TECHNICAL REPORT

ISO/TR 15377

Second edition
2007-02-01

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

Mesurage du débit des fluides au moyen d'appareils déprimogènes — Lignes directrices pour la spécification des diaphragmes, des tuyères et des tubes Venturi non couverts par l'ISO 5167

Reference number
ISO/TR 15377:2007(E)

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ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

Published in Switzerland

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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.

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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is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.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 15377 was prepared by Technical Committee ISO/TC 30, *Measurement of fluid flow in closed conduits*, Subcommittee SC 2, *Pressure differential devices*.

This second edition cancels and replaces the first edition (ISO/TR 15377:1998), which has been technically revised. It incorporates Technical Corrigendum ISO/TR 15377:1998/Cor.1:1999.

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

1 Scope

This Technical Report describes the geometry and method of use for conical-entrance orifice plates, quarter-circle orifice plates, eccentric orifice plates and Venturi tubes with 10,5° convergent angles. Recommendations are also given for square-edged orifice plates and nozzles under conditions outside the scope of ISO 5167.

NOTE The data on which this report is based are old or incomplete in some cases.

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, *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*

3 Terms and definitions

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

4 Symbols

For the purposes of this document, the symbols given in Table 1 apply.

Table 1 — Symbols

Symbols	Represented quantity	Dimensions M: mass L: length T: time	SI unit
a	Pressure-tapping hole diameter	L	m
C	Discharge coefficient	dimensionless	
d	Diameter of orifice or throat of primary device at operating conditions	L	m
D	Upstream internal pipe diameter at operating conditions	L	m
d_{tap}	Diameter of pressure tappings	L	m
e	Thickness of bore	L	m
E, E_1	Thickness of orifice plate	L	m
F_{E}	Correction factor	dimensionless	
k	Uniform equivalent roughness	L	m
p	Static pressure of the fluid	$\text{ML}^{-1}\,\text{T}^{-2}$	Pa
q_m	Mass flowrate	MT^{-1}	kg/s
r	Radius of profile	L	m
R_{a}	Arithmetical mean deviation of the (roughness) profile	L	m
Re	Reynolds number	dimensionless	
Re_D, Re_d	Reynolds number referred to D or d	dimensionless	
Re^*	Throat-tapping Reynolds number ($= d_{\text{tap}}\,Re_d/d$)	dimensionless	
β	Diameter ratio, $\beta = \frac{d}{D}$	dimensionless	
Δp	Differential pressure	$\text{ML}^{-1}\,\text{T}^{-2}$	Pa
ε	Expansibility (expansion) factor	dimensionless	
κ	Isentropic exponent	dimensionless	
λ	Friction factor	dimensionless	
ρ	Mass density of the fluid	ML^{-3}	kg/m^3
τ	Pressure ratio, $\tau = \frac{p_2}{p_1}$	dimensionless	

NOTE 1 Other symbols used in this Technical Report are defined at their place of use.

NOTE 2 Subscript 1 refers to the cross-section at the plane of the upstream pressure tapping. Subscript 2 refers to the cross-section at the plane of the downstream pressure tapping.

5 Square-edged orifice plates and nozzles: With drain holes, in pipes below 50 mm diameter, and as inlet and outlet devices

5.1 Drain holes through the upstream face of the square-edged orifice plate or nozzle

5.1.1 General

Square-edged orifice plates and nozzles with drain holes may be used, installed and manufactured in accordance with the following guidelines.

5.1.2 Square-edged orifice plates

If a drain hole is drilled through the orifice plate, the coefficient values specified in ISO 5167-2 should not be used unless the following conditions are observed.

a) D should be larger than 100 mm.

b) The diameter of the drain hole should not exceed 0,1d and no part of the hole should lie within a circle, concentric with the orifice, of diameter (D – 0,2d). The outer edge of the drain hole should be as close to the pipe wall as practicable.

c) The drain hole should be deburred and the upstream edge should be sharp.

d) Single pressure tappings should be orientated so that they are between 90° and 180° to the position of the drain hole.

e) The measured orifice diameter, d_m, should be corrected to allow for the additional orifice area represented by the drain hole of diameter d_k, as shown in the following equation:

$$d = d_m \left\{ 1 + 0{,}55 \left(\frac{d_k}{d_m} \right)^2 \right\} \tag{1}$$

NOTE This equation is based on the assumption that the value for $C\varepsilon(1 - \beta^4)^{-0{,}5}$ for flow through the drain hole is 10 % greater than the value for flow through the orifice.

