac{1 + K_5 \left(\frac{f}{c_c} \right)^2}{1 + K_5 \left(\frac{f}{c_g} \right)^2} \right] \tag{6}$$

where c_c is the velocity of sound in the calibration gas at the same conditions of pressure and temperature at which the density, ρ_r, is referred or at which the vibrating element is vibrating with the corresponding frequency.

For a given temperature and pressure, c_g depends on the natural gas composition. Typically, a change in the composition of the pipeline gas, resulting in a change in c_g of 10 m/s, can result in a change in the correction term in Equation (6) of 0,05 %.

c_g can either be directly measured (e.g. special devices or signals from ultrasonic flowmeters) or be calculated.

c_g can be calculated as a function of ρ_c or p_d, T_d and gas properties. Because ρ_c depends on c_g and c_g depends on ρ_c, an iteration procedure is, in this case, required. For the calculation method, refer to the manufacturer's manual.

However, the effect on the VOS correction factor of using ρ_t instead of ρ_c can be insignificant and use of ρ_t in this term is acceptable to simplify the calculations.

Another alternative in order to avoid iteration is to use ρ_c from the preceding calculation sequence; this procedure is valid only when there is no change in the gas and its process conditions.

The VOS correction factor can be simplified and even omitted depending on the accuracy required by the application and the difference between c_g and c_c.

6.2 Performance assessment and acceptance tests

6.2.1 Requirements and performance assessments for instrument selection

6.2.1.1 General

The necessary requirements and assessment tests depend on the purpose of the measurement and the conditions under which the instrument operates.

To allow the user to evaluate the performance of a type of transducer, the following special tests shall be performed by the manufacturer or in co-operation with the user on a selected number of instruments to verify the performance. Based upon those assessment tests, it shall be concluded which tests shall be performed on the individual transducers and which test results can be regarded as common for the specific type of transducers. The results from all tests shall be properly documented.

6.2.1.2 Sensitivity test

Apply a gas with known densities, including zero (vacuum), at a minimum of ten points spaced equidistant throughout the required operating range of the densitometer at constant temperature. The required densities are obtained by varying the pressure. The gas composition shall be constant during the tests.

The results of this test are used to establish the main constants. To develop the main constant, do not include the result at zero (vacuum).

Through this test, the measuring range for the density transducers is determined within which the second-order regression curve is valid.

6.2.1.3 Hysteresis test

Perform the sensitivity test with steadily increasing and decreasing pressure over the operating pressure range.

The result of this test is the transducer's ability to repeat results at varying pressure.

6.2.1.4 Repeatability test

Repeat the hysteresis test consecutively a sufficient number of times to obtain a 95 % confidence level.

The result of this test shows the transducer's ability to repeat after several pressurizations and depressurizations.

6.2.1.5 Continuity test

Steadily and slowly increase or decrease the pressure in the densitometer and continuously log the frequency output.

The result of this test shows the absence of discontinuities in the frequency output of the transmitter.

6.2.1.6 Test for temperature sensitivity

Perform the hysteresis test at a temperature well below and well above the normal calibration temperature. The results of this test are used to determine the temperature correction constants.

6.2.1.7 Test of sensitivity to velocity of sound

Perform sensitivity tests at normal calibration temperature with three different types of gases with differences in velocity of sound among the three gases of more than 30 m/s.

The results of this test are used to determine the velocity-of-sound correction constants. Provided these correction constants do not differ significantly from one transducer to another, these constants may be regarded as fixed for all transducers of identical design. “Significantly” means that the maximum deviation of the transducer tested on the VOS correction factor is less than 1/10 of the specified accuracy of the density transducer.

6.2.1.8 Test of flow rate sensitivity

Perform a number of sensitivity tests with different flow rates in both directions if applicable through the measuring chamber.

The results of this test are recommended limitations of flow rate through the density transducer and the effect of flow rate on the reading from the transducer.

6.2.1.9 Durability test

Repeat the repeatability test weekly for more than four weeks. Between the repeatability tests, the densitometer shall be exposed to a temperature both below the minimum operating temperature in the actual application (minimum 20 °C below normal calibration temperature) and above the maximum operating temperature (minimum 20 °C above normal calibration temperature), each for more than 24 h.

The results of this test are used to determine recommended storing conditions and the temporary and permanent effect on the transducer from exposure to extreme conditions, such as a low temperature in a blow-out situation.

6.2.2 Factory, purchasing and site acceptance tests

6.2.2.1 Factory acceptance test

Before delivery to the purchaser, the manufacturer shall, as a minimum, conduct the sensitivity test described in 6.2.1.2 on the individual transducer as part of the factory acceptance test.

This test, even with a reduced number of test points, is regarded as a calibration (see 6.4). The number of test points is related to accuracy.

The purchaser's requirements and the type of transducer can necessitate additional tests (see 6.2.1).

6.2.2.2 Purchasing acceptance test

The purchaser may, as an option, conduct and perform any of the tests described in 6.2.1 on any transducer.

6.2.2.3 Site acceptance test

A performance test under field conditions shall be performed with the instrument properly installed according to manufacturer recommendations or as agreed between user and manufacturer.

During the test the following items shall be checked, if applicable:

a) ensuring that gas is flowing through the density transducer;

b) differences in process conditions (P, T) in the flow meter and the densitometer;

c) adequate filtration/conditioning to prevent dirt or condensate from causing inaccurate operation of the densitometer;

d) interaction between the densitometer installation and the flowmeter;

e) sensitivity to pipeline noise and vibration;

f) unregistered gas, which passes through the densitometer but not through the flow meter;

g) proving system;

h) convenience of access to the densitometer for maintenance, e.g. gas/vacuum connections;

i) consistency in density reading between densitometers installed in parallel;

j) maintenance of sensitivity by performing a sensitivity test of the densitometer before and after the field installation.

6.3 Sampling and installation guidelines

6.3.1 General

The purpose of a proper installation is to provide representative and conditioned samples of gas for the densitometer, to obtain the same condition at the density transducer and at the location in the pipe where the density is being determined or to be able to correct for any differences in conditions, i.e. temperature and pressure, and to facilitate proper maintenance.

There are two methods of installation, in-line and on-line.

6.3.1.1 In-line installation

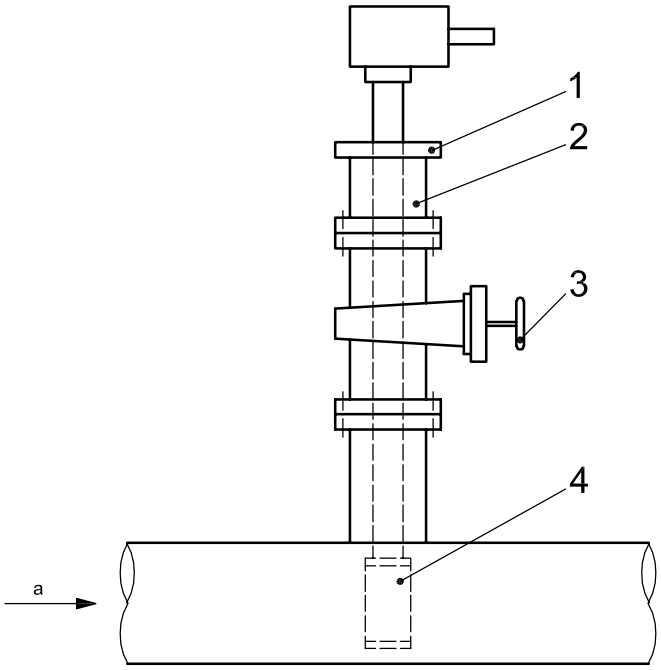
An example of in-line installation is shown in Figure 4. For easy access to the instrument without depressurizing the line, a retractor mechanism is recommended.

The pressure and temperature inside the densitometer is equal to the conditions in the line.

The location in the pipe is normally downstream to the flowmeter.

For flowmeters with negligible pressure drop (difference of pressure upstream and downstream the flowmeter), no temperature or pressure correction of the density is required to obtain density relevant for the flowmeter.

For flowmeters creating a pressure drop, the measured density shall be corrected to conditions at a location defined by the flowmeter. For orifice plates this will be either in the cross section plane of the downstream tapping points or the upstream tapping points.



Key

1 seal
2 seal housing
3 drain valve
4 retractable probe

a Direction of flow.

Figure 4 — In-line installation with retractor mechanism and the densitometer in the retractable probe

6.3.1.2 On-line installation

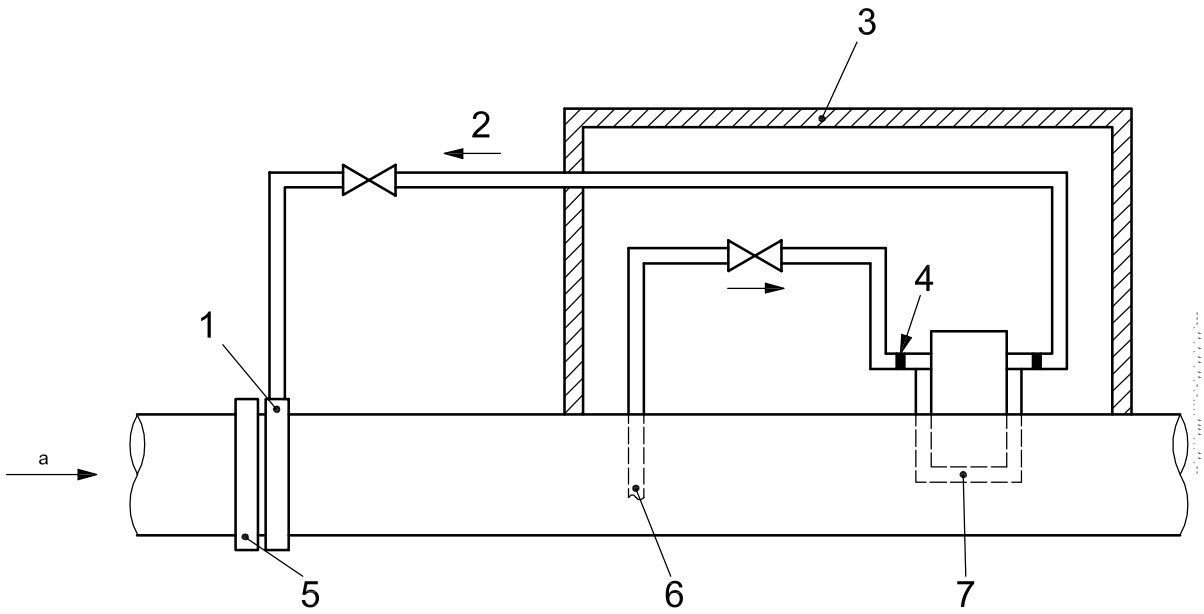
By this method, gas is extracted from the pipe and introduced into the densitometer. From the densitometer, the sample flow can either be returned into the pipe or be vented to atmosphere.

