TECHNICAL REPORT

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Measurement of fluid flow by means of pressure-differential devices — Guidelines for specification of nozzles and orifice plates beyond the scope of ISO 5167-1

Mesurage du débit des fluides au moyen d'appareils déprimogènes — Lignes directrices pour les spécifications des tuyères et diaphragmes non couverts par l'ISO 5167-1

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Contents

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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.

The main task of technical committees is to prepare International Standards, but in exceptional circumstances a technical committee may propose the publication of a Technical Report of one of the following types:

– type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;

– type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standard;

– type 3, 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).

Technical Reports of types 1 and 2 are subject to review within three years of publication, to decide whether they can be transformed into International Standards. Technical Reports of type 3 do not necessarily have to be reviewed until data they provide are considered to be no longer valid or useful.

ISO/TR 15377, which is a Technical Report of type 3, was prepared by Technical Committee ISO/TC 30, *Measurement of fluid flow in closed conduits*, Subcommittee SC 2, *Differential pressure methods*.

Measurement of fluid flow by means of pressure-differential devices — Guidelines for specification of nozzles and orifice plates beyond the scope of ISO 5167-1

1 Scope

This Technical Report describes the geometry and method of use for conical-entrance orifice plates, quarter-circle orifice plates and eccentric orifice plates. Recommendations are also given for square-edged orifice plates and nozzles under conditions outside the scope of ISO 5167-1.

2 Reference

ISO 5167-1:1991, *Measurement of fluid flow by means of pressure differential devices — Part 1 : Orifice plates, nozzles and Venturi tubes inserted in circular cross-section conduits running full.*

3 Symbols

The symbols used in this Technical Report are given in table 1.

4 Principle of the method of measurement and computation

The principle of the method of measurement and computation is as specified in clause 5 of ISO 5167-1:1991.

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.

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
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 rate of flow	MT^{-1}	kg/s
r	Radius of profile	L	m
R_a	Roughness criterion	L	m
Re	Reynolds number	dimensionless	
Re_D Re_d	Reynolds number referred to D or 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	
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 Some of the symbols used in this Technical Report are different from those used in ISO 5167-1.

NOTE 3 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.

5.1.2 Square-edged orifice plates

If a drain hole is drilled through the orifice plate, the coefficient values specified in ISO 5167-1: 1991 should not be used unless the following conditions are observed.

a) The pipe diameter 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 equations.

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

$$d_m \approx d \left\{ 1 - 0{,}55 \left(\frac{d_k}{d} \right)^2 \right\}$$

NOTE These equations are 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.

An additional uncertainty equivalent to 100 % of the drain hole correction should be added arithmetically to the discharge coefficient uncertainty when estimating the overall uncertainty of the flow measurement.

5.1.3 ISA 1932 nozzles

If a drain hole is drilled through the nozzle upstream face, the coefficient values specified in ISO 5167-1:1991 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 0,1 d 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 equations.

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

$$d_m \approx d \left\{ 1 - 0{,}40 \left(\frac{d_k}{d} \right)^2 \right\}$$

NOTE These equations are 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 throat of the nozzle.

An additional uncertainty equivalent to 100 % of the drain hole correction should be added arithmetically to the discharge coefficient uncertainty when estimating the overall uncertainty of the flow measurement.

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 ≤ D < 50 mm

5.2.1 General

Orifice plates should be installed and manufactured in accordance with ISO 5167-1.

5.2.2 Limits of use

When square-edged orifice plates are installed in pipes of bore 25 mm up 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 plastics 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 uniform equivalent roughness, k, should be < 0,03 mm for all diameter ratios. If the pipe is machined, the surface finish should be better than 0,3 µm.

b) Corner taps should be used, preferably of the carrier ring type detailed in figure 6 a) of ISO 5167-1: 1991.

c) The diameter ratio, β, should be within the range $0{,}23 \leq \beta \leq 0{,}7$ where $0{,}032 \leq C\beta^2(1 - \beta^4)^{-0{,}5} \leq 0{,}350$.

