TECHNICAL REPORT

ISO/TR 11583

First edition
2012-04-01

Measurement of wet gas flow by means of pressure differential devices inserted in circular cross-section conduits

Mesurage du débit de gaz humide au moyen d'appareils déprimogènes insérés dans des conduites de section circulaire

Reference number
ISO/TR 11583:2012(E)

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 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.

In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

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/TR 11583 was prepared by Technical Committee ISO/TC 30, *Measurement of fluid flow in closed conduits*, Subcommittee SC 2, *Pressure differential devices*.

Introduction

ISO 5167-1:2003, ISO 5167-2:2003, and ISO 5167-4:2003 include specifications for Venturi tubes and orifice plates, but are applicable only where the fluid can be considered as a single phase and the conduit is running full.

If the fluid being measured is a wet gas there is an overreading which can be corrected using suitable wet-gas correction equations.

Measurement of wet gas flow by means of pressure differential devices inserted in circular cross-section conduits

1 Scope

This Technical Report describes the measurement of wet gas with differential pressure meters. It applies to two-phase flows of gas and liquid in which the flowing fluid mixture consists of gas in the region of 95 % volume fraction or more (the exact limits on the mixture are defined in 6.4.3, 6.4.5, 7.5.3 and 7.5.5). This Technical Report is an extension of ISO 5167. The ranges of gases and liquids from which the equations in this Technical Report were derived are given in 6.4.1 and 7.5.1. It is possible that the equations do not apply to liquids significantly different from those tested, particularly to highly viscous liquids.

Although the over-reading equations presented in this Technical Report apply for a wide range of gases and liquids at appropriate gas-liquid density ratios, evaluating gas flowrates depends on information in addition to that required in single-phase flow: under certain conditions, a measurement of the pressure loss is sufficient; tracers can be used to measure the liquid flow; the total mass flowrate may be known (this is more likely in a wet-steam flow than in a natural gas/liquid flow); in a wet-steam flow a throttling calorimeter can be used.

Wet-gas measurement using Venturi tubes or orifice plates is covered in this Technical Report.

This Technical Report is only applicable to wet gas flows with a single liquid and is not intended for the oil and gas industry.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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 4006, *Measurement of fluid flow in closed conduits — Vocabulary and symbols*

ISO 5167-1:2003, *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full — Part 1: General principles and requirements*

ISO 5167-2:2003, *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full — Part 2: Orifice plates*

ISO 5167-4:2003, *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full — Part 4: Venturi tubes*

ISO/TR 15377, *Measurement of fluid flow by means of pressure-differential devices — Guidelines for the specification of orifice plates, nozzles and Venturi tubes beyond the scope of ISO 5167*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 4006, ISO 5167-1 and the following apply.

3.1
stratified flow
common regime in horizontal pipes at low gas velocities (typically 5 m/s or less) in which the free liquid runs along the bottom of the pipe with the gas flowing at the top of the pipe

3.2
annular flow
flow regime that in horizontal pipes occurs at medium gas velocities (typically 5 m/s to 15 m/s) in which the liquid flows around the pipe wall with the gas flowing through the centre of the pipe

NOTE In horizontal pipes, annular flow is not uniform; owing to gravitational effects, the liquid is present in higher quantities around the wall at the bottom of the pipe than higher up the pipe wall.

3.3
mist flow
flow regime that in horizontal pipes requires high gas velocities (typically 15 m/s or higher) to keep the liquid suspended in the gas and describes liquid in the flow being carried along in small-droplet form within the body of gas

3.4
slug flow
flow regime in which liquid travels along the pipe intermittently but in significant quantity, often due to the liquid becoming trapped in the flow line, for example at the bottom of a vertical pipe or when the flow is started after shutdown

3.5
liquid volume fraction
LVF
ratio of the liquid volume flowrate to the total volume flowrate, where the total volume flowrate is the sum of the liquid volume flowrate and the gas volume flowrate, all volume flowrates being at actual (not standard) conditions

3.6
gas volume fraction
GVF
ratio of the gas volume flowrate to the total volume flowrate, where the total volume flowrate is the sum of the liquid volume flowrate and the gas volume flowrate, all volume flowrates being at actual (not standard) conditions

4 Symbols and subscripts

See Table 1.

5 Principle of the method of measurement and computation

5.1 Principle of the method of measurement

The principle of the method of measurement using differential-pressure meters is based on the installation of a primary device (such as an orifice plate or a Venturi tube) into a pipeline. The installation of the primary device causes a pressure difference between the upstream side and the throat or downstream side of the device. The flowrate can be determined from the measured value of this pressure difference and from the knowledge of the characteristics of the flowing fluid as well as the circumstances under which the device is being used. It is assumed that the device is geometrically similar to one on which calibration has been carried out and that the conditions of use are the same, i.e. that it is in accordance with ISO 5167-2 or ISO 5167-4.