The sample flow shall not bypass the flowmeter for fiscal applications, and for other applications, only where no other practical options exist.

A sampling probe shall be used at the sampling point in accordance with ISO 10715.

To reduce the temperature differences between the densitometer and the line, the densitometer shall be installed in a pocket in the main pipe and the whole density transducer installation including the sampling lines shall be thermally insulated from the ambient. Care shall be taken to avoid the influence of noise and vibration in the pipe on the density transducer. Figures 5 and 6 show typical installation arrangements for orifice plates. The arrangement depends on the type of flowmeter associated with the densitometer and the operating conditions.

Figure 5 shows the pressure-recovery method, so-called since it utilizes the recovery of the pressure drop downstream of the orifice plate to drive the sample through the densitometer. The sample is returned at the downstream tapping point, but diametrically opposite to the tapping points used for differential pressure. Care shall be taken to ensure that there is a sufficient pressure drop to set up a flow in the sample line. With this method, a probe is used at the sampling point; it is recommended that the sampling line at the inlet side have smaller bore (e.g. 6 mm) than that at the outlet side (e.g. 12 mm).

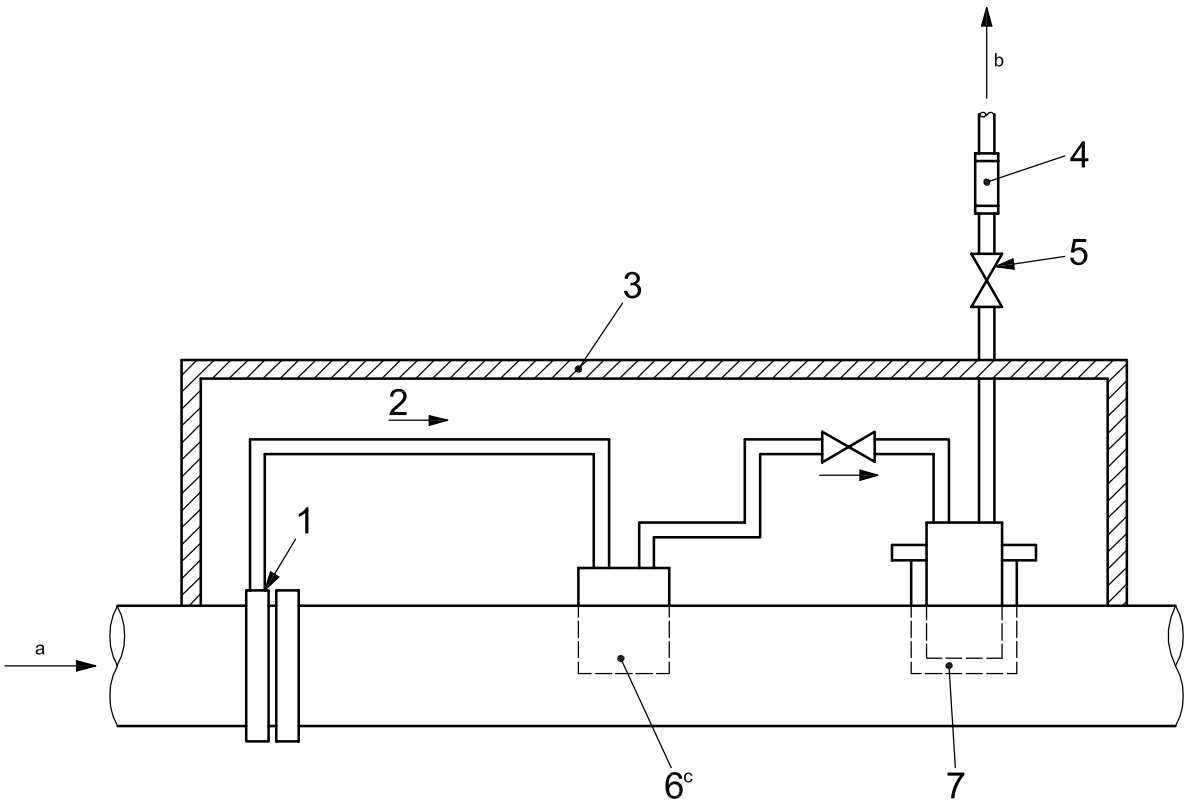


Key

1 downstream tap
2 sample return to downstream tapping
3 thermal insulation
4 filter
5 orifice plate
6 sampling probe
7 density transducer in pocket

[a] Direction of flow.

Figure 5 — Installation of a gas-density meter on an orifice plate system for the pressure-recovery method



Key

1 flange top
2 sample flow
3 thermal insulation
4 sample flow indicator
5 sample flow controller
6 filter installed in pocket
7 density transducer in pocket

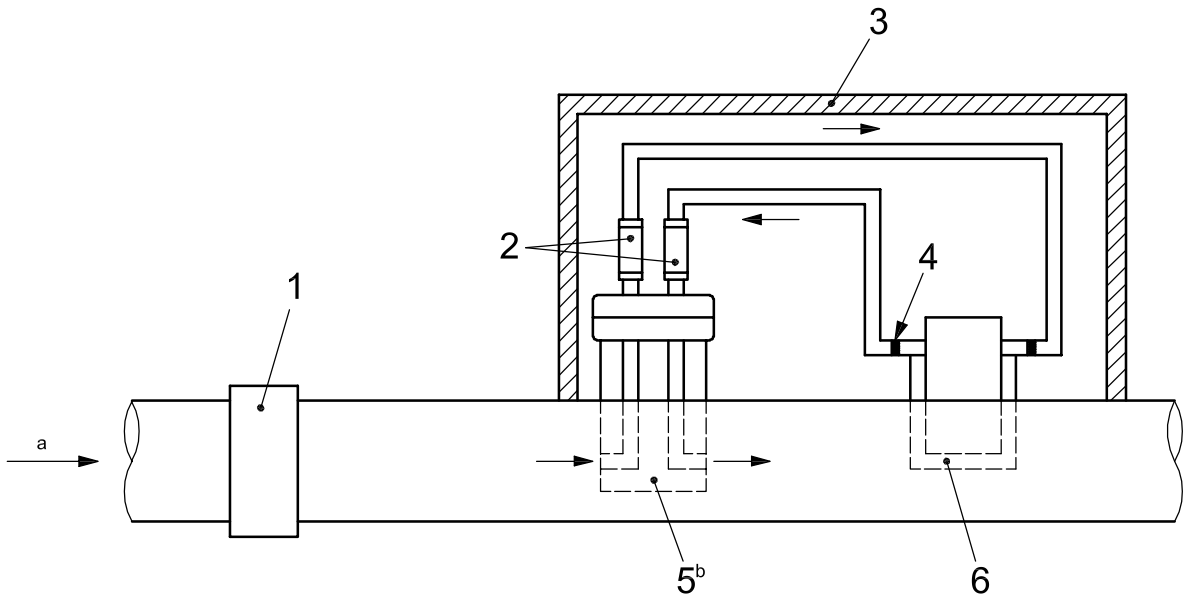
a Direction of flow.
b To vent.
c A filter may be installed in a pocket to reduce heat exchange between sample line and ambient.

NOTE In this case with the sampling from the upstream tapping of an orifice plate, no sampling probe is used.

Figure 6 — Principle of an on-line installation with sample gas to vent

Installation of any restriction in the sample line, such as filters, flow control valve(s) etc., should be between the sampling point and the densitometer. The density at the upstream (preferred) or downstream tapping point shall be used in flow calculations in accordance with ISO 5167-1. To further reduce temperature differences, filters upstream of the densitometers may be installed in pockets into the line. Due to the pressure drop created, flow control valves shall not be upstream of the densitometer as this can change the process conditions of the gas being measured by the density cell.

Figure 7 shows an example when there is no natural pressure drop in the pipe. The double-sided probe acts both as a sample retractor (upstream facing hole) and as a return of sample (downstream facing hole). In this case, the restrictions in the sampling tube shall be symmetrical on both sides of the densitometer to obtain the correct pressure in the densitometer. The sampling point may also be at the pressure-tapping point of the flowmeter; the sample may then be vented out of the pipe, e.g. to the atmosphere. Figure 6 shows such an installation in the case of an orifice meter. Special care shall be taken to prevent pipewall resident matter from entering the densitometer sampling system and meter, e.g. by applying an appropriate filter.



Key

1 flow meter
2 blocks with double-block-and-bleed valve
3 thermal insulation
4 filter
5 double sided sample probe
6 density transducer in pocket

a Direction of flow.

b A probe is used for sampling and there is no emission of gas.

Figure 7 — Principle for on-line installation when the flow meter causes no pressure drop (e.g. an ultrasonic meter)

Care shall be taken to avoid low temperature caused by a pressure drop over the flow controller, which can result in icing, condensation and blocking of sample outlet. Care shall also be taken to avoid differences in pressure between the pipe and the density transducer.

If it is not possible to obtain temperature equilibrium, a correction for the temperature difference between the densitometer and pipe may be calculated using Equation (7):

$$\rho_{\mathrm{L}} = \rho_{\mathrm{c}} \left(\frac{T_{\mathrm{d}}}{T_{\mathrm{L}}} \right) \left(\frac{p_{\mathrm{L}}}{p_{\mathrm{d}}} \right) \left(\frac{Z_{\mathrm{d}}}{Z_{\mathrm{L}}} \right) \tag{7}$$

where

T_{d} is the temperature in density transducer;

T_{L} is the temperature in pipe;

p_{d} is the pressure in the densitometer (can often be set equal to p_{L});

p_{L} is the pressure at the required location in the pipe;

Z_{d} is the compression factor in the densitometer;

Z_{L} is the compression factor in the pipe at the required location.

