TECHNICAL REPORT

ISO/TR 12767

Second edition
2007-09-01

Measurement of fluid flow by means of pressure differential devices — Guidelines on the effect of departure from the specifications and operating conditions given in ISO 5167

Mesurage du débit des fluides au moyen d'appareils déprimogènes — Lignes directrices relatives aux effets des divergences par rapport aux spécifications et aux conditions de fonctionnement données dans l'ISO 5167

Reference number
ISO/TR 12767:2007(E)

PDF disclaimer

This PDF file may contain embedded typefaces. In accordance with Adobe's licensing policy, this file may be printed or viewed but shall not be edited unless the typefaces which are embedded are licensed to and installed on the computer performing the editing. In downloading this file, parties accept therein the responsibility of not infringing Adobe's licensing policy. The ISO Central Secretariat accepts no liability in this area.

Adobe is a trademark of Adobe Systems Incorporated.

Details of the software products used to create this PDF file can be found in the General Info relative to the file; the PDF-creation parameters were optimized for printing. Every care has been taken to ensure that the file is suitable for use by ISO member bodies. In the unlikely event that a problem relating to it is found, please inform the Central Secretariat at the address given below.

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

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/TR 12767 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 12767:1998), which has been technically revised.

Introduction

ISO 5167 (all parts) specifies methods for flowrate measurement using pressure differential devices. Adherence to ISO 5167 (all parts) results in flowrate measurements whose uncertainty lies within specified limits. If, however, a flow-metering installation departs, for whatever reason, from the conditions specified in ISO 5167 (all parts), the specified limits of uncertainty may not be achieved. Many metering installations exist where these conditions either have not been or cannot be met. In these circumstances, it is usually not possible to evaluate the precise effect of any such deviations. However, a considerable amount of data exists which can be used to give a general indication of the effect of non-conformity to ISO 5167 (all parts), and it is presented in this Technical Report as a guideline to users of flow-metering equipment.

Measurement of fluid flow by means of pressure differential devices — Guidelines on the effect of departure from the specifications and operating conditions given in ISO 5167

1 Scope

This Technical Report provides guidance on estimating the flowrate when using pressure differential devices constructed or operated outside the scope of ISO 5167.

Additional tolerances or corrections cannot necessarily compensate for the effects of deviating from ISO 5167 (all parts). The information is given, in the first place, to indicate the degree of care necessary in the manufacture, installation and maintenance of pressure differential devices by describing some of the effects of non-conformity to the requirements; and in the second place, to permit those users who cannot comply fully with the requirements to assess, however roughly, the magnitude and direction of the resulting error in flowrate.

Each variation dealt with is treated as though it were the only one present. Where more than one is known to exist, there may be unpredictable interactions and care has to be taken when combining the assessment of these errors. If there is a significant number of errors, means of eliminating some of them have to be considered. The variations included in this Technical Report are by no means complete and relate largely to examples with orifice plates. An example with Venturi tubes has been placed at the end of its section. There are, no doubt, many similar examples of installations not conforming to ISO 5167 (all parts) for which no comparable data have been published. Such additional information from users, manufacturers and any others may be taken into account in future revisions of this Technical Report.

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

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

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

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

3 Terms and definitions

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

3.1
square edge
angular relationship between the orifice bore of the flow-measurement device and the upstream face, when the angle between them is 90° ± 0,3°

3.2
sharpness
radius of the edge between the orifice bore of the flow-measurement device and the upstream face

NOTE The upstream edge of the orifice bore is considered to be sharp when its radius is not greater than 0,000 4d, where d is the diameter of the orifice bore.