When estimating the overall uncertainty of the flow measurement, the following additional percentage uncertainty should be added arithmetically to the discharge coefficient percentage uncertainty:

$$55 \left(\frac{d_k}{d_m} \right)^2 \tag{2}$$

5.1.3 ISA 1932 nozzles

If a drain hole is drilled through the nozzle upstream face, the coefficient values specified in ISO 5167-3 should not be used unless the following conditions are observed.

a) The value of β should be less than 0,625.

b) The diameter of the drain hole should not exceed 0,1d and no part of the hole should lie within a circle, concentric with the throat, of diameter (D – 0,2d).

c) The length of the drain hole should not exceed 0,1D.

d) The drain hole should be deburred and the upstream edge should be sharp.

e) Single pressure tappings should be orientated so that they are between 90° and 180° to the position of the drain hole.

f) The measured diameter, d_m, should be corrected to allow for the additional throat area represented by the drain hole of diameter d_k, as shown in the following equation:

$$d = d_m \left\{ 1 + 0{,}40 \left(\frac{d_k}{d_m} \right)^2 \right\} \tag{3}$$

NOTE This equation is based on the assumption that the value for $C\varepsilon(1 - \beta^4)^{-0,5}$ for flow through the drain hole is 20 % less than the value for flow through the throat of the nozzle.

When estimating the overall uncertainty of the flow measurement, the following additional percentage uncertainty should be added arithmetically to the discharge coefficient percentage uncertainty:

$$40 \left(\frac{d_k}{d_m} \right)^2 \tag{4}$$

5.1.4 Long radius nozzles

Drain holes through these primary elements should not be used.

5.2 Square-edged orifice plates installed in pipes of diameter 25 mm $\leqslant D <$ 50 mm

5.2.1 General

Orifice plates should be installed and manufactured in accordance with ISO 5167-2.

5.2.2 Limits of use

When square-edged orifice plates are installed in pipes of bore 25 mm to 50 mm, the following conditions should be strictly observed.

a) The pipes should have high-quality internal surfaces such as drawn copper or brass tubes, glass or plastic pipes or drawn or fine-machined steel tubes. The steel tubes should be of stainless steel for use with corrosive fluids such as water. The roughness should be in accordance with ISO 5167-2:2003, 5.3.1.

b) Corner tappings should be used, preferably of the carrier ring type detailed in ISO 5167-2:2003, Figure 4 a).

c) The diameter ratio, β, should be within the range $0{,}5 \leqslant \beta \leqslant 0{,}7$.

NOTE It is possible to have $0{,}23 \leqslant \beta < 0{,}5$, but the uncertainty increases significantly if $d <$ 12,5 mm.

5.2.3 Discharge coefficients and corresponding uncertainties

The Reader-Harris/Gallagher equation [1] for corner tappings given in 5.3.2.1 of ISO 5167-2:2003 should be used for deriving the discharge coefficients, provided the pipe Reynolds numbers are within the limits given in ISO 5167-2:2003, 5.3.1.

An additional uncertainty of 0,5 % should be added arithmetically to the uncertainty derived from 5.3.3.1 of ISO 5167-2:2003.

5.3 No upstream or downstream pipeline

5.3.1 General

This clause should apply where there is no pipeline on either the upstream or the downstream side of the device or on both the upstream and the downstream sides of the device, that is for flow from a large space into a pipe or vice versa, or flow through a device installed in the partition wall between two large spaces.

5.3.2 Flow from a large space (no upstream pipeline) into a pipeline or another large space

5.3.2.1 Upstream and downstream tappings

The space on the upstream side of the device should be considered large if

a) there is no wall closer than $4d$ to the axis of the device or to the plane of the upstream face of the orifice or nozzle,

b) the velocity of the fluid at any point more than $4d$ from the device is less than 3 % of the velocity in the orifice or throat, and

c) the diameter of the downstream pipeline is not less than $2d$.

NOTE 1 The first condition implies, for example, that an upstream pipeline of diameter greater than $8d$ (that is where $\beta < 0{,}125$) can be regarded as a large space. The second condition, which excludes upstream disturbances due to draughts, swirl and jet effects, implies that the fluid is to enter the space uniformly over an area of not less than 33 times the area of the orifice or throat. For example, if the flow is provided by a fall in level of a liquid in a tank, the area of the liquid surface has to be not less than 33 times the area of the orifice or throat through which the tank is discharged.

The distance of the upstream tapping (i.e. the tapping in the large space) from the orifice or nozzle centreline should be greater than $4d$.

The upstream tapping should preferably be located in a wall perpendicular to the plane of the orifice and be within a distance of $0{,}5d$ from that plane. The tapping does not necessarily have to be located in any wall; it can be in the open space. If the space is very large, for example a room, the tapping should be shielded from draughts.

