
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*



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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.

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is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.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 tapings	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	$ML^{-1}T^{-2}$	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	$ML^{-1}T^{-2}$	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.

- D should be larger than 100 mm.
- 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.
- The drain hole should be deburred and the upstream edge should be sharp.
- Single pressure tapings should be orientated so that they are between 90° and 180° to the position of the drain hole.
- 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:

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

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:

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

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.

- The value of β should be less than 0,625.
- 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 $(D - 0,2d)$.
- The length of the drain hole should not exceed $0,1D$.
- The drain hole should be deburred and the upstream edge should be sharp.

- e) Single pressure tapings 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:

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

NOTE This equation is based on the assumption that the value for $C\epsilon(1 - \beta^4)^{-0,5}$ 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:

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

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 $25 \text{ mm} \leq D < 50 \text{ mm}$

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 tapings 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 $0,5 \leq \beta \leq 0,7$.

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

5.2.3 Discharge coefficients and corresponding uncertainties

The Reader-Harris/Gallagher equation ^[1] for corner tapings 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 tapplings

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 tapplings 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 tapplings 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 tapplings

5.3.2.2.1 Square-edged orifice plates with corner tapplings 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 tapplings where there is a flow from a large space should be as follows:

- $d \geq 12,5$ mm;
- downstream there is either a large space or a pipeline whose diameter is not less than $2d$;
- $Re_d \geq 3\,500$.

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

NOTE 2 Provided that $\beta \leq 0,2$ and $d \geq 12,5$ 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 $Re_d \geq 3\,500$ 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

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

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 $p_2/p_1 \geq 0,75$:

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

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:

- $d \geq 11,5$ mm;
- downstream there is either a large space or a pipeline whose diameter is not less than $2d$;
- $Re_d \geq 100\,000$.

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 $p_2/p_1 \geq 0,75$:

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

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:

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

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 $p_2/p_1 \geq 0,75$:

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

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 tapplings 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 tapplings 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 tapplings

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

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

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

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

Where $50 \text{ mm} \leq D \leq 1\,000 \text{ mm}$, 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:

- $d > 6 \text{ mm}$;
- $D \leq 500 \text{ mm}$.

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:

- $0,1 \leq \beta \leq 0,316$
- $80 \leq Re_D \leq 2 \times 10^5 \beta$

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.