4 Symbols and abbreviated terms

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

Table 1 — Symbols and units

Symbol	Quantity represented	**Dimensions** M: mass L: length T: time	SI units
c	Percentage change in discharge coefficient $[\equiv 100(\Delta C / C)]$	dimensionless	
C	Discharge coefficient	dimensionless	
C_c	Contraction 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_1	Carrier ring diameter	L	m
D_2	Orifice-plate support diameter	L	m
e	Relative uncertainty	dimensionless	
E	Orifice-plate thickness	L	m
E_e	Orifice thickness	L	m
k	Uniform equivalent roughness	L	m
L_1	Distance of upstream pressure tapping from upstream face of plate divided by pipe bore, D	dimensionless	
L_2'	Distance of downstream pressure tapping from downstream face of plate divided by pipe bore, D	dimensionless	
q_m	Mass rate of flow	MT^{-1}	kg/s
r	Orifice-plate edge radius	L	m
Re_d	Reynolds number based on throat bore of device	dimensionless	
Re_D	Reynolds number based on upstream pipe diameter	dimensionless	
u	Local axial velocity	LT^{-1}	m/s
u_{CL}	Centreline axial velocity	LT^{-1}	m/s
U	Mean axial velocity	LT^{-1}	m/s
Y	Modulus of elasticity of orifice-plate material	$ML^{-1}T^{-2}$	Pa
β	Diameter ratio, $(= d/D)$	dimensionless	
Δp	Differential pressure	$ML^{-1}T^{-2}$	Pa
Δp_y	Differential pressure required to reach orifice-plate yield stress	$ML^{-1}T^{-2}$	Pa

Table 1 (*continued*)

Symbol	Quantity represented	Dimensions M: mass L: length T: time	SI units
ε	Expansibility (expansion) factor	dimensionless	
λ	Friction factor	dimensionless	
ρ	Fluid density	ML^{-3}	kg/m^3
ρ_1	Fluid density at the upstream pressure tapping	ML^{-3}	kg/m^3
σ_y	Yield stress of orifice-plate material	$ML^{-1}T^{-2}$	Pa

5 Effect of errors on flowrate calculations

5.1 General

In this Technical Report, the effects of deviations from the conditions specified in ISO 5167 (all parts) are described in terms of changes in the discharge coefficient, ΔC, of the meter. The discharge coefficient, C, of a pressure differential device is given by Equation (1):

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

The sharp edge of an orifice plate ensures separation of the flow and consequently contraction of the fluid stream to the vena contracta. Defining the contraction coefficient, C_c, as the ratio of the flow area to the geometric area the orifice produces $C_c \approx 0{,}6$, which mainly accounts for the discharge coefficient, $C \approx 0{,}6$.

The effect of change in the discharge coefficient is illustrated by the following example.

Consider an orifice plate with an unduly rounded edge. The result of this will be to reduce the separation and increase C_c, leading in turn to reduced velocities at the vena contracta. The observed differential pressure will therefore decrease. From Equation (1), it can be seen that the discharge coefficient would therefore increase. Alternatively, as C_c increases, so does C. If no correction is made for this change in C, the meter reading will be less than the actual value.

It can therefore be concluded that:

a) an effect which causes an increase in discharge coefficient will result in a flowrate reading lower than the actual value if the coefficient is not corrected;

and conversely,

b) an effect which causes a decrease in discharge coefficient will result in a flowrate reading higher than the actual value if the coefficient is not corrected.

5.2 Quantifiable effects

When the user is aware of such effects and they can be quantified, the appropriate discharge coefficient can be used and the correct flowrate calculated. However, the precise quantification of these effects is difficult and so any flowrate calculated in such a manner should be considered to have an increased uncertainty.

Except where otherwise stated, an additional uncertainty factor, equivalent to 100 % of the discharge coefficient correction, should be added arithmetically to that of the discharge coefficient when estimating the overall uncertainty in the flowrate measurement.