5.2.3 Discharge coefficients and corresponding uncertainties

The Stolz equation for corner tappings given in 8.3.2.1 of ISO 5167-1: 1991 should be used for deriving the discharge coefficients provided the minimum pipe Reynolds numbers are above the following values.

$Re_D \geq 40\ 000\ \beta^2$ for $0{,}23 \leq \beta \leq 0{,}5$

$Re_D \geq 10\ 000$ for $0{,}5 \leq \beta \leq 0{,}7$

An additional uncertainty of 1,0 % should be added arithmetically to the uncertainty derived from 8.3.3 of ISO 5167-1:1991.

5.3 No upstream or downstream pipeline

5.3.1 General

This clause should apply where there is no pipeline on either or both the upstream or 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,

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 β < 0,125) may 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 is not to be 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 5 *d*.

NOTE 2 The upstream tapping should preferably be located in a wall perpendicular to the plane of the orifice and be within a distance of 0,5 *d* 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 5167-1: 1991. 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 tap should be used.

NOTE 3 When the upstream and downstream tappings are at different horizontal levels, it may be necessary to make allowance for the difference in hydrostatic head.

5.3.2.2 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 8 of ISO 5167-1: 1991.

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:

$d > 6$ mm

upstream: $\beta \leq 0{,}125$

pipeline downstream: $0{,}2 \leq \beta \leq 0{,}5$

large space downstream: $\beta \leq 0{,}125$

$C \beta^2 (1 - \beta^4)^{-0{,}5} \leq 0{,}009$

$Re_d \geq 50\,000$

5.3.2.2.3 The discharge coefficient, *C*, is equal to 0,596. 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 $p_1/p_2 > 0{,}75$:

$$\varepsilon = 1 - (0{,}41 + 0{,}35\beta^4)\frac{\Delta p}{\kappa p_1}$$

When β, $\Delta p/p_1$ and κ are assumed to be known without error, the percentage uncertainty of the value of ε is equal to $4\Delta p/p_1$.

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 the isentropic exponent of which is known.

5.3.2.3 ISA nozzle and Venturi nozzle

5.3.2.3.1 ISA nozzles and Venturi nozzles should be manufactured in accordance with clause 9 or 10.2 of ISO 5167-1:1991.

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

$d \geq 11{,}5$ mm

upstream: $\beta \leq 0{,}125$

pipeline downstream: $0{,}2 \leq \beta \leq 0{,}5$

large space downstream: $\beta \leq 0{,}125$

$C\beta^2(1 - \beta^4)^{-0{,}5} \leq 0{,}015$

$Re_d \geq 100\ 000$

5.3.2.3.3 The discharge coefficient, C, is equal to 0,99. The uncertainty in the value of C is 1 %.

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

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

The uncertainty on the expansibility factor, in percent, is equal to 2 $\Delta p/p_1$.

5.3.3 Flow into a large space (no downstream pipeline)

5.3.3.1 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 diameter of the upstream pipeline should be greater than 2,5 d (that is, $\beta < 0{,}4$).

The upstream tapping should be located as specified for corner tappings in ISO 5167-1:1991.

The distance of the downstream tapping (i.e. the tapping in the large space) from the orifice or nozzle centreline should be greater than 5d.

For Venturi nozzles, the throat tap should be used.

NOTE 1 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 2 Where the upstream and downstream tappings are at different horizontal levels, it may be necessary to make allowance for the difference in hydrostatic head.

5.3.3.1 Square-edged orifice plates with corner tappings

5.3.3.1.1 Square-edged orifice plates with corner tappings should be manufactured in accordance with clause 8 of ISO 5167-1: 1991.