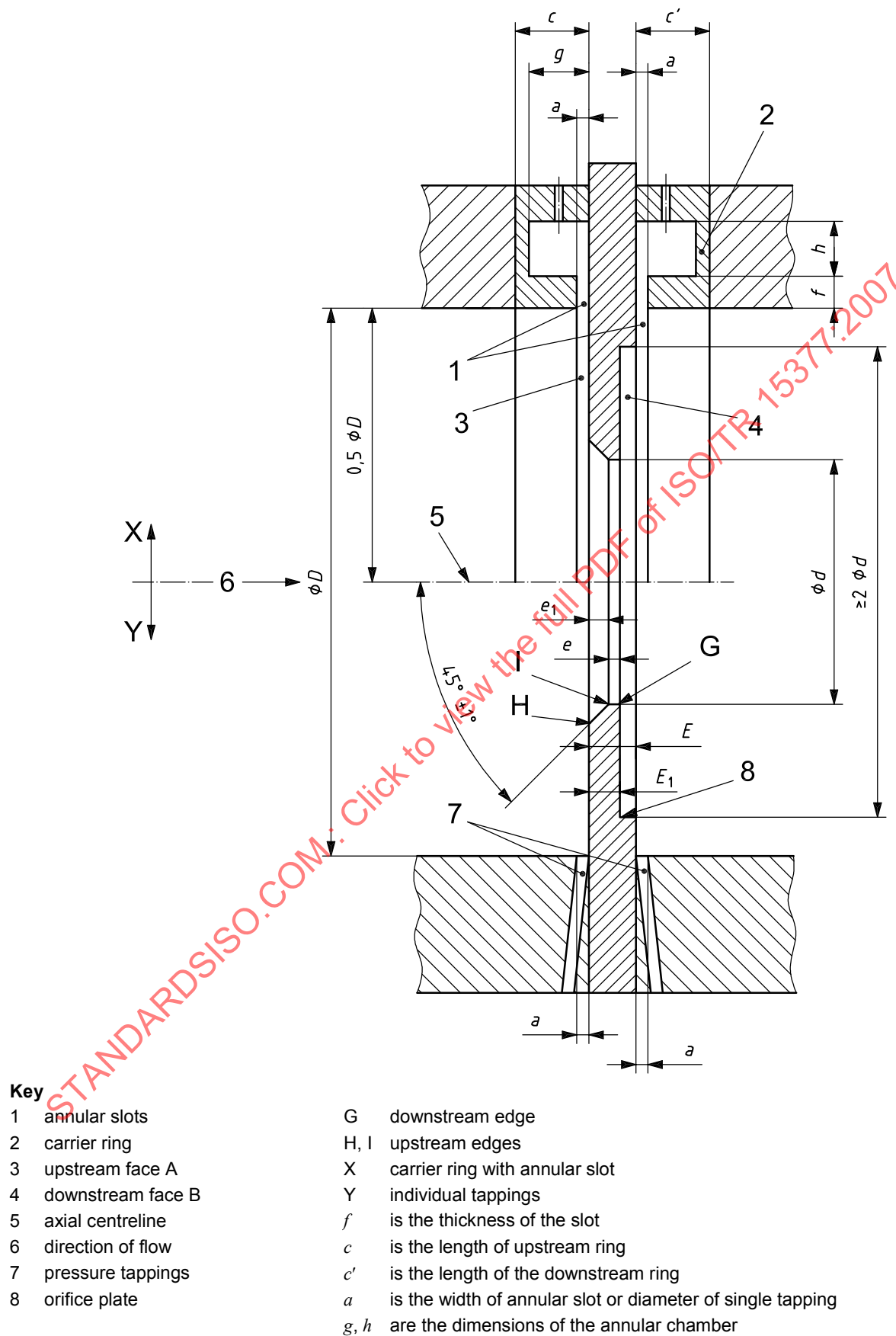


Figure 1 — Conical entrance orifice plate

Table 2 — Minimum internal diameter of upstream pipe for conical entrance orifice plates

Material	Condition	Minimum internal diameter mm
Brass, copper, lead, glass, plastics, steel	smooth, without sediments	25
	new, cold drawn	25
	new, seamless	25
	new, welded	25
	slightly rusty	25
	rusty	50
	slightly encrusted	200
	bituminized, new or used	25
	galvanized	25
	bituminized	25
Cast iron	not rusty	50
	rusty	200

6.1.3.1.2 Unless otherwise stated, the recommendations of 6.1.3.1.3 and 6.1.3.2 to 6.1.3.8 should apply only to that part of the plate located within the pipe.

6.1.3.1.3 Care should be taken in the design of the orifice plate and its installation to ensure that the plastic buckling and elastic deformation of the plate, due to the magnitude of the differential pressure or of any other stress, do not cause the slope of the straight line defined in 6.1.3.2.1 to exceed 1 % under flowing conditions.

6.1.3.2 Upstream face A

6.1.3.2.1 The upstream face of the plate A should be flat when the plate is installed in the pipe with zero differential pressure across it.

Provided it can be shown that the method of mounting does not distort the plate, this flatness may be measured with the plate removed from the pipe. Under these circumstances, the plate may be considered flat when the maximum gap between the flat portion of the upstream face of the plate and a straight edge of length D , laid across any diameter of the plate, is less than $0,005(D - d - 2e_1)/2$; i.e. the slope is less than 0,5 % when the orifice plate is examined prior to insertion into the meter line (see also ISO 5167-2:2003, Figure 2). The critical area is in the vicinity of the orifice bore. The uncertainty requirements for this dimension may be met using feeler gauges.

6.1.3.2.2 The upstream face of the orifice plate should have a roughness criterion $R_a \leq 10^{-4}d$ within a circle whose diameter is not less than $1,5d$ and which is concentric with the orifice.

NOTE It is useful to provide a distinctive mark, which is visible even when the orifice plate is installed, to show that the upstream face of the orifice plate is correctly installed relative to the direction of flow.

6.1.3.3 Downstream face B

The downstream face should be flat and parallel with the upstream face.

NOTE It is unnecessary to provide the same quality of surface finish for the downstream face as for the upstream face. The flatness and surface condition of the downstream face can be judged by mere visual inspection.

