INTERNATIONAL STANDARD

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Measurement of fluid flow in closed conduits — Thermal mass flowmeters

Mesure de débit des fluides dans les conduites fermées — Débitmètres massiques par effet thermique

Reference number
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Contents

Page

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 3.

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 International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 14511 was prepared by Technical Committee ISO/TC 30, *Measurement of fluid flow in closed conduits*, Subcommittee SC 5, *Velocity and mass methods*.

Introduction

This International Standard has been prepared to guide those concerned with the specification, testing, inspection, installation, operation and calibration of thermal mass gas flowmeters.

A list of standards related to ISO 14511 is given in the bibliography.

Measurement of fluid flow in closed conduits — Thermal mass flowmeters

1 Scope

This International Standard gives guidelines for the specification, testing, inspection, installation, operation and calibration of thermal mass gas flowmeters for the metering of gases and gas mixtures. It is not applicable to measuring liquid mass flowrates using thermal mass flowmeters.

This International Standard is not applicable to hot wire and other hot film anemometers, also used in making point velocity measurements.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

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

ISO 7066-2, *Assessment of uncertainty in the calibration and use of flow measurement devices — Part 2: Non-linear calibration relationships*

Guide to the expression of uncertainty in measurement (GUM). BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML, 1st edition, corrected and reprinted in 1995

IEC 61000-4, *Electromagnetic compatibility (EMC) — Part 4: Testing and measurement techniques*

3 Terms and definitions

For the purposes of this International Standard, the terms and definitions given in ISO 4006 and the following apply.

NOTE The term “gas” is used as a synonym for single gases, gas mixtures and vapours.

3.1 General terms

3.1.1
flowrate
quotient of the quantity of fluid passing through the cross-section of a conduit and the time taken for this quantity to pass through this section

NOTE In this International Standard, the term “flowrate” is used as a synonym for mass flowrate, unless otherwise stated.

3.1.2
mass flowrate
flowrate in which the quantity of fluid is expressed as a mass

NOTE The term “flowrate” is used as a synonym for mass flowrate in this International Standard, unless otherwise stated.

3.1.3
accuracy of measurement
closeness of the agreement between the result of a measurement and a true value of the measurand

NOTE Accuracy is a qualitative concept.

3.1.4
uncertainty of measurement
parameter, associated with the result of a measurement, that characterizes the dispersion of the values that can reasonably be attributed to the measurand

3.1.5
repeatability
⟨measuring instrument⟩ ability of a measuring instrument to provide closely similar indications for repeated applications of the same measurand under the same conditions of measurement

NOTE These conditions include:

— minimized variations resulting from the observer;

— the same measurement procedure;

— the same observer;

— the same measuring equipment, used under the same conditions;

— the same location;

— repeated measurements within a short period of time.

3.1.6
flow profile
graphic representation of the velocity distribution

NOTE The point flow velocity across the cross-section of a conduit is not constant. It varies as a consequence of upstream and downstream disturbances and with the Reynolds number of the flow stream. For a fully developed flow, the point flow velocity varies from 0 m/s at the pipe wall to a maximum value at the conduit centre. The flow profile describes the variation of the flow velocity across the conduit cross-section and may be expressed mathematically or graphically.

3.2 Specific terms

3.2.1
sensor
element of a measuring instrument or measuring chain that is directly affected by the measurand

3.2.2
laminar flow element
element inserted into the gas stream to establish a constant ratio between the main flow stream and the bypass flow through the sensor

3.2.3
thermal mass flowmeter
TMF meter
flow-measuring device which uses heat transfer to measure and indicate mass flowrate

NOTE The term thermal mass flowmeter also applies to the measuring portion of a thermal mass flow controller and not the control function.

3.2.4
capillary thermal mass flowmeter
CTMF meter
TMF meter normally consisting of a laminar flow element, bypass tube (capillary), temperature sensors (some designs include a separate heater) with supporting electronics and housing

3.2.5
insertion and/or in-line thermal mass flowmeter
ITMF meter
TMF meter normally consisting of one or two temperature sensing sensors (some designs have a separate heater) with supporting structure, electronics and housing, of which the sensors are exposed to the full gas stream

3.2.5.1
insertion-ITMF meter
ITMF meter with the sensors mounted on a probe, inserted through the process conduit wall, into the gas stream

3.2.5.2
in-line ITMF meter
ITMF meter with the sensors mounted in a flow body which serves as an integral part of the conduit

3.2.6
thermal mass flow controller
flow controlling device that comprises a TMF meter, a valve and controlling electronics

NOTE The output of the TMF meter is compared against an adjustable setpoint and the valve is correspondingly opened or closed to maintain the measured flowrate at the setpoint value.