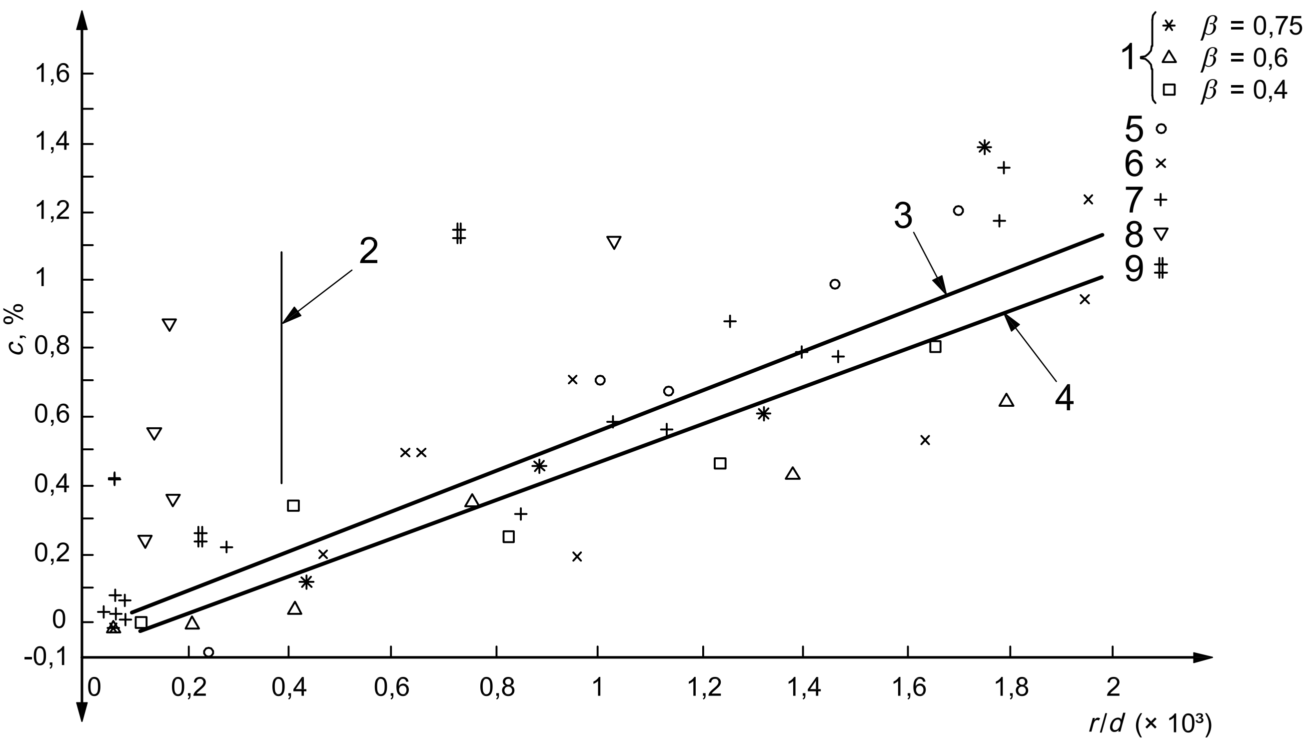
6 Effects of deviations in construction

6.1 Orifice-plate edge sharpness

Orifice plates that do not have the specified sharpness of the inlet edge (edge radius $r \leqslant 0{,}000\,4d$ in accordance with 5.1.7.2 of ISO 5167-2:2003), will have progressively increasing discharge coefficients as the edge radius increases. Tests have shown that the effect on the discharge coefficient, C, is to increase it by 0,5 % for r/d of 0,001, and by about 5 % for r/d of 0,01. This is an approximately linear relationship (see Figure 1 and Reference [1]). These values apply particularly to Re_d values above 300 000 and for β values below 0,7, but they can be used as a general guide for other values.

Measurement techniques for edge radius are available, but in general it is better to improve the edge sharpness to the required value rather than to attempt to measure it and make appropriate corrections.

The effect of nicks in orifice plates has also been measured in Reference [1].