6.1.3.4 Thicknesses e_1 , E_1 and E

6.1.3.4.1 The thickness, e_1 , of the conical entrance should be $0,084d \pm 0,003d$.

6.1.3.4.2 The thickness, E_1 , of the orifice plate for a distance of not less than $1,0d$ from the centreline axis should not exceed $0,105d$.

6.1.3.4.3 The thickness, E , of the orifice plate at a distance greater than $1,0d$ from the centreline axis may exceed $0,105d$ but should not exceed $0,1D$, and the extra thickness, if any, should be on the downstream face.

6.1.3.4.4 If $D \geq 200$ mm, the difference between the values of E_1 measured at any point of the plate should not be greater than $0,001D$. If $D < 200$ mm, the difference between the values of E_1 measured at any point of the plate should not be greater than 0,2 mm.

6.1.3.4.5 The values of E measured at any point on the plate should not differ from each other by more than $0,005D$.

6.1.3.5 Conical entrance

The upstream edge of the orifice should be bevelled at an angle of $45^\circ \pm 1^\circ$.

6.1.3.6 Parallel bore

6.1.3.6.1 The bore of the orifice should be parallel within $\pm 0,5^\circ$ to the centreline.

6.1.3.6.2 The axial length, e , of the parallel bore should be $0,021d \pm 0,003d$.

6.1.3.7 Edges H, I and G

6.1.3.7.1 The upstream edge H formed by the intersection of the conical entrance and the upstream face should not be rounded.

6.1.3.7.2 The upstream edge I formed by the intersection of the parallel bore and the conical entrance should not be rounded.

6.1.3.7.3 The upstream edges H and I and the downstream edge G should not have wire edges, burrs or any peculiarities visible to the naked eye.

6.1.3.8 Diameter of orifice

6.1.3.8.1 The diameter of the orifice, d , should be taken as the mean value of a number of measurements of the diameter distributed in axial planes and at approximately equal angles between adjacent measurements. At least four measurements of the diameter should be made.

No diameter should differ by more than 0,05 % from the value of the mean diameter.

6.1.3.8.2 The parallel bore of the orifice should be cylindrical and perpendicular to the upstream face.

6.1.4 Pressure tapings

Corner tapings as specified in 5.2.3 of ISO 5167-2:2003 should be used with conical entrance orifice plates. Both the upstream and downstream tapings should be the same.

6.1.5 Coefficients and corresponding uncertainties

6.1.5.1 The discharge coefficient, C , is equal to 0,734. The uncertainty on the value of C is 2 %.

6.1.5.2 The value of the expansibility factor ε for the conical entrance orifice plates should be taken as the arithmetic mean of that for square-edged orifice plates and that for ISA 1932 nozzles specified in 5.3.2.2 of ISO 5167-2: 2003 and 5.1.6.3 of ISO 5167-3:2003, respectively.

The values used should be calculated under the same conditions. The uncertainty on the expansibility factor, in percent, is given by $33(1 - \varepsilon)$.

6.1.5.3 The uncertainties on other quantities should be determined in accordance with Clause 8 of ISO 5167-1:2003.

6.2 Quarter-circle orifice plates

6.2.1 General

NOTE A quarter-circle 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.

Quarter-circle 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.

6.2.2 Limits of use

The limits of use for quarter-circle orifice plates should be as follows:

- $d \geq 15$ mm;
- $D \leq 500$ mm.

The lower limit of pipe diameter, D , depends on the internal roughness of the upstream pipeline and should be in accordance with Table 3 and such that:

- $0,245 \leq \beta \leq 0,6$
- $Re_D \leq 10^5 \beta$

The lower limit of the Reynolds number, Re_D , is given by the following equation:

$$Re_D(\text{min.}) = 1\,000\beta + 9,4 \times 10^6 (\beta - 0,24)^8 \quad (9)$$

For convenience, values of Re_D (min.) are given in Table 4.

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.

Table 3 — Minimum internal diameter of upstream pipe for quarter-circle orifice plates

Material	Condition	Minimum internal diameter mm
Brass, copper, lead, glass, plastics	smooth, without sediments	25
Steel	new, cold drawn	25
	new, seamless	25
	new, welded	25
	slightly rusty	50
	rusty	100
	slightly encrusted	200
	bituminized, new	25
	bituminized, used	75
	galvanized	50
Cast iron	bituminized	25
	not rusty	50
	rusty	200

6.2.3 Description

The axial plane cross-section of the orifice plate is shown in Figure 2.