Table 1 — Symbols

Symbol	Quantity	Dimension[a]	SI Unit
C	Coefficient of discharge	dimensionless	1
C_{Ch}	Chisholm coefficient	dimensionless	1
C_{fluid}	Concentration of tracer in fluid	dimensionless	1
d	Diameter of orifice or throat of Venturi tube at working conditions	L	m
D	Upstream internal pipe diameter (or upstream diameter of a Venturi tube) at working conditions	L	m
Fr_{gas}	Gas densiometric Froude number [see Equation (3)]	dimensionless	1
g	Acceleration due to gravity	LT^{-2}	$\mathrm{m/s}^2$
h	Specific enthalpy	$\mathrm{L}^2\mathrm{T}^{-2}$	J/kg
H	Function of the surface tension of the liquid (see 6.4.3)	dimensionless	1
L_{down}	Distance between the downstream end of the Venturi tube divergent section (measured from the end of the cone not the flange) and the downstream pressure tapping used to measure the pressure loss	L	m
p	Absolute static pressure of the fluid	$\mathrm{ML}^{-1}\,\mathrm{T}^{-2}$	Pa
q_m	Mass flowrate	MT^{-1}	kg/s
q_V	Volume flowrate	$\mathrm{L}^3\mathrm{T}^{-1}$	m^3/s
t	Temperature of the fluid	Θ	°C
X	Lockhart-Martinelli parameter [see Equation (2)]	dimensionless	1
β	Diameter ratio: $\beta = d/D$	dimensionless	1
Δp	Differential pressure	$\mathrm{ML}^{-1}\,\mathrm{T}^{-2}$	Pa
$\Delta\varpi$	Pressure loss (without correction for the pressure loss that would have taken place if the Venturi tube or orifice plate had not been present)	$\mathrm{ML}^{-1}\,\mathrm{T}^{-2}$	Pa
δ	Absolute uncertainty	—[b]	—[b]
ε	Expansibility [expansion] factor	dimensionless	1
κ	Isentropic exponent	dimensionless	1
ρ	Density of the fluid (subscript 1 denotes the value at the upstream tapping plane)	ML^{-3}	$\mathrm{kg/m}^3$
ϕ	Over-reading correction factor [see Equation (1)]	dimensionless	1

[a] L ≡ length; M ≡ mass; T ≡ time; Θ ≡ temperature.

[b] The dimensions and units are those of the corresponding quantity.

In a wet gas flow the gas flowrate is determined by evaluating an over-reading. The over-reading is due to the mass of liquid passing through the primary device. The over-reading is affected by the flow regime, which in a wet gas flow is generally stratified, annular or mist, although, in practice, wet gas flows may be a combination of these flow regimes. Other flow regimes can occur intermittently, particularly the slug flow regime if liquid has become trapped in the flow line, for example at the bottom of a vertical pipe.

Combinations of line conditions, pipe orientations, and gas-liquid ratios influence the type of flow regime present. An appreciation of which, if any, flow regime is likely to prevail can be extremely useful. The application of the same wet-gas measurement technique can produce widely different results depending on which flow regime predominates, and knowledge of the likely flow regime can therefore influence the correct choice of measurement principle to be applied.

NOTE Even in a horizontal pipe, liquid can be held-up by gas flows of 1 m/s or less and can remain almost stationary rather than flow with the gas.

5.2 Computation

The gas mass flowrate, $q_{m,\text{gas}}$, is given by

$$q_{m,\text{gas}} = \frac{C}{\sqrt{1-\beta^4}} \varepsilon \frac{\pi}{4} d^2 \frac{\sqrt{2 \Delta p \rho_{1,\text{gas}}}}{\phi} \quad (1)$$

where

C is given in 6.4.2 or 7.5.2 as appropriate;

ε is determined from the appropriate part of ISO 5167;

$\rho_{1,\text{gas}}$ is the upstream gas density;

ϕ is the over-reading correction factor.

NOTE In evaluating ε, the actual values of p_1 and p_2 measured in wet gas are used.

Factor ϕ depends on the primary device, on the gas-liquid density ratio, $\rho_{1,\text{gas}}/\rho_{\text{liquid}}$, where ρ_{liquid} is the density of the liquid, on the Lockhart-Martinelli parameter, X, as defined in Equation (2):

$$X = \left(\frac{q_{m,\text{liquid}}}{q_{m,\text{gas}}} \right) \sqrt{\frac{\rho_{1,\text{gas}}}{\rho_{\text{liquid}}}} \quad (2)$$

and on the gas densiometric Froude number, Fr_{gas}, as defined in Equation (3):

$$Fr_{\text{gas}} = \frac{4 q_{m,\text{gas}}}{\rho_{1,\text{gas}} \pi D^2 \sqrt{gD}} \sqrt{\frac{\rho_{1,\text{gas}}}{\rho_{\text{liquid}} - \rho_{1,\text{gas}}}} \quad (3)$$

where g is the acceleration due to gravity and $q_{m,\text{liquid}}$ is the liquid mass flowrate.