NOTE Z_{d} and Z_{L} are calculated from the available knowledge of the gas composition in the pipe.

6.4 Calibration

6.4.1 Laboratory calibration

The densitometer shall be calibrated and recalibrated at regular intervals in an approved laboratory. Calibration is normally performed with pure gas. The sensitivity test as described in 6.2.1.2 is used to establish K_0, K_1 and K_2.

The temperature correction coefficients are determined by varying the temperature as described in 6.1.2.

The velocity-of-sound correction constant, K_5, is normally determined for the type of densitometer through the type assessment tests (see 6.2.1.7).

Pressure and temperature shall be measured with equipment traceable to national standards or International Standards.

When the densitometer is calibrated using a reference (standard) densitometer, the latter shall be traceable to national standards or International Standards.

Calibration intervals in fiscal metering shall be no more than once every 5 years. The user shall examine the calibration frequency on the fiscal impact on the results.

6.4.2 Field calibration

Field calibration is normally not recommended due to lack of control of all influencing parameters.

6.5 Verification

6.5.1 Zero check

Most densitometers have no drift in the main constants if the densitometer‘s vibrating frequency is stable in vacuum.

After evacuating the densitometer to a vacuum less than the lower of 0,1 % of normal operating pressure and 1 kPa, the periodic time or frequency from the densitometer shall be recorded. If the measured periodic time differs from the value obtained in the laboratory calibration by less than 0,02 % of the normal operating density, the densitometer is acceptable. A larger deviation can mean a shift in sensitivity or deposit on the vibrating element. A recalibration is then necessary.

6.5.2 **Pressure shift test** (only for on-line installation)

A pressure shift test is carried out to verify that the pressure inside the densitometer is equal to the desired line pressure under flowing conditions.

With established flow through the sampling system, close the valve in the sampling line at the side of the densitometer not facing the tapping point where the desired pressure exists in the pipe. If no sudden change in density is observed, then it is likely that the pressure inside the densitometer is correct under flowing conditions.

If a sudden change in density is observed, then it is most likely that an undesired pressure drop exists in the sampling line under flowing conditions. The sampling line should then be checked for any blockage.

The sudden effect on density due to the sudden change in pressure should not be mistaken for the possible slower change in density due to a slow temperature change caused by a stoppage of flow through the densitometer.

6.6 Maintenance

Filters shall be checked and replaced at regular intervals. The conditions of the operating gas govern the length of time between the checks.

6.7 Quality control

6.7.1 General

In 6.7 is described a passive procedure that ensures the proper functioning of the density transducer primarily through recorded observations.

In addition, examples of quality checks and possible reasons for abnormal behaviour of the density readings are provided.

6.7.2 Check of consistency

The measured density can be compared, manually or automatically, with the expected value. The expected value can be based on knowledge of composition, pressure and temperature, or on other consistent measurements such as calorific value and velocity of sound and shall have at least the same accuracy as the measured density.

Alternatively, gas with a known quality may be introduced into the densitometer and the reading from the densitometer can be compared with the density calculated from the gas properties, pressure and temperature.

Any abnormal deviation (typically higher than 0,5 %) should result in alarm in the case of an automatic comparison. If multiple meter streams have individual density transducers, a maximum stream-to-stream deviation alarm should be set to function as a consistency check.

6.7.3 Recording of stability

The tolerated deviation between the expected and measured density in the consistency check quality procedure (see 6.7.2) depends on the accurate knowledge of the gas quality, pressure and temperature at all times and on their consistency.

Set tolerances should be periodically reviewed and maintained at as low a value as practicable.

A density reading that is more stable than that expected from the knowledge of variation in the gas composition can indicate no flow through the density transducer. This shall be checked and, if necessary, rectified.

Vibrations in the piping may give a density reading that is less stable than expected. This can be rectified either by the installation of an anti-vibration kit or by tracking the source and eliminating the vibration.

Lack of stability can also be caused by varying temperature differences between the pipe and the density transducer pocket. This can be rectified either by improving the thermal insulation or by using the temperature correction method given in Equation (7).

7 Pressure

7.1 Principle of measurement

7.1.1 General

The principles of measurement are the same for both differential and gauge pressure transmitters. In the latter, the high-pressure side corresponds to the absolute pressure of the natural gas in the pipeline, while the low-pressure side corresponds to the atmospheric pressure (see Figure 8).

For an absolute pressure transmitter, only one side is available for the pressure signal (see Figure 9).

7.1.2 Sensing elements

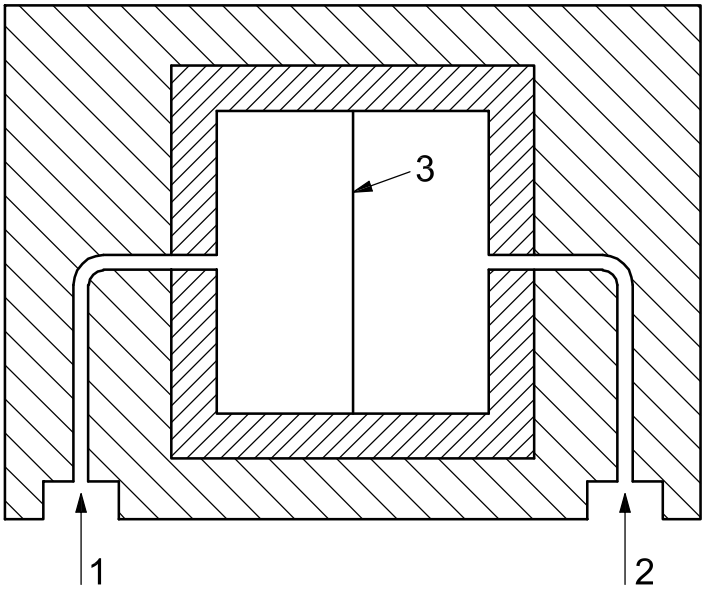
7.1.2.1 General

Three kinds of sensors are typically used in pressure transmitters: a capacitance sensor, a strain gauge or a resonant sensor.

7.1.2.2 Capacitance sensor

Process pressure is transmitted through the isolating diaphragm and fill fluid to the sensing diaphragm in the centre of the capacitance sensor.

Any change in pressure on the isolating diaphragm causes a change in the position of the sensing diaphragm. Capacitor plates on both sides of the sensing diaphragm detect its position.



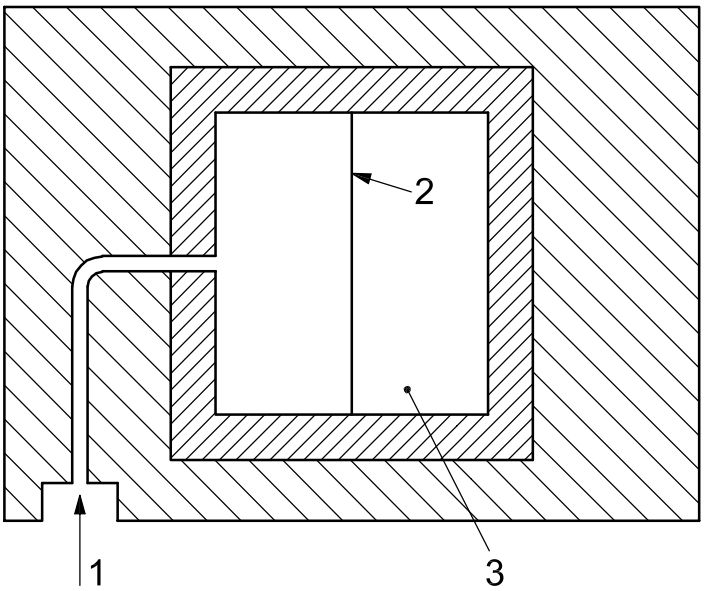
Key

1 upstream component of differential pressure (line pressure in the case of a gauge pressure transmitter)
2 downstream component of differential pressure (atmospheric pressure in the case of a gauge pressure transmitter)
3 sensing element

Figure 8 — Differential and gauge pressure sensor

7.1.2.3 Strain-gauge sensor

Process pressure is measured by mounting a strain gauge onto a thin film flexible diaphragm. The diaphragm is supported so that it is in contact with the pressure medium. A change in pressure, either positive or negative, displaces the diaphragm, causing the gauge to flex and to generate, in a Wheatstone bridge circuit, an electrical signal, which is directly proportional to the pressure applied. Examples of such strain gauge sensors are piezo-resistive, thin film and bonded sensors.



Key

1 line pressure, p
2 sensing element
3 vacuum

Figure 9 — Absolute pressure sensor

7.1.2.4 Resonant sensor

In this case, the process pressure modifies the natural vibration frequency of the resonator assembled in the pressure cell.

7.1.3 Output signal

In the case of smart transmitters, the signal from the sensor is measured electronically, converted to a digital format and sent to the electronic module where it is corrected by a microprocessor using stored characterization values. The corrected digital signal is then available, in engineering units, for readout; it can be transmitted to suitable digital interface devices and/or can be converted to an analogue, normalized output signal in accordance with IEC 60381-1 and IEC 60381-2 for output to conventional instrumentation.

For analogue transmitters, current and voltage output signals are available. 4 mA to 20 mA is a commonly used signal.

7.2 Performance assessment and acceptance tests

7.2.1 Requirements and performance assessments for instrument selection

A detailed description of the tests carried out in order to evaluate the transmitter performance is given in IEC 60381-1. The most important parameters to be tested are the following:

a) sensor measuring range;

b) damping;

c) power supply and load;

d) overpressure effects (e.g. effect of one-sided overload);

e) static-pressure effect and pressure-differential overloads (e.g. at line pressure, or from single-sided atmospheric depressurization, for differential pressure transmitters);

f) humidity and temperature effects;

g) electromagnetic compatibility, EMC;

h) accuracy;

i) stability;

j) mounting position effects.

As a result of these tests, the instrument documentation supplied by the manufacturers shall contain, besides a description of the principle of measurement and the instrument design, all the data for correct functioning.

7.2.2 Factory, purchasing and site acceptance tests

If required by the purchaser for each transmitter, the manufacturer shall perform a calibration (see 7.4) of the working span specified by the purchaser.