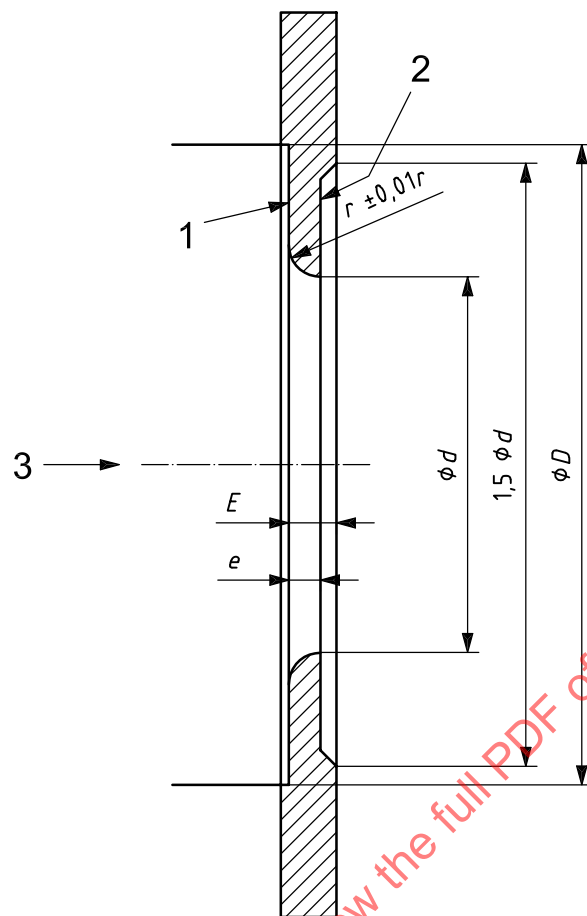
NOTE The letters shown in Figure 2 are for reference purposes in 6.2.3.2 to 6.2.3.7 only.

6.2.3.1 General shape

6.2.3.1.1 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.

6.2.3.1.2 Unless otherwise stated, the recommendations of 6.2.3.1.3 and of 6.2.3.2 to 6.2.3.7 should apply only to that part of the plate located within the pipe.

6.2.3.1.3 Care should be taken in the design of the orifice plate and its installation to ensure that the plastic buckling and elastic deformation of the plate, due to the magnitude of the differential pressure or of any other stress, do not cause the slope of the straight line defined in 6.2.3.2.1 to exceed 1 % under flowing conditions.

**Key**

- 1 upstream face A
- 2 downstream face B
- 3 direction of flow

Figure 2 — Quarter-circle orifice plate**6.2.3.2 Upstream face A**

6.2.3.2.1 The upstream face of the plate A should be flat when the plate is installed in the pipe with zero differential pressure across it.

Provided it can be shown that the method of mounting does not distort the plate, this flatness may be measured with the plate removed from the pipe. Under these circumstances, the plate may be considered flat when the maximum gap between the flat portion of the upstream face of the plate and a straight edge of length D , laid across any diameter of the plate, is less than the following values:

$$0,005 \left(\frac{D-d-2r}{2} \right) \quad \text{if } \beta \leq 0,571$$

$$0,005 \left\{ \left(\frac{D-d}{2} \right) - r + \sqrt{r^2 - \frac{0,01d^2}{\beta^2}} \right\} \quad \text{if } \beta > 0,571$$

That is, the slope is less than 0,5 % when the orifice plate is examined prior to insertion into the meter line (see also Figure 2 of ISO 5167-2:2003). The critical area is in the vicinity of the orifice bore. The uncertainty requirements for this dimension may be met using feeler gauges.

6.2.3.2.2 The upstream face of the orifice plate should have a roughness criterion $R_a \leq 10^{-4}d$ within a circle whose diameter is not less than $1,5d$ and which is concentric with the orifice.

NOTE It is useful to provide a distinctive mark, which is visible even when the orifice plate is installed, to show that the upstream face of the orifice plate is correctly installed relative to the direction of flow.

6.2.3.3 Downstream face B

The downstream face should be flat and parallel with the upstream face.

NOTE It is unnecessary to provide the same quality of surface finish for the downstream face as for the upstream face. The flatness and surface condition of the downstream face can be judged by mere visual inspection.