6 Venturi tubes

6.1 General

Venturi tubes are widely used for wet-gas applications. Among their advantages are:

a) they do not 'dam' the flow (unlike orifice plates);

b) they can be operated at higher differential pressures than orifice plates without incurring permanent meter damage [differential pressures up to and above 2 bar (200 kPa) can be contemplated; for a fixed gas mass flowrate the presence of liquid may greatly increase the differential pressure];

c) therefore, they have a relatively high turndown (typically 10:1) when used with suitably ranged differential pressure transmitters.

6.2 Design requirements

The design requirements for Venturi tubes are specified in ISO 5167-4. However, special attention should be paid to the following: the finish of the Venturi tube internal surface, which should be smooth and free from machining defects including burrs and ridges; the pressure tappings, which at the point of entry into the meter internal bore should have sharp edges and be free from burrs and wire edges; and the edge of the conical inlet, which should be sharp and free from manufacturing defects.

The equations in this Technical Report should only be applied to meters that have been installed horizontally. Installation of the Venturi tube at a low point of the piping configuration where liquid could collect should be avoided.

In respect of the number and location of the pressure tappings, the meter should not conform to ISO 5167-4; see 6.3.

In many situations, it is desirable that the Venturi tube be installed with suitable "double block and bleed" isolation valves so that the meter can be removed and inspected as required.

The presence of liquid in the flow line affects the flow profile as it enters the Venturi tube. This is a source of measurement uncertainty over and above that normally expected for dry-gas measurement. In order to minimize this additional uncertainty, upstream pipe work should be designed so that bends immediately upstream of the meter encourage any stratified liquid to flow at the bottom of the pipe. Moreover, it is not recommended that the reduced straight lengths outlined in ISO 5167-4 be used. Where possible, the longer lengths should be used in order to minimize measurement uncertainty. The use of flow conditioners in wet-gas applications is not recommended (see 12.1).

6.3 Pressure tappings

The meter should be installed horizontally with a single pair of pressure tappings. The recommended location for the tappings circumferentially is given in 12.3.

Any double block and bleed valve fitted to the tappings should be a full-bore valve.The use of compact or wafer double block and bleed valves introduces liquid traps into the impulse line.

In addition, a third pressure tapping may be located downstream of the Venturi conical expander outlet (the diffuser section) to facilitate the measurement of the fully recovered pressure. The optimum position for this third pressure tapping has not been definitively established, but is approximately $6D$ from the downstream end of the divergent section.

The ratio of the pressure loss to the differential pressure can be much higher than in a single phase flow. This ratio can be used under certain circumstances to determine the Lockhart-Martinelli parameter. Where the liquid mass flowrate is only measured discontinuously, significant variations in this ratio can help indicate when a new measurement of the liquid mass flowrate is required.

6.4 Computation of gas flowrate

6.4.1 General

The general model for the over-reading correction factor is reported in References [6] and [1]. Reference [3] includes an improved correlation. Extensive research (References [22] to [28]) includes the collection of data on which the equations in 6.4.2, 6.4.3 and 6.4.5 are based. Gas flowrate equations in this subclause appear in Reference [19].

Further research into the use of Venturi tubes in wet gas is still required.

The range of gases and liquids in the database from which the gas flowrate equations in this subclause have been derived is: nitrogen, argon, natural gas and steam; water (at ambient temperature and in a wet-steam flow), Exxsol D80[1]), Stoddard solvent (white spirit), and decane. It is possible that the equations do not apply to liquids significantly different from those tested, particularly to highly viscous liquids.

The wet gas flowrate is calculated from Equation (1) where C and ϕ are obtained from Equations (4) and (5), respectively.

Examples of how to perform the computations are given in Annex A.

6.4.2 Discharge coefficient

$$C = 1 - 0{,}046\,3 \exp\left(-0{,}05 Fr_{\text{gas,th}}\right) \min\left(1, \sqrt{\frac{X}{0{,}016}}\right) \tag{4}$$

where

$$Fr_{\text{gas,th}} = \frac{Fr_{\text{gas}}}{\beta^{2,5}}$$

6.4.3 Over-reading correction factor

$$\phi = \sqrt{1 + C_{\text{Ch}} X + X^2} \tag{5}$$

where C_{Ch} is given by the following equation:

$$C_{\text{Ch}} = \left(\frac{\rho_{\text{liquid}}}{\rho_{1,\text{gas}}}\right)^n + \left(\frac{\rho_{1,\text{gas}}}{\rho_{\text{liquid}}}\right)^n$$

where

$$n = \max\left[0{,}583 - 0{,}18\beta^2 - 0{,}578 \exp\left(\frac{-0{,}8 Fr_{\text{gas}}}{H}\right), 0{,}392 - 0{,}18\beta^2\right]$$

H depends on the liquid and is equal to 1 for hydrocarbon liquid, 1,35 for water at ambient temperature, and 0,79 for liquid water in a wet-steam flow. It is a function of the surface tension of the liquid.

1) Product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of this product.