For differential-pressure transmitters, an onsite check of the calibration shall be carried out to eliminate mounting-position and static-pressure effects.

7.3 Installation guidelines

7.3.1 Mechanical connections

In order to avoid significant metering errors, care shall be given to the installation of pressure transmitters for flow measurement. The transmitter shall be connected to the intended point of the installation. The mounting of differential pressure transmitters shall be carried out in accordance with ISO 2186 and to the manufacturer's specifications.

The piping between the process and the transmitter shall accurately transmit process variables. For this purpose, the general requirements are as follows.

a) Place the taps in the top or the side of the line and mount the transmitter beside or above the taps so that liquid drains into the process line.

b) Keep the impulse piping as short as possible enabling the above activities to be independent of environmental conditions.

c) Slope the impulse piping at least 0,08 m per meter downward from the transmitter toward the process connection.

d) Use impulse piping large enough to avoid friction effects and possible capillary ingress of moisture.

e) Prevent sediment deposits in impulse piping.

f) Do not use impulse piping lines for sampling.

g) For differential pressure transmitters, keep both impulse legs at the same temperature.

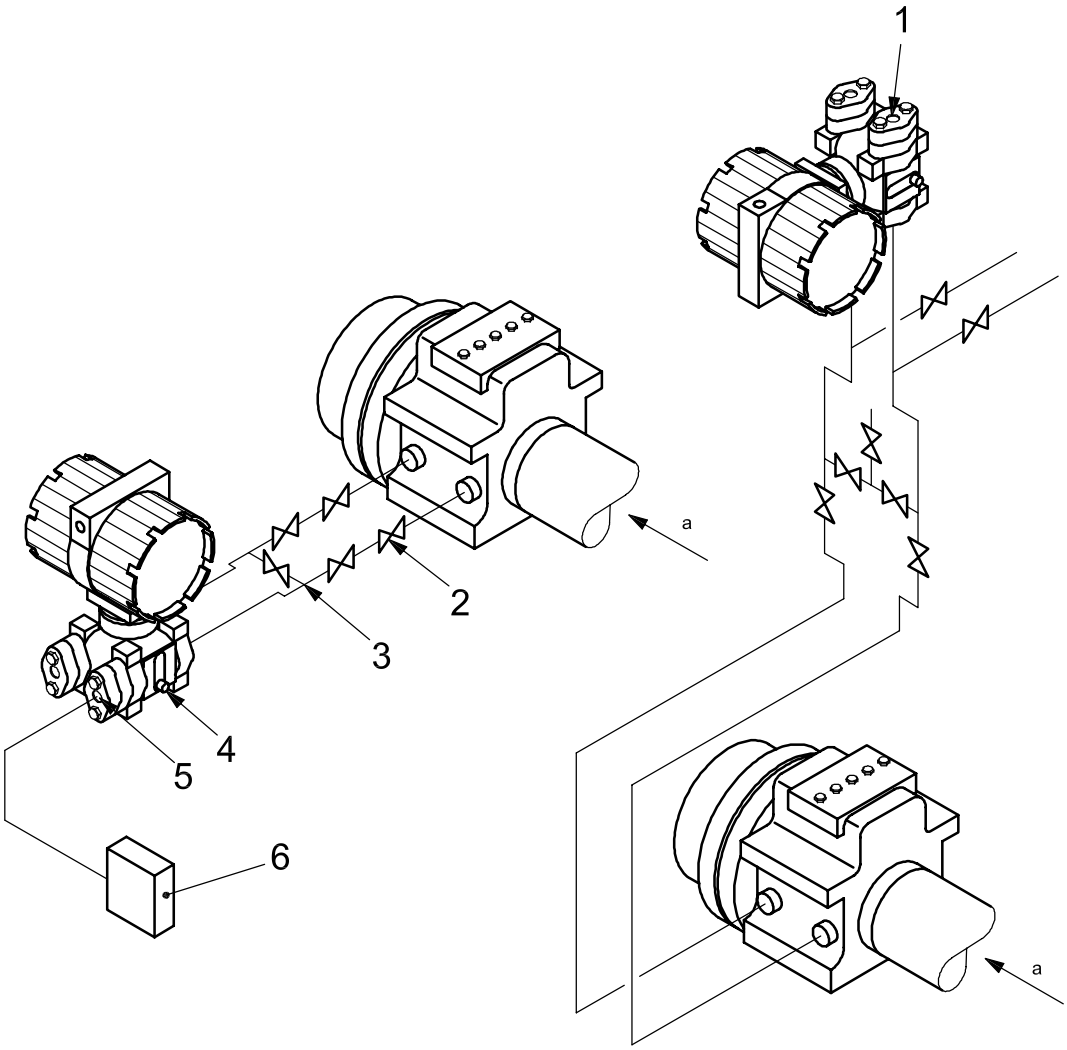
The transmitter shall be installed so as to minimize vibrations, shocks and environmental extremes. Where the environmental conditions fluctuate widely, enclosures with controlled environments can be required.

Field maintenance, checking and recalibration shall be easily carried out. For this purpose,

1) the connection to the transmitter shall incorporate valves, allowing the above operations without shutting down the whole installation;

2) an easy access to the transmitter shall be possible and personnel safety shall be guaranteed.

Examples of mechanical connections for differential pressure transmitters are shown in Figure 10.



Key

1 vent/drain plugs
2 valve
3 valve manifold
4 optional side mounted vent/drain plug
5 pipe plug
6 differential pressure reference device

a Direction of flow.

Figure 10 — Examples of mechanical connections

7.3.2 Electrical connections

Electrical connections shall conform to the instructions in the certification of transmitter conformity for the relevant type of protection or in the manufacturer's declaration.

They shall conform to the requirements of IEC 60079-14 and the specific requirements of the following standards for the transmitter type of protection:

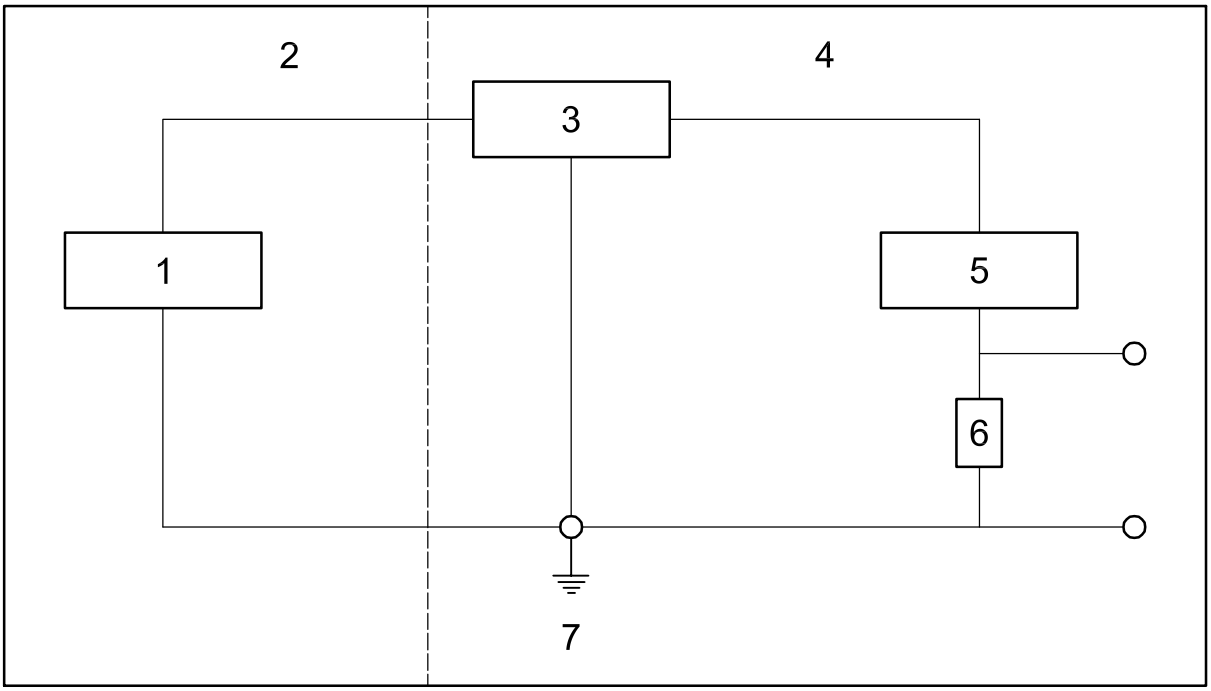
— IEC 60079-11 for type of protection "i";

— IEC 60079-1 for type of protection "d";

— IEC/TR 60079-15 for type of protection “n”.

Individual transmitters shall have a tag reporting the approvals in accordance with IEC 60079-0.

A basic connection scheme for “i” type of protection is shown in Figure 11. In practice, a lot of variations on this scheme are possible: for more information on the intrinsic safety-related methods, refer to the existing standards.



Key

1 transmitter
2 hazardous area
3 barrier
4 safe area
5 power supply
6 load
7 safety earth

Figure 11 — Example of installation with intrinsic-safety barriers (type “i”)

7.4 Calibration

7.4.1 General

A transmitter calibration is usually carried out using the following instruments:

— pressure reference device (e.g. deadweight tester);

— smart field communicator (only in case of smart transmitters);

— precision multi-meter or final readout device (e.g. flow computer, controllers);

— barometer (in case of absolute pressure transmitters).

Differential pressure transmitters can require a calibration procedure to compensate for static pressure effects, which introduce a systematic error. This operation can be done by setting the zero trim. Use of reference devices that are operated at line pressure avoids the above procedure.

It is recommended that calibration is carried out *in situ*. If calibration is carried out in a laboratory, care should be taken to avoid transportation and different orientation effects.

The calibration of transmitters shall be carried out at a minimum of two points (zero and maximum of adjusted range); more calibration points may be used to compensate for possible non-linearity of the transmitter.

(Re)adjustment of the instrument shall be carried out only when the readings of the device are outside the uncertainty band valid for the reading under consideration.

The pressure (absolute and differential) reference device shall have an uncertainty at least three times smaller than that of the transmitter.