6.2.3.4 Thicknesses e and E

6.2.3.4.1 The thickness, e , of the bore section should be not less than 2,5 mm and should not exceed $0,1D$.

6.2.3.4.2 Where the radius, r , of the profile exceeds $0,1D$, which is the case when β exceeds 0,571, the thickness of the plate should be reduced from r to $0,1D$ by removing metal from the upstream face.

When the thickness, E , of the orifice plate exceeds the radius, r , then the thickness of the plate should be reduced to equal this radius by removing metal from the downstream face to form a new downstream face in a recess of diameter $1,5d$ with its edge bevelled to 45° .

6.2.3.4.3 If $D \geq 200$ mm, the difference between the values of e measured at any point of the plate should not be greater than $0,001D$. If $D < 200$ mm, the difference between the values of e measured at any point of the plate should not be greater than 0,2 mm.

6.2.3.5 Upstream orifice profile

6.2.3.5.1 The profile of the upstream edge should be circular and of radius r with its centre on the downstream face of the plate.

NOTE The profile might not be a full quarter circle owing to the limit recommended in 6.2.3.4.2.

6.2.3.5.2 The radius, r , of the profile should be determined from the following equation:

$$r/d = 3,17 \times 10^{-6} e^{16,8\beta} + 0,055 4 e^{1,016\beta} + 0,029 \quad (10)$$

to within $\pm 0,05r$.

For convenience, values of r/d are given in Table 4.

The radius of the profile should be the same for all sections to within $\pm 0,01r$.

NOTE The permitted variation in profile radius allows an orifice plate designed for a given D to be used in pipes of $0,95D$ to $1,05D$.

6.2.3.5.3 The tangent to the profile at the downstream edge should be perpendicular to the upstream face of the plate to within $\pm 1^\circ$.

6.2.3.5.4 The profile surface should not have wire edges, burrs or any peculiarities visible to the naked eye.

6.2.3.6 Downstream edge

The downstream edge of the orifice should be square and should not have wire edges, burrs or any peculiarities visible to the naked eye.

6.2.3.7 Diameter of orifice

The diameter of the orifice, d , should be taken as the mean value of a number of measurements of the diameter distributed in axial planes and at approximately equal angles between adjacent measurements. At least four measurements of the diameter should be made.

No diameter should differ by more than 0,1 % from the value of the mean diameter.

6.2.4 Pressure tapplings

For pipes of diameter up to 40 mm, corner tapplings as specified in 5.2.3 of ISO 5167-2:2003 should be used with quarter-circle orifice plates. For pipes of diameter 40 mm or greater, either corner tapplings as specified in 5.2.3 of ISO 5167-2:2003 or flange tapplings as specified in 5.2.2 of ISO 5167-2:2003 should be used with quarter-circle orifice plates.

6.2.5 Coefficients and corresponding uncertainties

6.2.5.1 Discharge coefficient

The discharge coefficient, C , is given by the following equation:

$$C = 0,738\ 23 + 0,330\ 9\beta - 1,161\ 5\beta^2 + 1,508\ 4\beta^3 \quad (11)$$

The uncertainty on the value of C is 2 % when $\beta > 0,316$ and 2,5 % when $\beta \leq 0,316$.

For convenience, Table 4 gives values of C as a function of β .

6.2.5.2 Expansibility (expansion) factor

For the two tapping arrangements, the empirical formula for computing the expansibility (expansion) factor, ε , is as follows and is only applicable if $p_2/p_1 \geq 0,75$:

$$\varepsilon = 1 - (0,351 + 0,256\beta^4 + 0,93\beta^8) \left\{ 1 - \left(\frac{p_2}{p_1} \right)^{1/\kappa} \right\} \quad (12)$$

This formula is applicable only within the range of the limits of use given in 6.2.2.

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.

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

6.2.5.3 Uncertainties

The uncertainties of other quantities should be determined in accordance with Clause 8 of ISO 5167-1:2003.