The downstream tapping should be located as specified for corner tappings in ISO 5167-2. If the downstream side also consists of a large space, the tapping should be located as for the upstream tapping, except for Venturi nozzles where the throat tapping should be used.

NOTE 2 When the upstream and downstream tappings are at different horizontal levels, it may be necessary to make allowance for the difference in hydrostatic head. This is usually done by reading the differential-pressure transmitter with no fluid flow and making an appropriate correction.

5.3.2.2 Square-edged orifice plates with corner tappings

5.3.2.2.1 Square-edged orifice plates with corner tappings should be manufactured in accordance with Clause 5 of ISO 5167-2:2003.

5.3.2.2.2 The limits of use for square-edged orifice plates with corner tappings where there is a flow from a large space should be as follows:

— $d \geqslant 12{,}5$ mm;

— downstream there is either a large space or a pipeline whose diameter is not less than $2d$;

— $Re_d \geqslant 3\,500$.

NOTE 1 It is possible to have 12,5 mm $> d >$ 6 mm, but the uncertainty increases significantly if $d <$ 12,5 mm.

NOTE 2 Provided that $\beta \leqslant 0{,}2$ and $d \geqslant 12{,}5$ mm, the Reader-Harris/Gallagher (1998) equation given in 5.3.2.1 of ISO 5167-2:2003 can be used in a pipeline for $Re_d \geqslant 3\,500$ with an uncertainty on the value of the discharge coefficient, C, of 1 % (if $Re_D < 5\,000$).

5.3.2.2.3 The discharge coefficient, C, is given by

$$C = 0{,}596\,1 + 0{,}000\,521 \left(\frac{10^6}{Re_d} \right)^{0{,}7} \tag{5}$$

The uncertainty on the value of C is 1 %.

5.3.2.2.4 The expansibility factor, ε, is given by the following equation and is only applicable if $p_2/p_1 > 0{,}75$:

$$\varepsilon = 1 - 0{,}351 \left[1 - \left(\frac{p_2}{p_1} \right)^{1/\kappa} \right] \tag{6}$$

When $\Delta p/p_1$ and κ are assumed to be known without error, the relative uncertainty of the value of ε is equal to $3{,}5 \frac{\Delta p}{\kappa p_1}$ %.

Test results for the determination of ε are known for air, steam and natural gas only. However, there is no known objection to using the same formula for other gases and vapours whose isentropic exponent is known.

5.3.2.3 ISA 1932 nozzles

5.3.2.3.1 ISA 1932 nozzles should be manufactured in accordance with 5.1 of ISO 5167-3:2003.

5.3.2.3.2 The limits of use for ISA 1932 nozzles where there is flow from a large space should be as follows:

— $d \geqslant 11{,}5$ mm;

— downstream there is either a large space or a pipeline whose diameter is not less than $2d$;

— $Re_d \geqslant 100\,000$.

5.3.2.3.3 The discharge coefficient, C, is equal to 0,99. The uncertainty in the value of C is expected to be no better than 1 %.

5.3.2.3.4 The expansibility factor, ε, is given by the following equation and is only applicable if $p_2/p_1 \geqslant 0{,}75$:

$$\varepsilon = \left\{ \left(\frac{\kappa \tau^{2/\kappa}}{\kappa - 1} \right) \left(\frac{1 - \tau^{(\kappa-1)/\kappa}}{1 - \tau} \right) \right\}^{0{,}5} \tag{7}$$

The relative uncertainty of the value of ε is equal to $2 \Delta p/p_1$ %.

5.3.2.4 Venturi nozzle

5.3.2.4.1 Venturi nozzles should be manufactured in accordance with 5.3 of ISO 5167-3:2003.

5.3.2.4.2 The limits of use for Venturi nozzles where there is flow from a large space should be as follows:

- $d \geqslant 50$ mm;
- downstream there is either a large space or a pipeline whose diameter is not less than $2d$;
- $3 \times 10^5 \leqslant Re_d \leqslant 3 \times 10^6$.

5.3.2.4.3 The discharge coefficient, C, is equal to 0,985 8. The uncertainty in the value of C is expected to be no better than 1,5 %.

5.3.2.4.4 The expansibility factor, ε, is given by the following equation and is only applicable if $p_2/p_1 \geqslant 0{,}75$:

$$\varepsilon = \left\{ \left(\frac{\kappa \tau^{2/\kappa}}{\kappa - 1} \right) \left(\frac{1 - \tau^{(\kappa-1)/\kappa}}{1 - \tau} \right) \right\}^{0{,}5} \quad (8)$$

The relative uncertainty of the value of ε is equal to $4\,\Delta p/p_1$ %.