7.4.2 Smart transmitter calibration

The first step of smart transmitter calibration consists of matching the digital pressure variable reading of the transmitter to a reference pressure input. This operation, necessary to trim the sensor of the transmitter and to verify, and if necessary to correct, its characteristic curve previously stored by the manufacturer, shall be carried out in two phases:

— correction of the lower range value;

— correction of the upper range value.

If necessary, an additional calibration step, consisting of correcting any errors in the electronics circuitry converting the digital signal into a standardized analogue signal, can be made. This operation allows the adjustment of the analogue signal in line with the digital signal from the sensor.

NOTE If a re-ranging only is required, it is sufficient to use a smart field communicator. However, with this operation, the transmitter accuracy can decrease.

For a detailed description of calibration procedures and corrections, refer to manufacturer manuals.

7.4.3 Analogue transmitter calibration

Analogue transmitter calibration consists of connecting a reference pressure input to the transmitter and adjusting the electrical output signal. Usually this operation is made by setting the zero and span-adjustment screws (it is advisable to adjust the span first).

For a correct calibration procedure, it is strongly recommended to follow the manufacturer specifications.

7.5 Verification

Periodically, the transmitter output shall be checked at one or more points in its working range, comparing it with reference pressure values. The agreement between the measured and the reference value at each point shall be within the permitted tolerance. If this is not the case, a recalibration of the instrument shall be made or the transmitter replaced.

For differential pressure transmitters, before a verification, it is necessary to consider the previous correction for the static pressure effect; use of reference devices that are operated at line pressure avoids the requirement for this procedure.

A calibration of a metering system, including associated transmitters, against approved and traceable standards along with the process conditions at the occasion of the calibration may be used in some jurisdictions as the basis for the issuance of a meter calibration certificate. This information constitutes the footprint of the meter for use during future verifications. These verifications consist solely of the test of one representative parameter of the transmitter at the same process conditions for comparison with the footprint. A successful verification, in applicable jurisdictions, which, can lead to re-certification.

7.6 Maintenance

All maintenance work shall be done in accordance with manufacturer specifications.

7.7 Quality control

Quality control on pressure measurements can be obtained by installing another transmitter for monitoring purposes and/or rationalizing the periodical verifications.

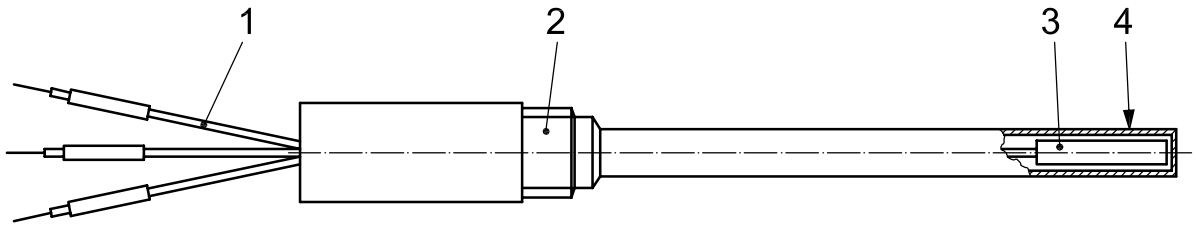
NOTE The long-term transmitter stability can be monitored by recording all the results of the verifications and calibrations and, consequently, adjustment of verification and calibration intervals can be planned, e.g. using control limits and significance limits.

8 Temperature

8.1 Principle of measurement

In custody transfer operations, the gas temperature is widely measured by means of resistance thermometer detectors (RTD).

An RTD consists of a measurement resistance placed in a protective sheath, internal connecting wires and external terminals in order to connect it with the electrical measurement devices (see Figure 12).



Key

1 cable terminals
2 thread
3 thermometric resistance
4 protective sheath

Figure 12 — Typical construction of an RTD

An RTD is based on the principle that the electrical resistance of a metal increases with its temperature. The metal most commonly used in RTD sensors is platinum (Pt) because of the following physical characteristics:

— reproducibility of the temperature/resistance curve;

— chemical characteristics constant over time;

— high electric resistivity;

— high temperature coefficient, α.

NOTE Platinum is a noble metal that does not oxidize, has an high melting point and exhibits little evaporation at temperatures lower than 1 200 °C. It can be obtained in an ultra-pure state, which guarantees a highly reproducible characteristic curve.

Electrical temperature sensors such as RTDs produce a low-level signal, proportional to the sensed temperature. Long wires between the sensor and electrical measurement devices can result in large errors due to the noise, unless great care is taken with shielding. In addition, extra compensation wires (see 8.3.5) are needed between the sensor and electrical measurement devices.

These problems can be eliminated by mounting a signal-conditioning device close to the measurement point. A temperature transmitter offers a convenient, reliable and economical way to do this, provided that this transmitter has adequate (environmental) specifications.

The temperature is converted to a standardized analogue electrical signal in accordance with IEC 60381-1 or to a digital signal, which is transmitted to further processing.

The temperature/resistance relationships used for compliance with this International Standard shall be in accordance with IEC 60751.

8.2 Performance assessment and acceptance tests

8.2.1 Requirements and performance assessments for instrument selection

It is necessary to consider many elements during the choice of an RTD, depending on the specific use. The choice is usually based on the following parameters:

a) application;

b) operating temperature range;

c) dynamic characteristics (time constant);

d) safety conditions;

e) precision under static conditions, depending on the combination of the following parameters:

- calibration;
- sensitivity;
- self-heating;
- long term reproducibility;
- connections;
- cost.

For temperature measurement in a gas flow, a cylindrical sensing element is generally adopted.

Information on the behaviour in the operating temperature range, such as repeatability, electrical insulation, time constant and self-heating factors, shall be provided by the manufacturer or obtained by a performance assessment (see 8.2.2).

Methods for evaluating transmitter performance shall be in accordance with those given in IEC 60770-1.

8.2.2 Factory, purchasing and site-acceptance tests

RTDs shall comply with the requirements of IEC 60751. The following tests shall be carried out by the manufacturer in order to demonstrate such compliance:

a) routine production tests performed on every RTD:

- insulation resistance,
- resistance tolerance;

b) sample tests performed on a limited number of sensors under controlled conditions:

- insulation resistance,
- resistance accuracy,
- thermal response time,
- self-heating,
- immersion error,
- thermo-electric effect,
- limiting temperatures,
- effect of temperature cycling;

c) additional tests for RTDs used in severe environmental conditions:

- drop tests,
- vibration tests,
- pressure tests.

A detailed description of these acceptance tests is given in IEC 60751.

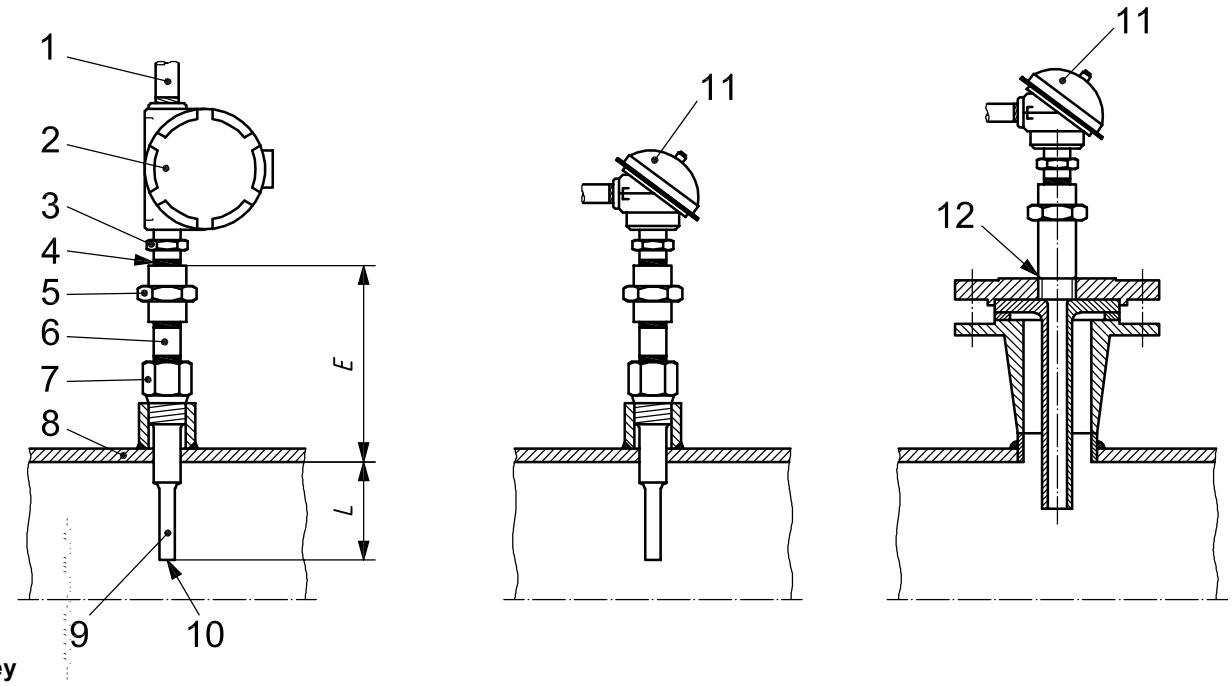
8.3 Installation guidelines

When the thermowell (see 8.3.1) with the thermometer probe is inserted into the moving fluid, the boundary layer tends to resist the transfer of heat to the probe and at the same time heat is lost to the surroundings via the probe. The latter effect can be reduced by applying thermal insulation.

8.3.1 Thermowell

The thermometer probe shall be mounted in a thermowell (see Figure 13) to protect it from the adverse effects of corrosion, vibration or excessive pressures and to give easy access to the probe unit.

The thermowell shall mechanically resist the static and the dynamic loads caused by flow induced resonance.



Key

1 conduit for field wiring (dc power)
2 transmitter
3 sensor hex
4 sensor adapter
5 union of coupling
6 extension nipple
7 thermowell hex
8 wall of pipe
9 sensitive portion of sensor
10 thermowell
11 connection head
12 thread
E extension length
L immersion length

Figure 13 — RTD installation

8.3.2 Selection of the measuring point

In general, the RTD shall be mounted perpendicular to the pipe wall, as illustrated in Figure 14.