Table 4 — Discharge coefficients for quarter-circle orifice plates

β	C	r/d	Re_D (min.)
0,245	0,772	0,100	250
0,250	0,772	0,101	250
0,260	0,772	0,101	260
0,270	0,773	0,102	270
0,280	0,773	0,103	280
0,290	0,773	0,104	290
0,300	0,774	0,105	300
0,310	0,774	0,106	310
0,320	0,775	0,106	320
0,330	0,775	0,107	330
0,340	0,776	0,108	340
0,350	0,776	0,109	350
0,360	0,777	0,110	360
0,370	0,778	0,111	370
0,380	0,779	0,112	380
0,390	0,780	0,114	390
0,400	0,781	0,115	400
0,410	0,783	0,116	420
0,420	0,784	0,118	430
0,430	0,786	0,119	450
0,440	0,787	0,121	460
0,450	0,789	0,123	490
0,460	0,791	0,125	510
0,470	0,794	0,127	540
0,480	0,796	0,129	580
0,490	0,799	0,132	630
0,500	0,802	0,135	700
0,510	0,805	0,139	780
0,520	0,808	0,143	880
0,530	0,812	0,147	1 000
0,540	0,816	0,153	1 200
0,550	0,820	0,159	1 400
0,560	0,824	0,167	1 600
0,570	0,829	0,174	1 900
0,580	0,834	0,183	2 300
0,590	0,839	0,194	2 700
0,600	0,844	0,207	3 300

6.3 Eccentric orifice plates

6.3.1 General

The eccentric orifice plate is designed to be installed so that it does not obstruct the flow of entrained gas, liquid or sediments in a fluid, whilst remaining simple to manufacture and install. Eccentric orifice plates should be used in accordance with Clause 6 of ISO 5167-1:2003 and installed in accordance with Clause 6 (except 6.5.3) of ISO 5167-2:2003.

6.3.2 Limits of use

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

- $d \geq 50$ mm
- $100 \text{ mm} \leq D \leq 1\,000$ mm
- $0,46 \leq \beta \leq 0,84$
- $2 \times 10^5 \beta^2 \leq Re_D \leq 10^6 \beta$

6.3.3 Description

The eccentric orifice plate is shown in Figure 3.

NOTE The letters shown in Figure 3 are for reference purposes in 6.3.3.2 to 6.3.3.9 only.

6.3.3.1 General shape

6.3.3.1.1 The part of the plate inside the pipe should be circular and the orifice should be internally tangential to the pipe bore. The faces of the plate should be flat and parallel.

6.3.3.1.2 Unless otherwise stated, the recommendations of 6.3.3.1.3 and of 6.3.3.2 to 6.3.3.9 apply only to that part of the plate located within the pipe.

6.3.3.1.3 Care should be taken in the design of the orifice plate and its installation to ensure that the plastic buckling and elastic deformation of the plate, due to the magnitude of the differential pressure or of any other stress, do not cause the slope of the straight line defined in 6.3.3.2.1 to exceed 1 % under flowing conditions.

6.3.3.2 Upstream face A

6.3.3.2.1 The upstream face of the plate A should be flat when the plate is installed in the pipe with zero differential pressure across it.

Provided it can be shown that the method of mounting does not distort the plate, this flatness may be measured with the plate removed from the pipe. Under these circumstances, the plate may be considered flat when the maximum gap between the flat portion of the upstream face of the plate and a straight edge of length D laid across any diameter of the plate is less than $0,005(D - d)/2$; i.e. the slope is less than about 0,5 % when the orifice plate is examined prior to insertion into the meter line (see also ISO 5167-2:2003, Figure 2). The critical area is in the vicinity of the orifice bore. The uncertainty requirements for this dimension may be met using feeler gauges.

