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Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full —

Part 1:
General principles and requirements

Mesure de débit des fluides au moyen d'appareils déprimogènes insérés dans des conduites en charge de section circulaire —

Partie 1: Principes généraux et exigences générales

Reference number
ISO 5167-1:2003(E)

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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 5167-1 was prepared by Technical Committee ISO/TC 30, *Measurement of fluid flow in closed conduits*, Subcommittee SC 2, *Pressure differential devices*.

This second edition of ISO 5167-1, together with the first editions of ISO 5167-2, ISO 5167-3 and ISO 5167-4, cancels and replaces the first edition (ISO 5167-1:1991), which has been technically revised, and ISO 5167-1:1991/Amd.1:1998.

ISO 5167 consists of the following parts, under the general title *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full*:

— *Part 1: General principles and requirements*

— *Part 2: Orifice plates*

— *Part 3: Nozzles and Venturi nozzles*

— *Part 4: Venturi tubes*

Introduction

ISO 5167, consisting of four parts, covers the geometry and method of use (installation and operating conditions) of orifice plates, nozzles and Venturi tubes when they are inserted in a conduit running full to determine the flowrate of the fluid flowing in the conduit. It also gives necessary information for calculating the flowrate and its associated uncertainty.

ISO 5167 is applicable only to pressure differential devices in which the flow remains subsonic throughout the measuring section and where the fluid can be considered as single-phase, but is not applicable to the measurement of pulsating flow. Furthermore, each of these devices can only be used within specified limits of pipe size and Reynolds number.

ISO 5167 deals with devices for which direct calibration experiments have been made, sufficient in number, spread and quality to enable coherent systems of application to be based on their results and coefficients to be given with certain predictable limits of uncertainty.

The devices introduced into the pipe are called “primary devices”. The term primary device also includes the pressure tappings. All other instruments or devices required for the measurement are known as “secondary devices”. ISO 5167 covers primary devices; secondary devices[1] will be mentioned only occasionally.

ISO 5167 consists of the following four parts.

a) This part of ISO 5167 gives general terms and definitions, symbols, principles and requirements as well as methods of measurement and uncertainty that are to be used in conjunction with Parts 2 to 4 of ISO 5167.

b) Part 2 of ISO 5167 specifies orifice plates, which can be used with corner pressure tappings, D and $D/2$ pressure tappings[2], and flange pressure tappings.

c) Part 3 of ISO 5167 specifies ISA 1932 nozzles[3], long radius nozzles and Venturi nozzles, which differ in shape and in the position of the pressure tappings.

d) Part 4 of ISO 5167 specifies classical Venturi tubes[4].

Aspects of safety are not dealt with in Parts 1 to 4 of ISO 5167. It is the responsibility of the user to ensure that the system meets applicable safety regulations.

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[1] See ISO 2186:1973, *Fluid flow in closed conduits — Connections for pressure signal transmissions between primary and secondary elements.*

[2] Orifice plates with vena contracta pressure tappings are not considered in ISO 5167.

[3] ISA is the abbreviation for the International Federation of the National Standardizing Associations, which was succeeded by ISO in 1946.

[4] In the USA the classical Venturi tube is sometimes called the Herschel Venturi tube.

Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full —

Part 1:
General principles and requirements

1 Scope

This part of ISO 5167 defines terms and symbols and establishes the general principles for methods of measurement and computation of the flowrate of fluid flowing in a conduit by means of pressure differential devices (orifice plates, nozzles and Venturi tubes) when they are inserted into a circular cross-section conduit running full. This part of ISO 5167 also specifies the general requirements for methods of measurement, installation and determination of the uncertainty of the measurement of flowrate. It also defines the general specified limits of pipe size and Reynolds number for which these pressure differential devices are to be used.

ISO 5167 (all parts) is applicable only to flow that remains subsonic throughout the measuring section and where the fluid can be considered as single-phase. It is not applicable to the measurement of pulsating flow.