Key

1 National Engineering Laboratory (NEL, UK) tests —— $D = 300$ mm

2 ISO limit —— $r = 0{,}000\,4d$

3 others

4 NEL

5 $D = 50$ mm (Reference [56])

6 $D = 100$ mm (Reference [56])

7 $D = 150$ mm (Reference [34])

8 $D = 75$ mm (Reference [57])

9 $D = 100$ mm (Reference [58])

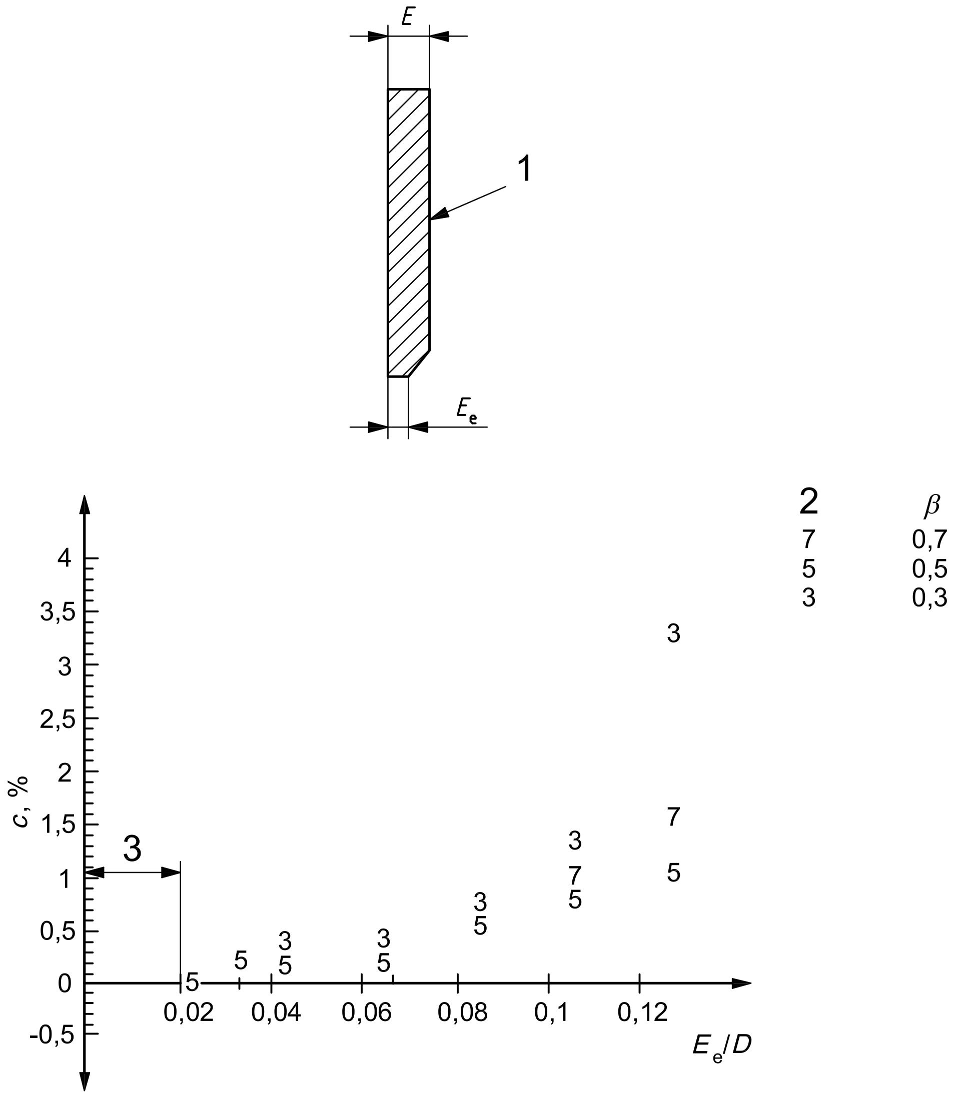
c change in discharge coefficient

r/d radius ratio

Figure 1 — Effect of edge radius on discharge coefficient

6.2 Thickness of orifice edge

For orifice plates, the increase in discharge coefficient due to excessive thickness of the orifice edge (see 5.1.5 of ISO 5167-2:2003) can be appreciable. With a straight-bore orifice plate in a 150 mm pipe, the changes in discharge coefficient shown in Figure 2 were obtained (see Reference [2]).