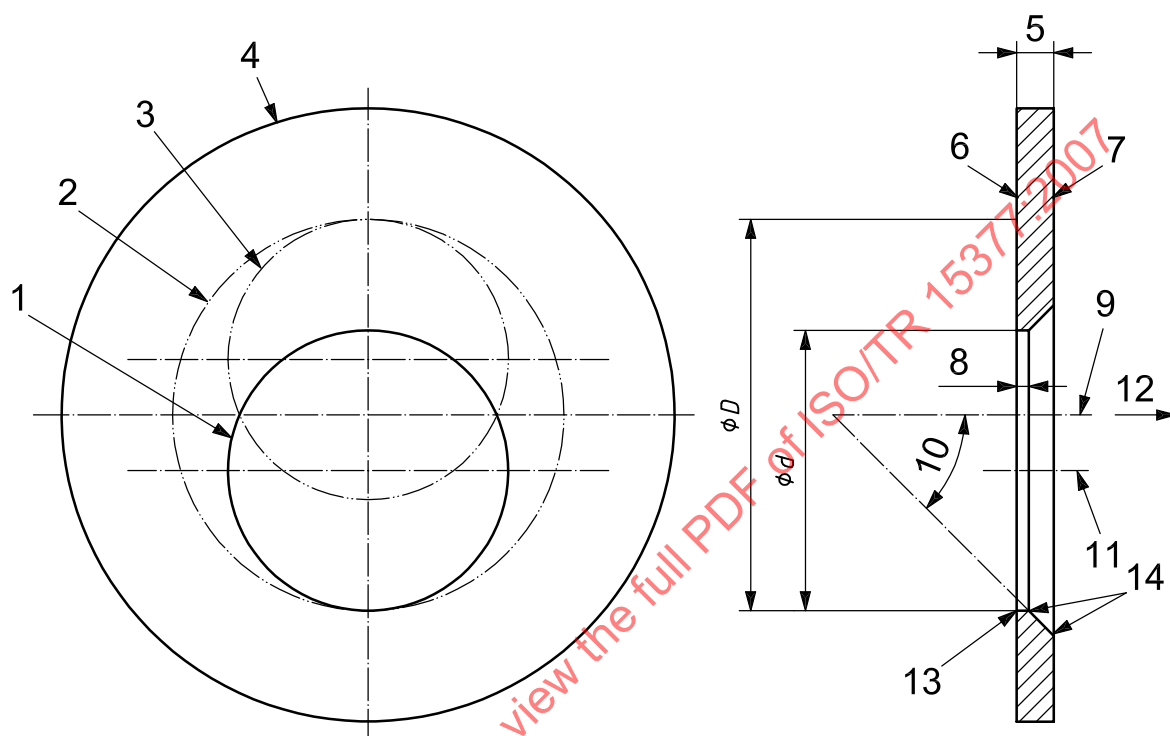
6.3.3.2.2 The upstream face of the orifice plate should have a roughness criterion $R_a \leq 10^{-4}d$ within a circle whose diameter is not less than $1,5d$ and which is concentric with the orifice, except for that part outside diameter D (see 6.3.3.1.2).

NOTE It is useful to provide a distinctive mark, which is visible even when the orifice plate is installed, to show that the upstream face of the orifice plate is correctly installed relative to the direction of flow.

6.3.3.3 Downstream face B

The downstream face should be flat and parallel with the upstream face.

NOTE It is unnecessary to provide the same quality of surface finish for the downstream face as for the upstream face. The flatness and surface condition of the downstream face can be judged by mere visual inspection.



Key

- 1 orifice
- 2 pipe bore
- 3 alternative position of orifice
- 4 outside diameter of the plate
- 5 thickness, E , of the plate
- 6 upstream face A
- 7 downstream face B
- 8 thickness, e , of the orifice
- 9 plate centreline
- 10 angle of bevel, f
- 11 orifice centreline
- 12 direction of flow
- 13 upstream edge G
- 14 downstream edges H and I

Figure 3 — Eccentric orifice plate

6.3.3.4 Thicknesses e and E

6.3.3.4.1 The thickness, e , of the orifice should be between $0,005D$ and $0,02D$.

6.3.3.4.2 The values of e measured at any point on the orifice should not differ from each other by more than $0,001D$.

6.3.3.4.3 The thickness, E , of the orifice plate should be between e and $0,05D$.

6.3.3.4.4 If $D \geq 200$ mm, the difference between the values of E measured at any point of the plate should not be greater than $0,001D$. If $D < 200$ mm, the difference between the values of E measured at any point of the plate should not be greater than 0,2 mm.

6.3.3.5 Angle of bevel

6.3.3.5.1 If the thickness, E , of the plate exceeds the thickness, e , of the orifice, the plate should be bevelled on the downstream side and the bevelled surface should be well finished.

6.3.3.5.2 The angle of bevel, f , should be $45^\circ \pm 15^\circ$.

6.3.3.5.3 The plate should not be bevelled if its thickness, E , is less than or equal to $0,02D$.

NOTE Although detrimental effects from debris trapped in the invert of the downstream bevel are considered unlikely, entrapment will be eliminated by restricting the thickness, E , of the plate to the thickness, e , of the orifice, so that no bevel is necessary.