Using this installation, severe vibration of the probe can result from the fluid flow around the inserted probe. Care should be taken in locating this probe and care should be taken so that the maximum allowable fluid velocity is not exceeded.

The measurement point is indicated in the specific standard for each flowmeter.

8.3.3 Electrical isolation of the temperature transducer

Electrical isolation prevents disturbances caused by variations in the isolation resistance of the sensing elements. These are generally caused by impurities penetrating into the junction box and by the cathodic protection of the pipe.

A good electrical isolation is recommended.

Minimum insulation resistance values shall conform to the requirements of IEC 60751.

8.3.4 Restrictions on the thermowell

Where thermowell pockets are in close proximity to each other, care shall be taken not to install them in line. This is to prevent the downstream probes from being subjected to unduly high stresses as a result of vortex shedding and vibrations. The problem of vortex shedding can be minimized by spacing the thermowell pockets radially around the pipe.

To ensure good temperature measurement, thermowells shall protrude into the pipework to approximately 1/3 of the nominal inside diameter, measured from the inner wall. However, for pipes larger than 300 mm where resonant vibrations of the thermowell are known to be a problem, the design of the thermowell can restrict the depth of insertion. Resonant-vibration problems can be avoided by the application of conical instead of parallel thermowells. For larger pipes, insertion depths of 75 mm to 100 mm are conservative.

For smaller pipes where the insertion depth becomes larger than 3/4 of the nominal inside diameter of the pipe, thermowells shall be installed in a pipe bend or obliquely at 45° to the flow direction.

The RTD should be completely inserted in the thermowell.

The air between the measuring element and the well is a very poor heat conductor and results in measurement errors. Another effect of the air is to slow the response time of the element. A liquid filling the empty space is the solution generally adopted; care should be taken to ensure an adequate freezing point of the liquid.

Care should also be taken regarding external temperature conditions, including heat transfer due to radiation and ambient temperature.

This effect should be limited by thermal insulation around the pipe including the RTD, generally over a length of $5D$ on both sides of the RTD where the RTD is installed. This insulation design shall allow access to the connections for checking and maintenance.

8.3.5 Electrical connections

For correct measurement of temperature, the effect of the resistance of the wires connecting the sensor to the electrical measurement device shall be eliminated. This is particularly important at locations where there are large variations of ambient temperature.

As a 2-wire connection can cause measuring errors due to the length of the connecting wires and the environmental temperature, it is recommended to use a 4-wire connection.

8.3.6 Self-heating effect

The measurement current through the RTD causes self-heating through the Joule effect. In order to minimize this effect, an appropriate shape of the protective sheath and low supply currents shall be used, whose values shall be provided by manufacturers. This effect is negligible for commonly used connection cables (less than 0,02 °C at 1 mA).

8.4 Calibration

8.4.1 Sensor calibration

In the case of a temperature transducer, the sensing element is kept in a thermostatic bath and the measured temperature is compared with that of a primary thermometer traceable to the International Temperature Scale of 1990 (ITS-90) [1].

The calibration procedure of an RTD is carried out in two steps:

a) sensor calibration with the reference values;

b) data processing to obtain the correction curve (table or analytical function).

Depending on the temperature range of the RTD being calibrated, it is necessary to select the temperature points (a minimum of three) where the resistance values are measured.

In order to reduce the errors due to temperature fluctuations in the thermostatic bath, it is convenient to repeat each calibration point at least five times. In order to avoid thermal inhomogeneity of the bath, care should be taken that the sensing elements of RTDs be close to each other or that a temperature-equalization block be used.

When an RTD calibration is carried out, a number of resistance values corresponding to temperature measurements are determined. Subsequently, it is necessary to characterize the transducer with a best-fit calibration curve. Characterization is normally done by the manufacturer of the RTD assembly and/or transmitter.

From practice, it is known that Pt 100 elements hardly change over the years; therefore, after initial calibration, recalibration is not normally needed.

8.4.2 Transmitter calibration

Usually, the transmitter is factory calibrated to the temperature range shown on the nameplate. Calibration of the transmitter can also be performed by substituting a resistance decade box for the sensor. The uncertainty of the resistance decade box should be equal or better than 0,01 %.

8.5 Verification

A periodic check shall be carried out to verify that the temperature devices are within the fixed tolerances. To carry out this check, a reference RTD shall be installed in a thermowell close to the RTD being tested and the readings compared; they shall be within a predetermined limit.

A periodical verification of the RTD performance can be carried out over a restricted temperature range. For example, a liquid bath at the ice point can be used in order to check the resistance value at 0 °C (R_0).

8.6 Maintenance

The manufacturer's specifications shall be followed for the maintenance of RTDs and transmitters.

8.7 Quality control

Quality control of temperature measurements can be obtained by installing another probe for monitoring purposes and/or rationalizing the periodical verifications with the application of control and significance limits.

The long-term stability of an RTD shall be monitored by recording all test results. This enables the planning of proper verification and calibration intervals.

(Re)adjustment of the instrument shall be carried out only when the readings of the device are outside the uncertainty band valid for the reading under consideration.

For temperature transmitters, shorter verification and calibration intervals are recommended.

9 Compression factor

9.1 Principle of measurement

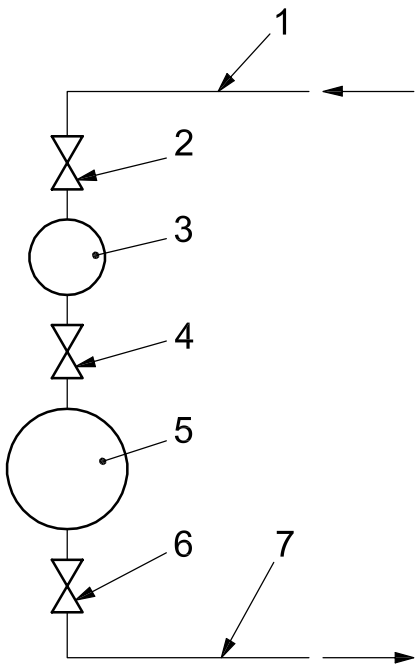
9.1.1 Working limits

The Z-meter works only at line pressures that give a ratio pressure/compression factor higher than 1 MPa and lower than 9 MPa.

9.2 Working principle

The Z-meter is, in principle, an expansion-type meter using a single-step rather than a multiple-step expansion like the conventional laboratory Burnett apparatus.

The apparatus consists essentially of two vessels, 1 and 2, of inside volumes V_1 and V_2, respectively, ($V_1 < V_2$), and three valves surrounded by a massive metallic wall of great thermal inertia (see Figure 14). The small volume, consisting of a tube, is welded as a spiral around the large cylindrical volume to improve thermal exchanges between them.



Key

1 gas inlet
2 valve 1
3 vessel 1 with volume V_1
4 valve 2
5 vessel 2 with volume V_2
6 valve 3
7 gas outlet

Figure 14 — Diagram of a Z-meter

The operation of the Z-meter is cyclic and is divided into two phases:

a) Phase 1: valves 1 and 3 are opened and valve 2 is closed. Vessel 1 is filled with the sample gas at pressure, p_1, and temperature, T, and vessel 2 is at atmospheric pressure, p_2.

b) Phase 2: valves 1 and 3 are closed and valve 2 is opened. The volume, V_1, of sample gas in vessel 1 expands into the volume, V_2, of vessel 2 and when temperature stability is re-established, the pressure, p_3, in vessels 1 and 2 is measured.

The valves are opened or closed by means of a pneumatic motor controlled by an electrovalve. They are interlocked by means of a mechanical link.

The pressures measured before and after the expansion allow the calculation of the compression factor, Z. The compression factor, Z_1, is calculated by applying the equation of state to volumes V_1, V_2 and $V_3 = V_1 + V_2$, at pressure, p_1, and temperature, T, in terms of the (unknown) "low-pressure" compression factors, Z_2 and Z_3, as given in Equation (8):

$$Z_1 = \frac{p_1}{\left(\frac{p_3}{Z_3}\right)(k_V + 1) - \left(\frac{p_2}{Z_2}\right)k_V} \tag{8}$$

where

$$k_V = \frac{V_2}{V_1}$$

Equation (8) is valid only if the temperature before and after the expansion is the same, because of the large thermal buffer and the small amount of gas sample.

The volume ratio, k_V , shall be determined before the measurement by calibration of the Z-meter using a gas of known compressibility, as determined from a compressibility table.

9.2.1 Calculation

The values for Z_2 and Z_3, are obtained using the relationship between the compression factor and the pressure as given in Equation (9):

$$Z(p,T) = 1 + B_1(T)p + B_2(T)p^2 \tag{9}$$

where

p_2, p_3 are less than 0,3 MPa;

$B_2(T)$ is an average coefficient, calculated for natural gases, that varies little from one gas to another;

NOTE For natural gases, this value can be set to $1{,}5 \times 10^{-6}$. This value is frequently set to zero, depending on the required precision.

$B_1(T)$ is obtained as an approximation from Equation (10):

$$B_1(T) = \frac{Z_1 - 1 - C(T)p_1}{p_1} \tag{10}$$

An iterative scheme which takes $Z_2 = Z_3 = 1$ as its starting point is used to solve Equation (8). This new value of Z_1 is then used in Equation (10) to calculate a new $B_1(T)$ and then, using Equation (9), to calculate new

values for Z_2 and Z_3. These values are then put back into Equation (8). The equation is considered "solved" when the difference between the two successive values of Z_1 is very low. In practice, three steps are sufficient.

A better determination of the C coefficient should be made for laboratory measurements where a higher degree of accuracy is needed and where pure gases are used. In that case, the determination of the compression factor of the unknown gas is done in two steps: the first step consists of determining the compression factors at several pressures with $C = 0$ and then calculating the C coefficient of the equation using a "least squares method" fit, and then re-entering this value into the equation for Z.

9.2.2 Method of extrapolating Z for other conditions

9.2.2.1 General

This method is used for predicting the value $Z_f(p_f,T_f)$ from the value $Z_i(p_i,T_i)$, i.e. for other pressure and temperature conditions (for example, if the temperature of the Z-meter is not exactly the same of that of the line gas).

Equations (11) and (12) use the factor $k_Z(p,t)$, that is, the ratio of $Z(p,t)$ and Z_n, the compression factor at the reference conditions p = 101,325 kPa, t_n = 0 °C.