Key

1 section of an orifice plate
2 symbol
3 limit of standard

c change in discharge coefficient
E_e/D orifice thickness to upstream internal pipe diameter ratio

Figure 2 — Change in discharge coefficient as a function of orifice thickness

6.3 Condition of upstream and downstream faces of orifice plate

The upstream face should be flat and smooth. Excessive roughness leads to an increase in the discharge coefficient. Tests have indicated that a surface roughness of 0,000 3d will cause an increase in discharge coefficient of the order of 0,1 %. Since the requirement for edge sharpness is $r \leqslant$ 0,000 4d, an increase in plate roughness will make it difficult to define the edge sharpness or to confirm that the sharp edge requirement has been met.

Local damage to the upstream face or edge of an orifice plate does not adversely affect the discharge coefficient, provided that the damage is kept as far away from the pressure tapping as possible (see Reference [1]). The discharge coefficient is much less sensitive to the surface condition of the downstream face of the plate (Reference [1]).

Large-scale lack of flatness, e.g. “dishing”, leads to flow-measurement errors. A “dishing” of 1 % in the direction of flow causes the reading to be below the actual value, i.e. an increase in C of about 0,2 % for $\beta = 0{,}2$ and of about 0,1 % for $\beta = 0{,}7$. Distortion against the direction of flow also causes errors which could be either positive or negative depending on the amount of distortion.

6.4 Position of pressure tappings for an orifice

6.4.1 General

Values of the orifice-plate discharge coefficient for the three standard tapping positions (corner, flange, D and D/2) can be calculated using Equation (4) of ISO 5167-2:2003 (see Reference [55]). Where the tapping positions fall outside the tolerances permitted in ISO 5167-2 for the three positions, the discharge coefficient may be estimated as described in 6.4.2. It should be emphasized that an additional uncertainty factor needs to be associated with the use of non-standard tapping positions.

6.4.2 Calculation of discharge coefficient

Calculate the actual values of L_1 and L_2'. The discharge coefficient can be estimated only if $L_1 \leqslant 1$ and $L_2' \leqslant 0{,}47$.

Using the actual values of L_1 and L_2', estimate the discharge coefficient using Equation (4) of ISO 5167-2:2003.

6.4.3 Estimation of additional uncertainty

If tappings lie between the flange and the corner tappings, the additional uncertainty, e, expressed as a percentage, can be estimated from:

$$e = 25 \left| \frac{C_{\mathrm{F}}}{C_{\mathrm{CT}}} - 1 \right| \qquad (2)$$

where

C_{F} is the discharge coefficient for flange tappings;

C_{CT} is the discharge coefficient for corner tappings.

If tappings lie between the D and $D/2$ tappings and the flange tappings, the additional uncertainty, e, expressed as a percentage, can be estimated from:

$$e = 25 \left| \frac{C_{D \text{ and } D/2}}{C_{\mathrm{F}}} - 1 \right| \qquad (3)$$

where

$C_{D \text{ and } D/2}$ is the discharge coefficient for D and $D/2$ tappings.

6.4.4 Example

Consider an orifice meter with $\beta = 0{,}6$, $Re_D = 10^6$, $D = 250$ mm and tappings at 0,15D upstream and downstream of the plate.

To estimate the discharge coefficient, use Equation (4) of ISO 5167-2:2003 with $L_1 = L_2' = 0{,}15$.

The tappings in this example lie between the flange tapping and D and $D/2$ tapping positions. From Tables A.8 and A.2, respectively, of ISO 5167-2:2003: $C_F = 0{,}605\,1$; $C_{D \text{ and } D/2} = 0{,}607\,0$. Therefore

$$e = 25\left|\frac{0{,}605\,1}{0{,}607\,0} - 1\right| = 0{,}078$$

The uncertainty in the discharge coefficient is 0,5 % (see 5.3.3.1 of ISO 5167-2:2003).

Therefore, overall uncertainty is $0{,}5 + 0{,}078 \approx 0{,}6$ % (i.e. the uncertainties have simply been added together).