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 4006:1991, *Measurement of fluid flow in closed conduits — Vocabulary and symbols*

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 5167-3:2003, *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full — Part 3: Nozzles and Venturi nozzles*

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*

3 Terms and definitions

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

NOTE The following definitions are given only for terms used in some special sense or for terms for which it seems useful to emphasize the meaning.

3.1 Pressure measurement

3.1.1
wall pressure tapping
annular slot or circular hole drilled in the wall of a conduit in such a way that the edge of the hole is flush with the internal surface of the conduit

NOTE The pressure tapping is usually a circular hole but in certain cases may be an annular slot.

3.1.2
static pressure of a fluid flowing through a pipeline

p

pressure which can be measured by connecting a pressure-measuring device to a wall pressure tapping

NOTE Only the value of the absolute static pressure is considered in ISO 5167 (all parts).

3.1.3
differential pressure

Δp

difference between the (static) pressures measured at the wall pressure tappings, one of which is on the upstream side and the other of which is on the downstream side of a primary device (or in the throat for a Venturi nozzle or a Venturi tube), inserted in a straight pipe through which flow occurs, when any difference in height between the upstream and downstream tappings has been taken into account

NOTE In ISO 5167 (all parts) the term “differential pressure” is used only if the pressure tappings are in the positions specified for each standard primary device.

3.1.4
pressure ratio

τ

ratio of the absolute (static) pressure at the downstream pressure tapping to the absolute (static) pressure at the upstream pressure tapping

3.2 Primary devices

3.2.1
orifice
throat
opening of minimum cross-sectional area of a primary device

NOTE Standard primary device orifices are circular and coaxial with the pipeline.

3.2.2
orifice plate
thin plate in which a circular opening has been machined

NOTE Standard orifice plates are described as “thin plate” and “with sharp square edge”, because the thickness of the plate is small compared with the diameter of the measuring section and because the upstream edge of the orifice is sharp and square.

3.2.3
nozzle
device which consists of a convergent inlet connected to a cylindrical section generally called the “throat”

3.2.4
Venturi nozzle
device which consists of a convergent inlet which is a standardized ISA 1932 nozzle connected to a cylindrical part called the “throat” and an expanding section called the “divergent” which is conical

3.2.5
Venturi tube

device which consists of a convergent inlet which is conical connected to a cylindrical part called the “throat” and an expanding section called the “divergent” which is conical

3.2.6
diameter ratio

β

⟨of a primary device used in a given pipe⟩ ratio of the diameter of the orifice or throat of the primary device to the internal diameter of the measuring pipe upstream of the primary device

NOTE However, when the primary device has a cylindrical section upstream, having the same diameter as that of the pipe (as in the case of the classical Venturi tube), the diameter ratio is the ratio of the throat diameter and the diameter of this cylindrical section at the plane of the upstream pressure tappings.

3.3 Flow

3.3.1
flowrate
rate of flow

q

mass or volume of fluid passing through the orifice (or throat) per unit time

3.3.1.1
mass flowrate
rate of mass flow

q_m

mass of fluid passing through the orifice (or throat) per unit time

3.3.1.2
volume flowrate
rate of volume flow

q_V

volume of fluid passing through the orifice (or throat) per unit time

NOTE In the case of volume flowrate, it is necessary to state the pressure and temperature at which the volume is referenced.

3.3.2
Reynolds number

Re

dimensionless parameter expressing the ratio between the inertia and viscous forces

3.3.2.1
pipe Reynolds number

Re_D

dimensionless parameter expressing the ratio between the inertia and viscous forces in the upstream pipe

$$Re_D = \frac{V_1 D}{\nu_1} = \frac{4 q_m}{\pi \mu_1 D}$$

3.3.2.2
orifice or throat Reynolds number

Re_d

dimensionless parameter expressing the ratio between the inertia and viscous forces in the orifice or throat of the primary device

$$Re_d = \frac{Re_D}{\beta}$$

3.3.3
isentropic exponent

κ

ratio of the relative variation in pressure to the corresponding relative variation in density under elementary reversible adiabatic (isentropic) transformation conditions

NOTE 1 The isentropic exponent κ appears in the different formulae for the expansibility [expansion] factor ε and varies with the nature of the gas and with its temperature and pressure.