3.2.7
transmitter
associated electronics providing the heater with electrical power and transforming the signals from the temperature sensors to give output(s) of the measured parameters

NOTE The transmitter can be integrally mounted to a TMF meter. However, for some applications the transmitter can be remotely installed away from the flow sensor.

3.2.8
retractor mechanism
⟨insertion-ITMF meters⟩ mechanical arrangement including an isolation valve that allows the positioning and/or extraction of the flow sensor within the conduit

3.2.9
rangeability
statement of the minimum and maximum limits of which an individual sensor can measure and indicate

EXAMPLE For a maximum flowrate = 1 000 kg/h and a minimum flowrate = 10 kg/h, the rangeability = 10 kg/h to 1 000 kg/h.

3.2.9.1
turndown
numerical ratio of the maximum to minimum limits of which an individual sensor can measure

EXAMPLE For a maximum flowrate = 1 000 kg/h and a minimum flowrate = 10 kg/h, the turndown ratio = 1 000/10 = 100:1.

NOTE In practice, the terms rangeability and turndown are used interchangeably and can be associated with an uncertainty statement.

3.2.10
***k*-factor**
numerical factor unique to each TMF meter which is associated with the mass flowrate derived during the calibration and when programmed into the transmitter ensures that the meter performs to its stated specification

NOTE When a surrogate gas has been used for calibration purposes, the manufacturer's gas factor list or database has been applied for conversion to the desired gas under process conditions.

3.2.11
normalized volumetric flowrate (GB)
standardized volumetric flowrate (US)
flowrate for which the quantity of fluid is expressed in terms of volume, with the fluid density calculated at a known and fixed pressure and temperature condition

NOTE 1 The values used to define these reference conditions (also known as "standard reference conditions") are industry and country specific and therefore shall always be specified when these units are used. Typical reference conditions are 0 °C and 101,325 kPa.

NOTE 2 Normalized volumetric units or volumetric units specified to standard reference conditions, such as "Nm^3/h", are commonly used with CTMF and ITMF meters, however this practice is not recommended as they are neither SI units nor symbols and their use without knowledge of the reference conditions will lead to significant errors. In this International Standard, volumetric units specified to standard reference conditions are followed by the expression "(normalized)", e.g. m^3/h (normalized).

3.2.12
normalized velocity (GB)
standardized velocity (US)
flowrate for which the quantity of fluid is expressed in terms of the speed of flow, with the fluid density calculated at a known and fixed pressure and temperature condition

NOTE 1 The values used to define these reference conditions (also known as "standard reference conditions") are industry and country specific and therefore shall always be specified when these units are used. Typical reference conditions are 0 °C and 101,325 kPa.

NOTE 2 Normalized volumetric units or volumetric units specified to standard reference conditions, such as "Nm/s", are commonly used with CTMF and ITMF meters, however this practice is not recommended as they are neither SI units or symbols and their use without knowledge of the reference conditions will lead to significant errors. In this International Standard, volumetric units specified to standard reference conditions are followed by the expression "(normalized)", e.g. m/s (normalized).

4 Selection of thermal mass flowmeters

TMF meters fall into two basic design categories:

a) capillary TMF meters (CTMF meters);

b) full bore TMF meters, consisting of the following two types (ITMF meter):

   1) insertion type;

   2) in-line type.

The choice of appropriate design for a particular application is primarily dependent on:

— the required flowrate and range;

— the cleanliness of the gas;

— the conduit dimensions.

The two basic types of TMF meters have a number of overlapping characteristics for flowrate and conduit dimensions as shown in Table 1. Other factors may influence the final choice of the meter depending on the application. Table 1 is a guideline only and the manufacturer's specifications should be consulted for the absolute limits.

Table 1 — Preliminary TMF meter selection criteria

Characteristic	**CTMF meter**	**ITMF meter**	
		In-line	Insertion
Typical flow range	< 2 000 m^3/h [a, b] at reference conditions of 0 °C and 101,325 kPa	0,22 kg/h to 7 000 kg/h [a, b]	≫ 5 kg/h [a, b, c]
Typical conduit size	3 mm to 200 mm	8 mm to 200 mm	> 80 mm
Gas condition	Clean and dry only	Preferably clean and dry [d]	
Gas temperature	< 70 °C	< 500 °C	

a Flow range is dependent on the conduit size.

b Quoted flow range in air or nitrogen.

c This is the minimum flowrate in a 80 mm conduit. Flowrates in excess of 100 t/h can be achieved in large conduits.

d The ITMF meter can operate in the presence of dirty and/or wet gases. However, its performance is impaired.