6.5 Condition of pressure tappings

Experience has shown that large errors can be created by pressure tappings which have burrs or deposits on, or close to, the edge where the tapping penetrates the pipe wall. This is particularly the case where the tappings are in the main flow stream, such as throat tappings in nozzles or Venturi tubes, where small burrs can give rise to significant percentage errors. Upstream corner tappings and downstream tappings in relatively dead zones are much less liable to cause this problem.

The installation shall be inspected before use and at regular intervals to ensure that these anomalies are not present.

7 Effects of pipeline near the meter

7.1 Pipe diameter

The internal diameter of the pipe upstream and downstream of the primary device should always be measured to ensure that it is in accordance with 6.4 of ISO 5167-2:2003, 6.4 of ISO 5167-3:2003 or 6.4.1 of ISO 5167-4:2003. Errors in the upstream internal diameter measurement cause errors in the calculated flowrate, which are given by:

$$\frac{\delta q_m}{q_m} = \frac{-2\beta^4}{(1-\beta^4)}\frac{\delta D}{D} \tag{4}$$

These errors become significant for large β, e.g. with $\beta = 0{,}75$, a positive 1 % error in D will cause a negative 1 % error in q_m.

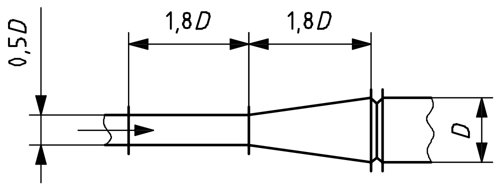
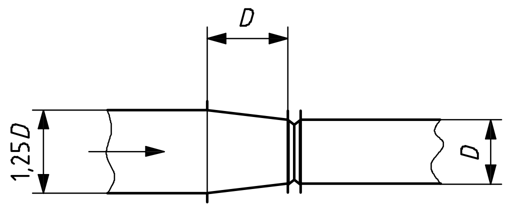
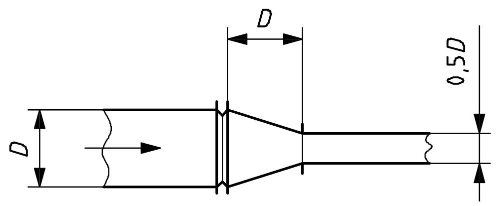
The downstream pipe is far less critical, as for an orifice plate, an ISA 1932 nozzle or a long radius nozzle its diameter need only be within 3 % of that of the upstream pipe (see 6.4.6 of ISO 5167-2:2003 or 6.4.6 of ISO 5167-3:2003) and for a Venturi nozzle or a Venturi tube its diameter need only be ⩾ 90 % of the diameter at the end of the divergent section (see 6.4.6 of ISO 5167-3:2003 or 6.4.1.3 of ISO 5167-4:2003).

7.2 Steps and taper sections

Sudden enlargements of the pipe in the vicinity of the primary device should always be avoided as large errors in flow measurement result from their use. Similarly, tapering sections of pipe can lead to significant errors, as can be seen from Table 2 which gives the order of errors to be expected when an orifice plate with corner tappings is immediately preceded or followed by a taper piece.

The information in Table 2 indicates that a taper piece divergent in the direction of flow, and placed immediately upstream, is not recommended, since discharge-coefficient increases of up to 50 % result. On the other hand, a convergent taper piece, whether installed before or after the orifice plate, and provided it is not of a steeper angle than those shown, results in coefficient changes of generally less than 2 %.