NOTE 2 There are many gases and vapours for which no values for κ have been published so far, particularly over a wide range of pressure and temperature. In such a case, for the purposes of ISO 5167 (all parts), the ratio of the specific heat capacity at constant pressure to the specific heat capacity at constant volume of ideal gases can be used in place of the isentropic exponent.

3.3.4
Joule Thomson coefficient

isenthalpic temperature-pressure coefficient

μ_{JT}

rate of change of temperature with respect to pressure at constant enthalpy:

$$\mu_{\mathrm{JT}} = \left.\frac{\partial T}{\partial p}\right|_H$$

or

$$\mu_{\mathrm{JT}} = \frac{R_{\mathrm{u}} T^2}{p C_{\mathrm{m},p}} \left.\frac{\partial Z}{\partial T}\right|_p$$

where

T is the absolute temperature;

p is the static pressure of a fluid flowing through a pipeline;

H is the enthalpy;

R_{u} is the universal gas constant;

$C_{\mathrm{m},p}$ is the molar-heat capacity at constant pressure;

Z is the compressibility factor

NOTE The Joule Thomson coefficient varies with the nature of the gas and with its temperature and pressure and can be calculated.

3.3.5
discharge coefficient

C

coefficient, defined for an incompressible fluid flow, which relates the actual flowrate to the theoretical flowrate through a device, and is given by the formula for incompressible fluids

$$C = \frac{q_m \sqrt{1-\beta^4}}{\frac{\pi}{4} d^2 \sqrt{2 \Delta p \rho_1}}$$

NOTE 1 Calibration of standard primary devices by means of incompressible fluids (liquids) shows that the discharge coefficient is dependent only on the Reynolds number for a given primary device in a given installation.

The numerical value of C is the same for different installations whenever such installations are geometrically similar and the flows are characterized by identical Reynolds numbers.

The equations for the numerical values of C given in ISO 5167 (all parts) are based on data determined experimentally.

The uncertainty in the value of C can be reduced by flow calibration in a suitable laboratory.

NOTE 2 The quantity $1/\sqrt{1-\beta^4}$ is called the “velocity of approach factor”, and the product

$$C \frac{1}{\sqrt{1-\beta^4}}$$

is called the “flow coefficient”.

3.3.6
expansibility [expansion] factor

ε

coefficient used to take into account the compressibility of the fluid

$$\varepsilon = \frac{q_m \sqrt{1-\beta^4}}{\frac{\pi}{4} d^2 C \sqrt{2 \Delta p \rho_1}}$$

NOTE Calibration of a given primary device by means of a compressible fluid (gas) shows that the ratio

$$\frac{q_m \sqrt{1-\beta^4}}{\frac{\pi}{4} d^2 \sqrt{2 \Delta p \rho_1}}$$

is dependent on the value of the Reynolds number as well as on the values of the pressure ratio and the isentropic exponent of the gas.

The method adopted for representing these variations consists of multiplying the discharge coefficient C of the primary device considered, as determined by direct calibration carried out with liquids for the same value of the Reynolds number, by the expansibility [expansion] factor ε.

The expansibility factor, ε, is equal to unity when the fluid is considered incompressible (liquid) and is less than unity when the fluid is compressible (gaseous).

This method is possible because experiments show that ε is practically independent of the Reynolds number and, for a given diameter ratio of a given primary device, ε only depends on the pressure ratio and the isentropic exponent.

The numerical values of ε for orifice plates given in ISO 5167-2 are based on data determined experimentally. For nozzles (see ISO 5167-3) and Venturi tubes (see ISO 5167-4) they are based on the thermodynamic general equation applied to isentropic expansion.

3.3.7
arithmetical mean deviation of the roughness profile

Ra

arithmetical mean deviation from the mean line of the profile being measured

NOTE 1 The mean line is such that the sum of the squares of the distances between the effective surface and the mean line is a minimum. In practice *Ra* can be measured with standard equipment for machined surfaces but can only be estimated for rougher surfaces of pipes. See also ISO 4288.