5.3.3.1 Where 25 mm $\leq D <$ 50 mm, the limits given in 5.1.2 should apply except that:

$0{,}4 \leq \beta \leq 0{,}7$

$0{,}1 \leq C\beta^2 (1 - \beta^4)^{-0{,}5} \leq 0{,}35$

Where 50 mm $\leq D \leq$ 1000 mm, the limits given in 8.3.1 of ISO 5167-1: 1991 should apply except that:

$0{,}4 \leq \beta \leq 0{,}8$

$0{,}1 \leq C\beta^2 (1 - \beta^4)^{-0{,}5} \leq 0{,}50$

5.3.3.1.1 Where 25 mm $\leq D <$ 50 mm, the coefficients and uncertainties given in 5.1.3 should apply.

Where 50 mm $\leq D \leq$ 1000 mm, the coefficients and uncertainties given in 8.3.2 and 8.3.3 of ISO 5167-1:1991 should apply.

5.3.3.2 ISA nozzle and Venturi nozzle

5.3.3.2.1 ISA nozzles and Venturi nozzles should be manufactured in accordance with clause 9 or 10.2 of ISO 5167-1: 1991.

5.3.3.2.2 The limits given in 9.1.6.1 of ISO 5167-1: 1991 should apply except that:

$$0,4 \leq \beta \leq 0,8$$

$$0,16 \leq C\beta^2 (1 - \beta^4)^{-0,5} \leq 0,75$$

5.3.3.2.3 The coefficients and uncertainties given in 9.1.6.2, 9.1.6.3 and 9.1.7 of ISO 5167-1:1991 should apply.

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 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 clauses 6 and 7 of ISO 5167-1:1991.

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:

$$0,1 \leq \beta \leq 0,316$$

$$0,007 \leq C\beta^2 (1 - \beta^4)^{-0,5} \leq 0,074$$

$$80 \leq Re_D \leq 2 \times 10^5 \beta$$

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.