5.3.3 Flow into a large space (no downstream pipeline)

5.3.3.1 General

The space on the downstream side of the device should be considered large if there is no wall closer than $4d$ to the axis of the device or to the downstream face of the orifice plate or nozzle.

The upstream tapping should be located as specified for corner tappings in ISO 5167-2 and in ISO 5167-3 for orifice plates and nozzles respectively.

The distance of the downstream tapping (i.e. the tapping in the large space) from the orifice or nozzle centreline should be greater than $4d$.

For Venturi nozzles, the throat tapping should be used.

The downstream tapping should preferably be located in a wall perpendicular to the plane of the orifice and be within a distance of $0{,}5d$ from that plane. The tapping does not necessarily have to be located in any wall; it can be in the open space. If the space is very large, for example a room, the tapping should be shielded from draughts.

NOTE Where the upstream and downstream tappings are at different horizontal levels, it may be necessary to make allowance for the difference in hydrostatic head.

5.3.3.2 Square-edged orifice plates with corner tappings

5.3.3.2.1 Square-edged orifice plates with corner tappings should be manufactured in accordance with Clause 5 of ISO 5167-2:2003.

5.3.3.2.2 Where 25 mm $\leqslant D <$ 50 mm, the limits given in 5.2.2 and 5.2.3 should apply.

Where 50 mm $\leqslant D \leqslant$ 1 000 mm, the limits given in 5.3.1 of ISO 5167-2:2003 should apply.

5.3.3.2.3 Where 25 mm $\leqslant D <$ 50 mm, the coefficients and uncertainties given in 5.2.3 should apply.

Where 50 mm $\leqslant D \leqslant$ 1 000 mm, the coefficients and uncertainties given in 5.3.2 and 5.3.3 of ISO 5167-2:2003 should apply, except that an additional uncertainty of 0,4 % is to be added arithmetically to the uncertainty derived from 5.3.3.1 of ISO 5167-2:2003.

5.3.3.3 ISA 1932 nozzles and Venturi nozzles

5.3.3.3.1 ISA 1932 nozzles and Venturi nozzles should be manufactured in accordance with 5.1 or 5.3 of ISO 5167-3:2003.

5.3.3.3.2 The limits given in 5.1.6.1 or 5.3.4.1 of ISO 5167-3:2003 should apply.

5.3.3.3.3 The coefficients and uncertainties given in 5.1.6.2, 5.1.6.3 and 5.1.7 or in 5.3.4.2, 5.3.4.3 and 5.3.5 of ISO 5167-3:2003 should apply, except that in the case of an ISA 1932 nozzle an additional uncertainty of 0,4 % should be added arithmetically to the uncertainty derived from 5.1.7.1 of ISO 5167-3:2003.

6 Orifice plates (except square-edged)

6.1 Conical entrance orifice plates

6.1.1 General

NOTE A conical entrance orifice plate has the characteristic that its discharge coefficient remains constant down to a low Reynolds number, thus making it suitable for the measurement of the flowrate of viscous fluids such as oil. Conical entrance orifice plates are further distinguished from other types of orifice plates in that their discharge coefficient is the same for any diameter ratio within the limits specified in this Technical Report.

Conical entrance orifice plates should be used and installed in accordance with Clause 6 of ISO 5167-1:2003 and Clause 6 of ISO 5167-2:2003.

6.1.2 Limits of use

The limits of use for conical entrance orifice plates should be as follows:

— $d > 6$ mm;

— $D \leqslant 500$ mm.

The lower limit of pipe diameter, D, depends on the internal roughness of the upstream pipeline and should be in accordance with Table 2 and within the following limits:

— $0{,}1 \leqslant \beta \leqslant 0{,}316$

— $80 \leqslant Re_D \leqslant 2 \times 10^5 \beta$

NOTE Within these limits, the value of β is chosen by the user taking into consideration parameters such as required differential pressure, uncertainty, acceptable pressure loss and available static pressure.

6.1.3 Description

The axial plane cross-section of the orifice plate is shown in Figure 1.

NOTE The letters shown in Figure 1 are for reference purposes in 6.1.3.2 to 6.1.3.8 and 6.1.4 only; 6.1.4 refers to 5.2.3 of ISO 5167-2:2003.

6.1.3.1 General shape

6.1.3.1.1 The part of the plate inside the pipe should be circular and concentric with the pipe centreline. The faces of this plate should always be flat and parallel.