NOTE 2 For pipes, the uniform equivalent roughness k may also be used. This value can be determined experimentally (see 7.1.5) or taken from tables (see Annex B).

4 Symbols and subscripts

4.1 Symbols

Table 1 — Symbols

Symbol	Quantity	Dimension[a]	SI unit
C	Coefficient of discharge	dimensionless	—
$C_{m,p}$	Molar-heat capacity at constant pressure	$ML^2T^{-2}\Theta^{-1}mol^{-1}$	J/(mol·K)
d	Diameter of orifice (or throat) of primary device under working conditions	L	m
D	Upstream internal pipe diameter (or upstream diameter of a classical Venturi tube) under working conditions	L	m
H	Enthalpy	$ML^2T^{-2}mol^{-1}$	J/mol
k	Uniform equivalent roughness	L	m
K	Pressure loss coefficient (the ratio of the pressure loss to the dynamic pressure, $\rho V^2/2$)	dimensionless	—
l	Pressure tapping spacing	L	m
L	Relative pressure tapping spacing: $L = l/D$	dimensionless	—
p	Absolute static pressure of the fluid	$ML^{-1}T^{-2}$	Pa
q_m	Mass flowrate	MT^{-1}	kg/s
q_V	Volume flowrate	L^3T^{-1}	m^3/s
R	Radius	L	m
Ra	Arithmetical mean deviation of the (roughness) profile	L	m
R_u	Universal gas constant	$ML^2T^{-2}\Theta^{-1}mol^{-1}$	J/(mol·K)
Re	Reynolds number	dimensionless	—
Re_D	Reynolds number referred to D	dimensionless	—
Re_d	Reynolds number referred to d	dimensionless	—
t	Temperature of the fluid	Θ	°C
T	Absolute (thermodynamic) temperature of the fluid	Θ	K
U'	Relative uncertainty	dimensionless	—

Table 1 *(continued)*

Symbol	Quantity	Dimension[a]	SI unit
V	Mean axial velocity of the fluid in the pipe	LT^{-1}	m/s
Z	Compressibility factor	dimensionless	—
β	Diameter ratio: $\beta = d/D$	dimensionless	—
γ	Ratio of specific heat capacities[b]	dimensionless	—
δ	Absolute uncertainty	[c]	[c]
Δp	Differential pressure	$ML^{-1}T^{-2}$	Pa
Δp_c	Pressure loss across a flow conditioner	$ML^{-1}T^{-2}$	Pa
$\Delta \varpi$	Pressure loss across a primary device	$ML^{-1}T^{-2}$	Pa
ε	Expansibility [expansion] factor	dimensionless	—
κ	Isentropic exponent[b]	dimensionless	—
λ	Friction factor	dimensionless	—
μ	Dynamic viscosity of the fluid	$ML^{-1}T^{-1}$	Pa·s
μ_{JT}	Joule Thomson coefficient	$M^{-1}LT^{2}\Theta$	K/Pa
ν	Kinematic viscosity of the fluid: $\nu = \mu/\rho$	$L^{2}T^{-1}$	m^2/s
ξ	Relative pressure loss (the ratio of the pressure loss to the differential pressure)	dimensionless	—
ρ	Density of the fluid	ML^{-3}	kg/m^3
τ	Pressure ratio: $\tau = p_2/p_1$	dimensionless	—
ϕ	Total angle of the divergent section	dimensionless	rad

[a] M = mass, L = length, T = time, Θ = temperature

[b] γ is the ratio of the specific heat capacity at constant pressure to the specific heat capacity at constant volume. For ideal gases, the ratio of the specific heat capacities and the isentropic exponent have the same value (see 3.3.3). These values depend on the nature of the gas.

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

4.2 Subscripts

Subscript	Meaning
1	At upstream tapping plane
2	At downstream tapping plane

5 Principle of the method of measurement and computation

5.1 Principle of the method of measurement

The principle of the method of measurement is based on the installation of a primary device (such as an orifice plate, a nozzle or a Venturi tube) into a pipeline in which a fluid is running full. The installation of the primary device causes a static 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 (see ISO 5167-2, ISO 5167-3 or ISO 5167-4).