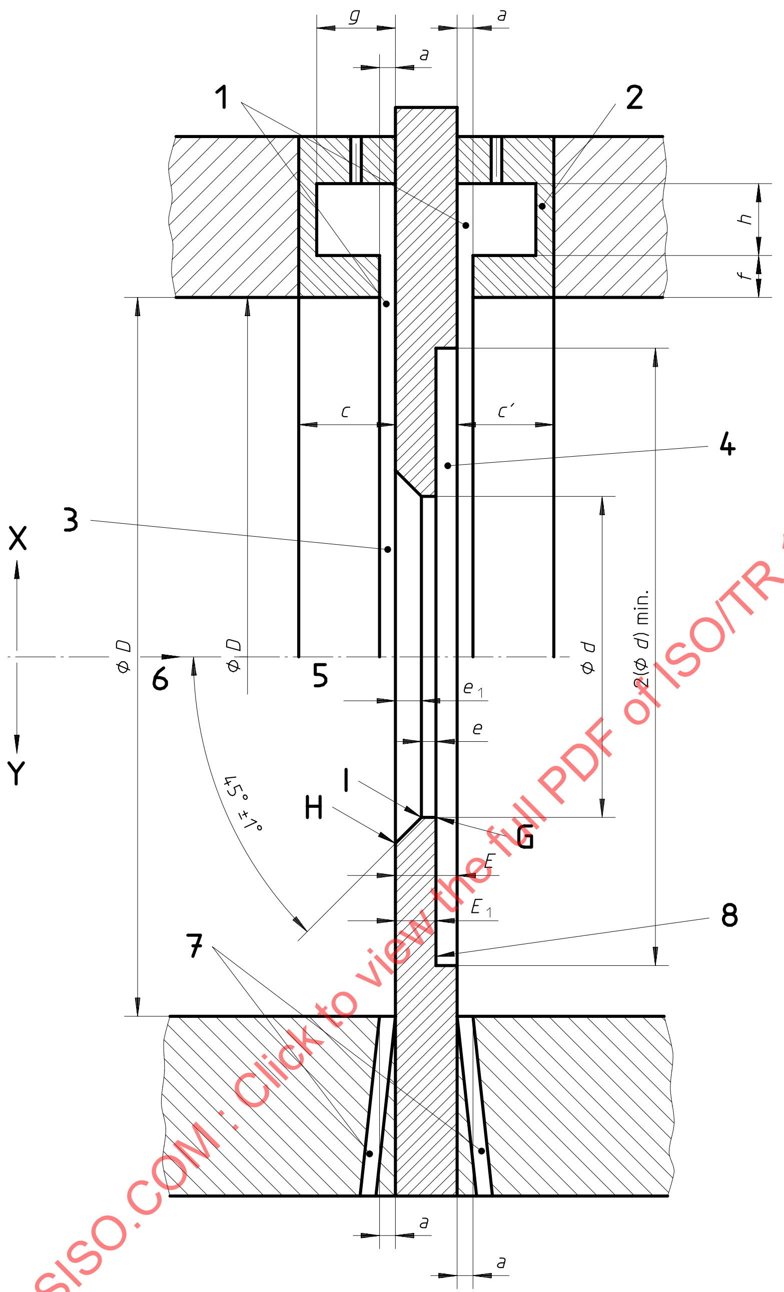
6.1.3 Description

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

The letters shown in figure 1 are for reference purposes in 6.1.3.2 to 6.1.3.8 only.

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.



Key

1 Annular slots
2 Carrier ring
3 Upstream face A
4 Downstream face B
5 Axial centreline
6 Direction of flow
7 Pressure tappings
8 Orifice plate
X Carrier ring with annular slot
Y Individual tappings

Figure 1 — Conical entrance orifice plate

Table 2 — Minimum internal diameter of upsteam 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
cast iron	bituminized	25
	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, does 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.

NOTE 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 if the slope of a straight line connecting any two points of its surface in relation to a plane perpendicular to the centreline is less than 0,5 %, ignoring the inevitable local defects of the surface which are invisible to the naked eye.

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 The values of E_1 measured at any point on the plate should not differ from each other by more than 0,001D.

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° ± 1°.

6.1.3.6 Parallel bore

6.1.3.6.1 The bore of the orifice should be parallel within ± 0,5° to the centreline.

6.1.3.6.2 The axial length, e, of the parallel bore should be 0,021d ± 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 tappings

Corner tappings as specified in 8.2.2 of ISO 5167-1:1991 should be used with conical entrance orifice plates. Both the upstream and downstream tappings 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 mean of that for square-edged orifice plates and that for ISA 1932 nozzles specified in 8.3.2.2 and 9.1.6.3 of ISO 5167-1:1991 respectively.

The values used should be calculated at 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 11 of ISO 5167-1:1991.

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 measurement of flowrate of viscous fluids such as oil.

Quarter-circle orifice plates should be used and installed in accordance with clauses 6 and 7 of ISO 5167-1:1991.

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 within the following limits:

$0{,}245 \leq \beta \leq 0{,}6$

$0{,}046 \leq C\beta^2 (1 - \beta^4)^{-0{,}5} \leq 0{,}326$

$Re_D \leq 10^5 \beta$

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

$$Re_D \text{ (min.)} = 1000\beta + 9{,}4 \times 10^6 (\beta - 0{,}24)^8$$

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

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

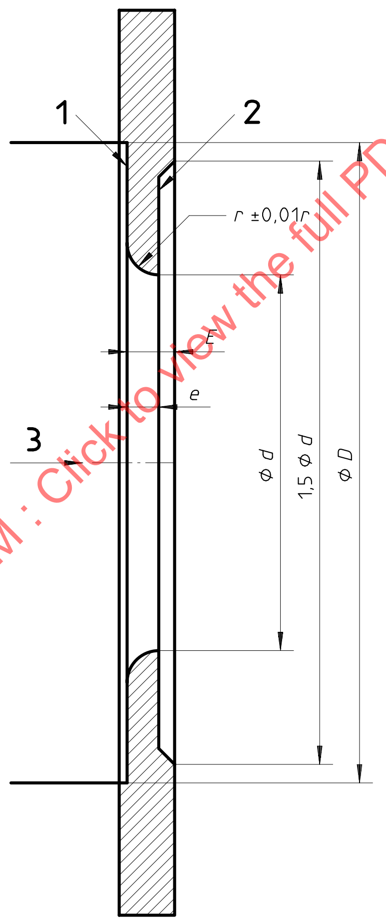
The letters shown in figure 2 are for reference purposes in 6.2.3.2 to 6.2.3.7 only.