For other reference conditions, the values a, b, e and g should be recalculated.

The method is based on experimental values. For example, for a step of 5 °C and for various gases, even containing up to 25 mol % of nitrogen or up to 28 mol % of carbon dioxide, the relative deviation between the measured value of Z and the extrapolated value is lower than 0,1 %.

9.2.2.2 Temperature extrapolation (isobaric)

Extrapolate $k_{Z,f}$ at a different temperature using Equation (11):

$$k_{Z,f} = \left[1 + \left(a + bK_i\right)\left(t_f - t_i\right)\right] K_{Z,i} \tag{11}$$

where

$a = 1{,}858\,4 \times 10^{-2}$

$b = -\,1{,}886\,4 \times 10^{-2}$

The significance of this formula is that the local derivative of k_Z relative to the temperature, under isobaric conditions, is a function of the local value of k_Z. To get the best performance, the iteration should be carried out in steps of 1 °C maximum (the smaller the step, the more symmetrical the method when determining $k_{Z,f}$ from $k_{Z,i}$ and then returning to $k_{Z,i}$).

9.2.2.3 Pressure extrapolation (isothermic)

Extrapolate $k_Z(p, t)$ at a different pressure using Equation (12):

$$K_Z(p,T) = 1 + et + f(p - p_n) + g(p - p_n)^2 \tag{12}$$

where

$e = 2{,}8 \times 10^{-5}$

$g = 1{,}5 \times 10^{-6}$

NOTE These two coefficients, e and g, are average coefficients calculated on the bases of many different natural gases and vary little from one gas to another. It is possible to improve the method through specific determination of coefficient g for a family of gases.

Solve Equation (12) using a value of f calculated with the initial $k_{Z,i}(p_i,t_i)$.

9.3 Performance assessment and acceptance tests

9.3.1 General

The tests given in 9.3.2 to 9.3.8 shall be performed to verify the performance of the instrument.

9.3.2 Repeatability test

Carry out a sufficient number of measurements of the compression factor of a sample of gas under the same conditions of pressure and temperature, to obtain a 95 % confidence level.

9.3.3 Accuracy test

Carry out measurements with a pure gas at several points in the pressure range. Compare these measurements with the values from the compressibility table of the pure gas.

9.3.4 Sensitivity test

Having calibrated the Z-meter with a pure gas, measure a reference gas (pure or mixture), the value of which is known from a compressibility table, at different pressure points and compare the results.

9.3.5 Temperature-effect test

Calibrate the Z-meter at different temperatures (minimum between 5 °C and 35 °C). Allow a stabilization time of at least 12 h for each temperature. Compare the results.

NOTE This is really a test on the reaction of the absolute pressure transmitter with temperature variations.

9.3.6 Response time test

Measure the time necessary to get a steady reading of the instrument after another gas is applied at the inlet of the Z-meter.

9.3.7 Absolute pressure transmitter tests

Carry out the tests described in Clause 7.

9.3.8 Temperature probe tests

Carry out the tests described in Clause 8.

9.4 Sampling and installation guidelines

The goal is that the sample of gas flowing into the Z-meter be representative and conditioned. Gas is extracted from the pipe and introduced into the Z-meter at line pressure.

It is recommended that a filter be installed before the inlet of the Z-meter to avoid possible liquid or particles entering into the instrument.

The Z-meter shall be installed at a temperature between 5 °C and 35 °C on a horizontal and stable surface.

If the Z-meter is installed in the field, it is recommended that it be placed close to the small cabin enclosing the meter run. The cabin should be thermally insulated but not the piece of meter run inside it. In this way, the pipeline acts as an exchanger and the temperature in the cabin is kept close to that of the gas. Usually the difference is less than 5 °C. The vent of the Z-meter should be brought outside the room or the cabin.

The system shall provide some connection facilities for verification with reference gases.

The built-in absolute pressure transmitter and the temperature sensor or transmitter shall be connected in accordance with manufacturer's instructions.

It is necessary that sufficient pressure be available to start the motor.

9.5 Calibration

The determination of the volume ratio $k_V = V_2/V_1$ is the most important phase of the Z-meter calibration. Equation (8) can be rearranged to calculate the ratio, as given by Equation (13):

$$k_V = \frac{\frac{p_1}{Z_1} - \frac{p_3}{Z_3}}{\frac{p_3}{Z_3} - \frac{p_2}{Z_2}} \tag{13}$$

where

p_1, p_2 and p_3 are measurements made during a Z-meter calibration run;

Z_1, Z_2 and Z_3 are the known values for the calibration gas.

Hence, to calibrate the Z-meter volume ratio k_V, a gas whose value has been determined reliably and very accurately from the compressibility table shall be employed. This gas shall be of very high purity (for example nitrogen or methane having a purity of $\geqslant$ 99,95 %). Usually, nitrogen, methane, argon or helium are used.

For this pure gas, it is recommended that the tables used be those chosen for the GERG databank [2], which are also used for the calculation of the Z factor from the analysis of the gas composition.

The measurement of the pressure, p_1, is made from a very accurate pressure standard, for example a dead-weight standard balance (normally having an uncertainty of 1×10^{-4} or 5×10^{-5} of the measured value), taking into account the difference between the level of the Z-meter and that of the pressure standard. The pressures p_2 and p_3 are measured by the same absolute pressure transmitter using the previously determined calibration function. The temperature is measured by a platinum resistance sensor or by a transmitter inserted in the body of the Z-meter.

The volume ratio, k_V, is calculated at different pressures covering the working range (e.g. between 3 MPa and 7 MPa with a step of 500 kPa). At each pressure, the measurements are repeated (e.g. five times). After collecting all the data, the average of the different k_V ratios is calculated. At this point, it is possible to stop and to consider the Z-meter as being calibrated.

However, a better determination of k_V can be calculated. It is assumed that the dispersion of the different k_V values found during the calibration of the Z-meter is the result of errors in the measurement of the pressure before and after expansion because p_1 is measured very accurately and k_V is a physical constant of the system. This can be improved by using the following procedure.

Recalculate all the p_3 values using Equation (8) and the volume ratio k_V that has just been determined. Determine the new coefficients of the calibration function of the transmitter by fitting all the pairs (measured p_2 and calculated p_3) with corresponding signals. Use the new coefficients for the transmitter for the Z measurements. The k_V factors are then recalculated using this new calibration function for the absolute transmitter and averaged.

9.6 Verification

Carry out a periodic verification of the Z-meter using a gas whose value is known from the compressibility-factor table, comparing the value of the measured Z with the value of the table at different pressures, p_1 (for example, methane or helium).

If mixtures are used as reference gases, their compression factor should be calculated in accordance with ISO 12213-1.

The verification can be carried out very easily because the Z-meter is not inside the line, so it can be disconnected from the line gas. It is necessary only to provide a means to bring the reference gas into the system. In case of problems, the Z-meter should be recalibrated in the laboratory.

Carry out a periodic check of the line-pressure transmitter and temperature transmitter or sensor in accordance with the manufacturer's specifications.

9.7 Maintenance

Carry out all maintenance procedures as described in the manufacturer's manual.

Filters shall be checked at regular intervals and replaced, if necessary.

NOTE The condition of the operating gas governs the length of time between checks.

9.8 Quality control

When more than one Z-meter is running on a station measuring the same gas quality, it is possible to compare them continuously. The different values of $Z(p,T)$ collected for each Z-meter can be extrapolated using Equation (11) for temperature and Equation (12) for pressure to a value of Z at one reference pressure and reference temperature, for example at 5 MPa and 15 °C.

If the composition of the gas is available (for example by gas chromatography), a comparison can be made between measured values of the compression factor and values calculated using the equation given in ISO 12213-2.

If the superior calorific value, relative density, carbon dioxide and hydrogen content are available, comparison can be made between measured values of the compression factor and values calculated using the equation given in ISO 12213-3.

Annex A
(informative)

Guidance for instrument selection, instrument test and operational procedures

In this annex, there are three flow charts that should be regarded as guidelines for all the instruments considered in this International Standard concerning

— requirements and performance assessments for instrument selection;

— factory, purchasing and site acceptance tests;

— operational procedures.