6.3.3.6 Edges G, H and I

6.3.3.6.1 The upstream edge G and the downstream edges H and I should not have wire edges, burrs or any peculiarities visible to the naked eye.

6.3.3.6.2 The upstream edge G should be considered sharp if the edge radius is not greater than $0,000\ 4d$.

NOTE 1 If $d \geq 125$ mm, this recommendation may be considered as satisfied by mere visual inspection, checking that the edge does not seem to reflect a beam of light when viewed by the naked eye.

NOTE 2 If $d < 125$ mm, visual inspection is not sufficient but this recommendation can be considered as satisfied if the upstream face of the orifice plate is finished by a very fine radial cut from the centre outwards.

However, if there is any doubt as to whether this recommendation is satisfied, the edge radius should actually be measured.

6.3.3.7 Diameter of orifice

6.3.3.7.1 The diameter of the orifice, d , should be taken as the mean value of a number of measurements of the diameter distributed in axial planes and at approximately equal angles between adjacent measurements. At least four measurements of the diameter should be made.

6.3.3.7.2 The parallel bore of the orifice should be cylindrical and perpendicular to the upstream face.

No diameter should differ by more than 0,05 % from the value of the mean diameter.

6.3.3.7.3 The diameter, d , should be between $0,46D$ and $0,84D$.

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.

6.3.3.8 Symmetrical plates

If the orifice plate is intended to be used for measuring reverse flows then

- a) the plate should not be bevelled,
- b) the two faces should be as specified for the upstream face in 6.3.3.2,

- c) the thickness, E , of the plate should be equal to the thickness, e , of the orifice as described in 6.3.3.4.1, and
- d) the two edges of the orifice should be as specified for the upstream edge in 6.3.3.6.2.

6.3.3.9 Pressure tapings

Eccentric orifice plates should be used with a single pair of corner tapings as specified in ISO 5167-2:2003, 5.2.3, except that the pressure-tapping hole diameter, a , should be within the limits $3 \text{ mm} \leq a \leq 10 \text{ mm}$.

NOTE In an eccentric orifice plate, the orifice is not concentric with the pipe bore and, consequently, the pressure difference depends on the angular position of the pressure tapings.

Ideally, the pressure tapings should be diametrically opposite the point at which the orifice is tangential to the wall of the pipe. All discharge coefficient values in this Technical Report are based on such a disposition. However, rotating the tapings by only 90° from the ideal position would result in an error of not more than $+2 \%$ in the discharge coefficient.

Since the orifice is usually either at the top or at the bottom of the pipe, placing the pressure tapings diametrically opposite may cause other problems, such as air entrainment if tapings are at the very top, or blockage by dirt when they are at the bottom of the pipe. In such cases, it is permissible to rotate the tapings by 30° from the vertical centreline of the pipe without the risk of incurring any significant additional flow metering uncertainty.

6.3.4 Coefficients and corresponding uncertainties

6.3.4.1 The discharge coefficient, C , is given by the following equation:

$$C = 0,935\,5 - 1,688\,9\beta + 3,042\,8\beta^2 - 1,798\,9\beta^3 \quad (13)$$

For convenience, Table 5 gives values of C as a function of β .

When β , D , Re_D and k/D are assumed to be known without error, the uncertainty of the value of C is 1% when $\beta \leq 0,75$.

The uncertainty when $\beta > 0,75$ is 2% .

6.3.4.2 The discharge coefficient should be multiplied by the appropriate correction factor for pipe roughness, F_E , given in Table 6 in terms of β and relative pipe roughness k/D . The value of the uniform equivalent roughness, κ , depends on several factors such as height, distribution, angularity and other geometric aspects of the roughness element at the pipe wall. A pressure loss test of a sample length of the particular pipe should be carried out to determine the value satisfactorily. However, approximate values of κ for different materials can be obtained from Table B.1 of ISO 5167-1:2003.

6.3.4.3 The expansibility factor, ε , is given by the following equation and is only applicable if $p_2/p_1 \geq 0,75$:

$$\varepsilon = 1 - (0,351 + 0,256\beta^4 + 0,93\beta^8) \left\{ 1 - \left(\frac{p_2}{p_1} \right)^{1/\kappa} \right\} \quad (14)$$

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

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.