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, does 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 Upstream 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.

NOTE 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 if the slope of a straight line connecting any two points of its surface in relation to a plane perpendicular to the centreline is less than 0,5 %, ignoring the inevitable local defects of the surface which are invisible to the naked eye.

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 1,5*d* 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 0,1*D*.

6.2.3.4.2 Where the radius, *r*, of the profile exceeds 0,1*D*, 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.

6.2.3.4.3 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 1,5*d* with its edge bevelled to 45 °.

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

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 may not be a full quarter circle due 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:

$$r/d = 3{,}17 \times 10^{-6}\, e^{\,16{,}8\beta} + 0{,}0554 e^{1{,}016\beta} + 0{,}029$$

within ± 0,05*r*.

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

The radius of the profile should be the same for all sections within ± 0,01*r*.

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

6.2.3.5.3 The tangent to the profile at the downstream edge should be perpendicular to the upstream face of the plate within ± 1°.

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, nor 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 tappings

For pipes of diameter up to 40 mm, corner tappings as specified in 8.2.2 of ISO 5167-1:1991 should be used with quarter-circle orifice plates. For pipes of diameter 40 mm or greater, either corner tappings as specified in 8.2.2 of ISO 5167-1:1991 or flange tappings as specified in 8.2 of ISO 5167-1:1991 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:

$$C = 0{,}73823 + 0{,}3309\beta - 1{,}1615\beta^2 + 1{,}5084\beta^3$$

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:

$$\varepsilon = 1 - (0{,}41 + 0{,}35\beta^4)\frac{\Delta p}{\kappa p_1}$$

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 the isentropic exponent of which is known.

However, the formula is applicable only if $\frac{p_2}{p_1} \geq 0{,}75$

When β, $\Delta p/p_1$ and κ are assumed to be known without error, the percentage uncertainty of the value of ε is equal to 4 $(\Delta p/p_1)$ % when $\beta \leq 0{,}6$.

6.2.5.3 Uncertainties

The uncertainties of other quantities should be determined in accordance with clause 11 of ISO 5167-1:1991.

Table 4 — Discharge coefficients for quarter-circle orifice plates

β	*C*	*r/d*	*ReD* 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	1000
0,540	0,816	0,153	1200
0,550	0,820	0,159	1400
0,560	0,824	0,167	1600
0,570	0,829	0,174	1900
0,580	0,834	0,183	2300
0,590	0,839	0,194	2700
0,600	0,844	0,207	3300

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 and installed in accordance with clause 7 (except 7.5.3.3) of ISO 5167-1:1991.

6.3.2 Limits of use

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

$d \geq 50$ mm

$100 \text{ mm} \leq D \leq 1000 \text{ mm}$

$0{,}46 \leq \beta \leq 0{,}84$

$0{,}136 \leq C\beta^2 (1 - \beta^4)^{0{,}5} \leq 0{,}423$

$2 \times 10^5 \beta^2 \leq Re_D \leq 10^6 \beta$

6.3.3 Description

NOTE The eccentric orifice plate is shown in figure 3. 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 should 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, does 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.

NOTE 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 if the slope of a straight line connecting any two points of its surface in relation to a plane perpendicular to the centreline is less than 0,5 %, ignoring the inevitable local defects of the surface which are invisible to the naked eye.

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.