5 Capillary thermal mass flowmeter (CTMF meter)

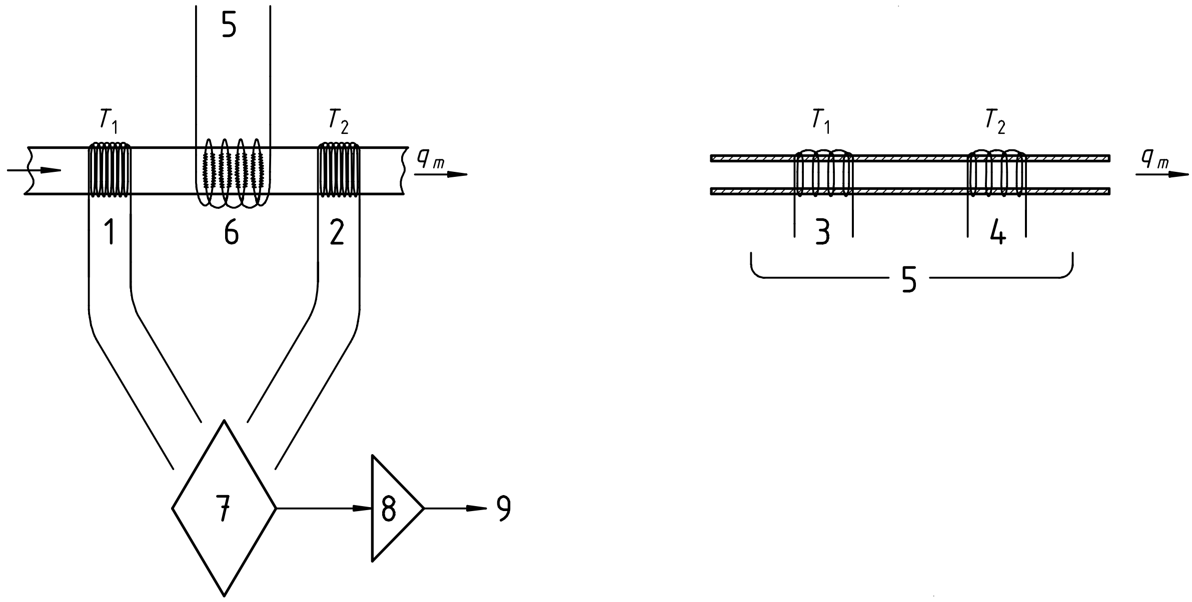
5.1 Principles of measurement

A typical CTMF meter consists of a meter body and flow sensor. The flow sensor is mounted integrally into the meter body. A defined portion of the gas flow from the meter body is diverted through the (bypass) flow sensor, through which the gas flowrate is measured.

Figure 1 shows a simplified CTMF meter with a typical flow sensor consisting of a thin tube and two temperature sensors. Depending upon the meter manufacturer, the heater can either be combined with each temperature sensor or be located separately in the middle of the flow sensor, i.e. between the temperature sensor upstream (T_1) and the one downstream (T_2) of the gas flow.

A precision power supply delivers constant heat to the flow sensor. Under stopped-flow conditions, both sensors measure the same temperature. As the flowrate increases, heat is carried away from the upstream sensor (T_1) towards the downstream sensor (T_2). A bridge circuitry interprets the temperature difference and an amplifier provides the flowrate output signal.

The measured temperature difference between the two sensors is proportional to the mass flowrate.



a) Two temperature sensors and separate heater

b) Two self-heating temperature sensors

Key

1 Upstream temperature sensor T_1

2 Downstream temperature sensor T_2

3 Upstream temperature sensor T_1 (with heater)

4 Downstream temperature sensor T_2 (with heater)

5 Constant power supply P

6 Heater

7 Bridge circuitry

8 Amplifier

9 Flow signal output (typically 0 V to 5 V d.c. for 4 mA to 20 mA)

Figure 1 — Simplified CTMF meter

The flow sensor measures the mass flowrate as a function of temperature difference. This can be expressed according to first law of thermodynamics (heat in = heat out, for no losses) for which the following equations apply:

$$P = \left[q_m \times c_p \times \frac{T_2 - T_1}{f_{\text{CTMF}}} \right] + L \tag{1}$$

or after rearranging equation (1)

$$q_m = \frac{(P - L) \times f_{\text{CTMF}}}{c_p \, (T_2 - T_1)} \tag{2}$$

where

q_m is the mass flowrate, expressed in kilograms per second;

c_p is the specific heat, expressed in joules per kilogram per kelvin [J/(kg·K)], of the gas at constant pressure;