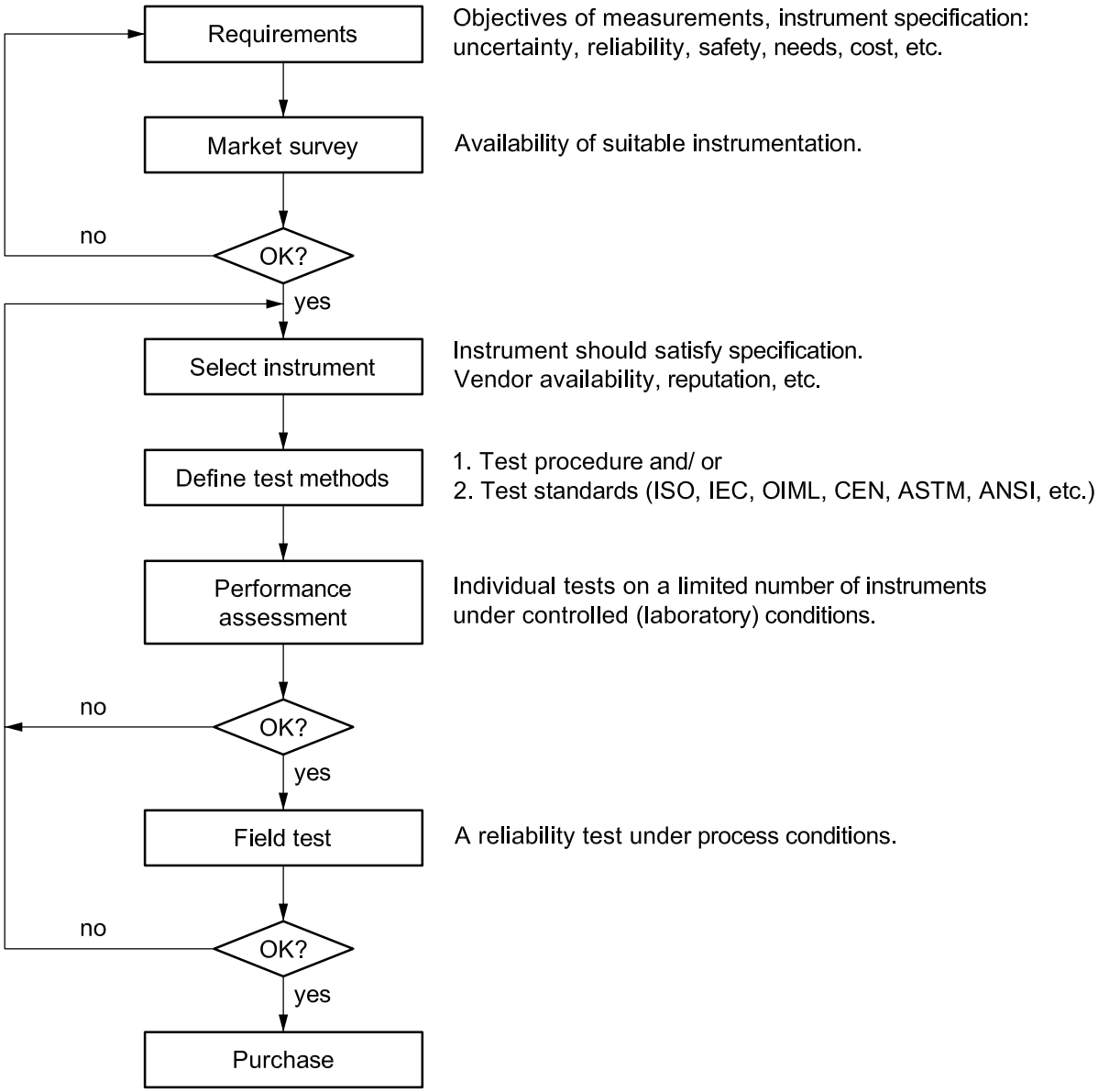


Figure A.1 — Requirements and performance assessments for instrument selection

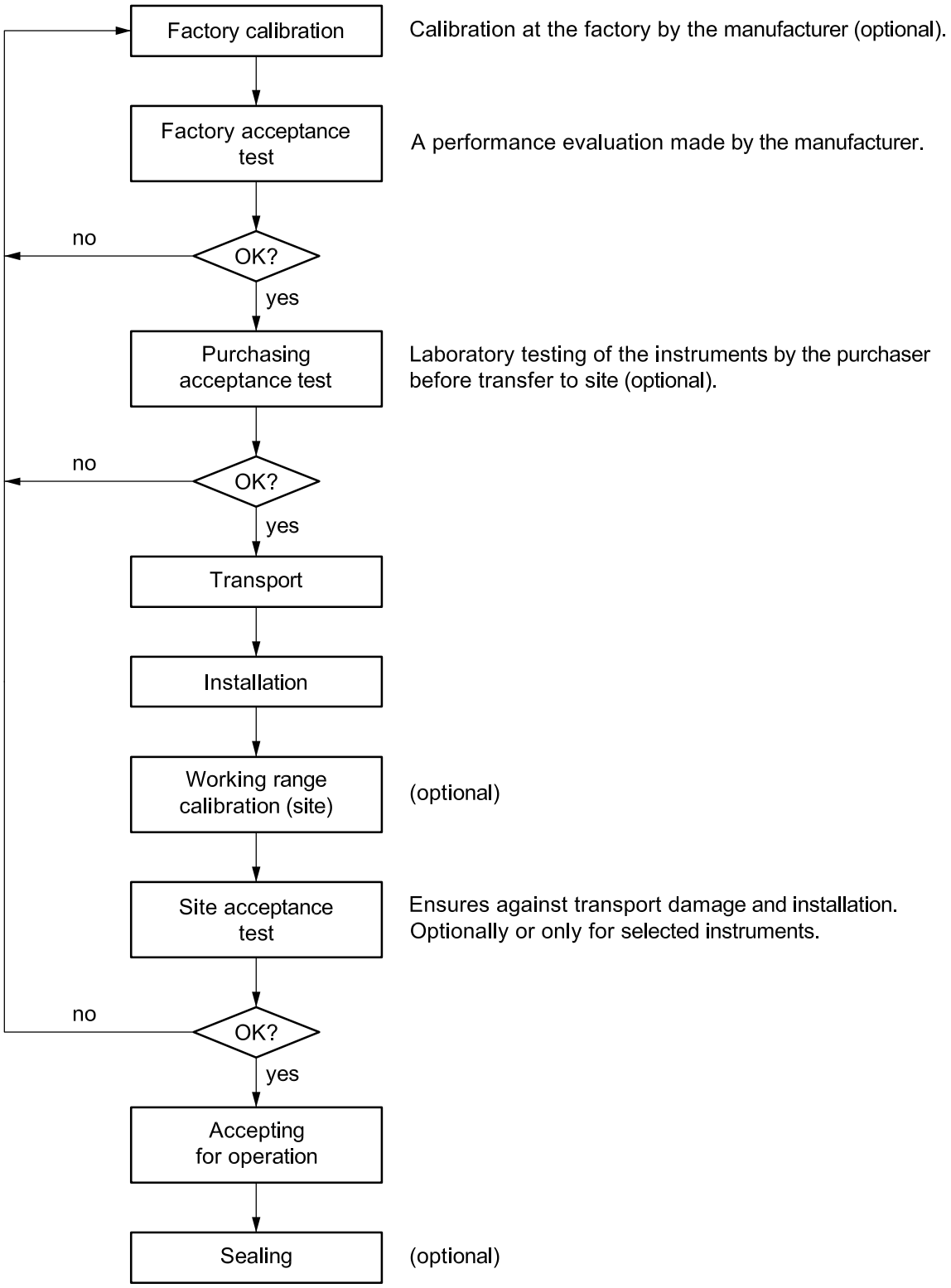


Figure A.2 — Factory, purchasing and site-acceptance tests

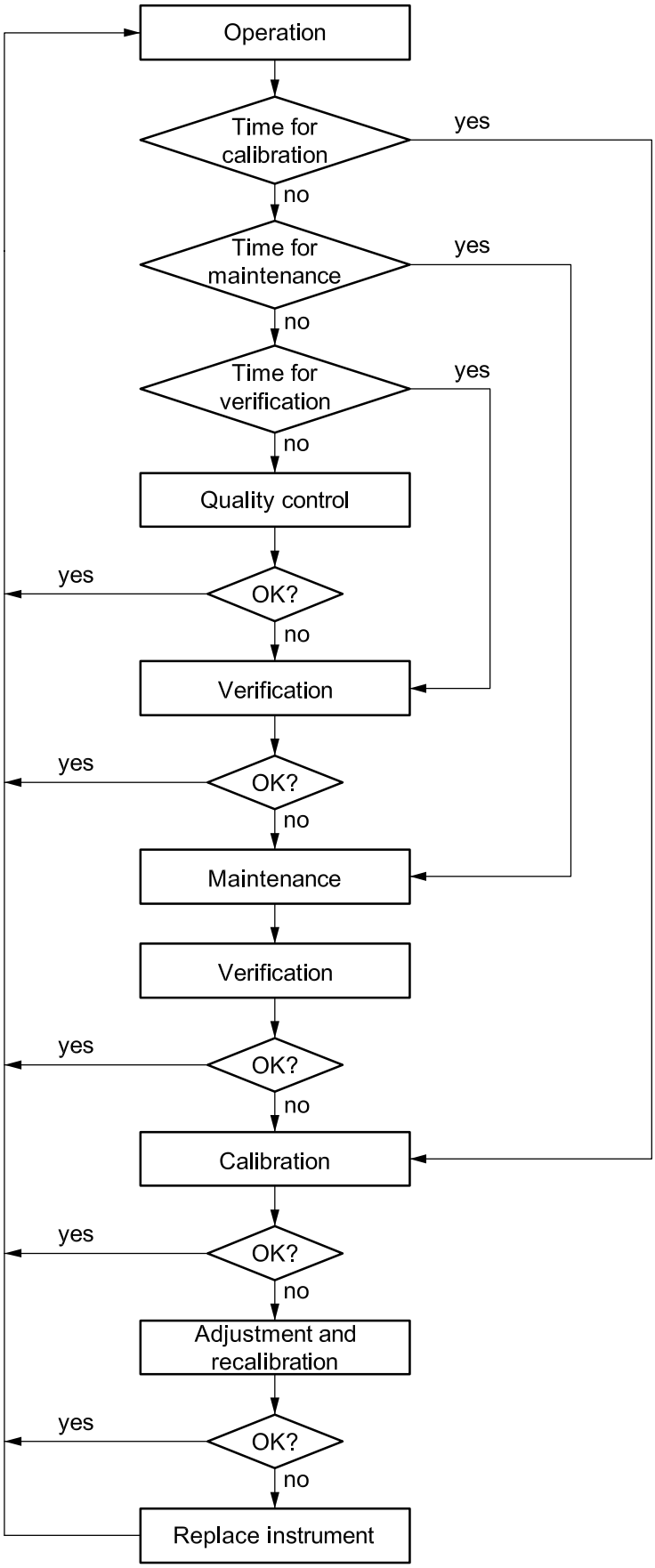


Figure A.3 — Operational procedures

Annex B
(informative)

Instrument documentation

In addition to a short description of the principle of measurement, the instrument design, the auxiliary equipment for signal processing and the range of application, the instrument documentation should include all necessary data for correct functioning and proper choice of the instrument.

The following data are of particular importance for the instrument documentation:

a) general:

- type,
- model,
- manufacturer,
- weight,
- dimensions,
- materials,
- costs;

b) installation:

- measuring range,
- operating pressure,
- flow rate,
- allowable ambient conditions,
- protection class,
- connecting dimensions,
- installation requirements;

c) gas sampling:

- temperature of the gas,
- pressure of the gas,
- flow rate of the gas,
- humidity and pollution of the gas,
- mounting position;

d) operation:

- set-up and start-up procedures,
- maintenance,
- verification and recalibration time intervals,
- handling,
- trouble shooting,
- robustness;

e) electrical data:

- output,
- supply voltage,
- consumption,
- load;

f) measurement characteristics:

- uncertainty,
- linearity,
- sensitivity,
- repeatability,
- stability,
- response time,
- limits (e.g. pressure and temperature).

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