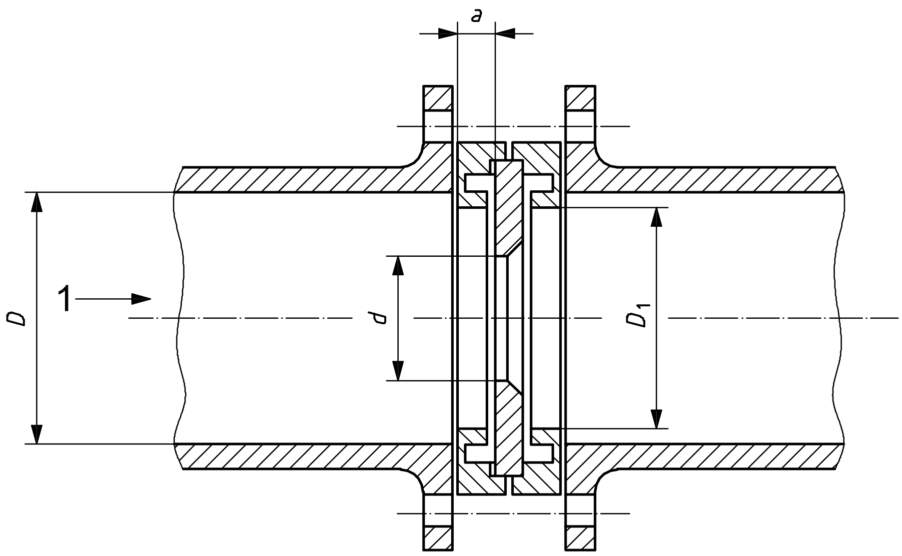
Table 2 — Effect of taper pieces

Position of orifice plate	β	**Order of the discharge coefficient change to be expected** %
a) Immediately downstream from a divergent taper piece 	0,4 0,7	+ 10 + 50
b) Immediately downstream from a convergent taper piece 	0,4 0,7	− 0,5 − 2
c) Immediately upstream from a convergent taper piece 	0,4 0,7	0 to − 1 + 1

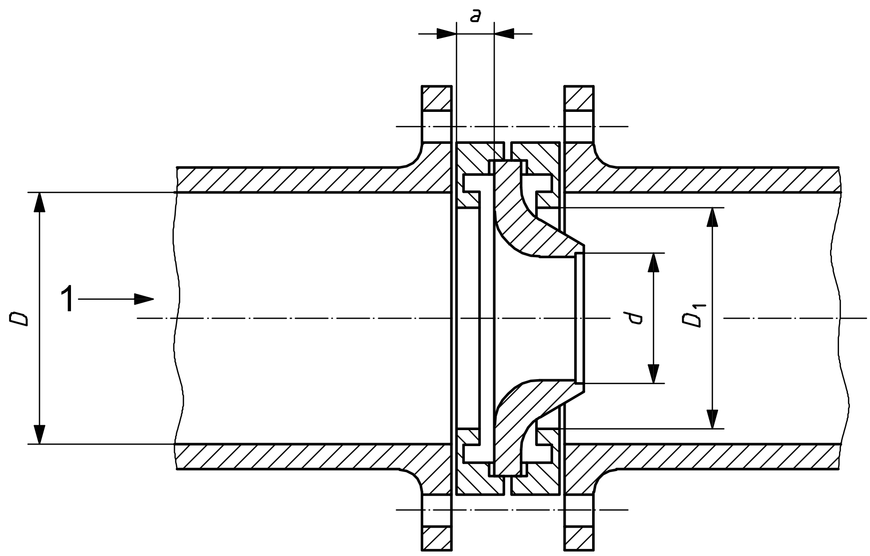
7.3 Diameter of carrier ring

The requirements for the sizing and concentric mounting of carrier rings for orifice plates and nozzles are specified in 6.4 and 6.5 of ISO 5167-2:2003, 6.4 and 6.5 of ISO 5167-3:2003 and Figure 4 of ISO 5167-2:2003. If the requirement of 6.5.4 of ISO 5167-2:2003 and 6.5.4 of ISO 5167-3:2003 (i.e. that the centred carrier ring should not protrude into the pipe) is not met, relatively large flow-measurement errors will be introduced. Figure 3 shows such an installation and Figure 4, using the same notation, shows the approximate errors introduced for the given conditions, where a is the width of the portion of the carrier ring upstream of the upstream face of the orifice plate or nozzle. It is emphasized that in arriving at these errors, the internal carrier ring diameter, D_1, and not the diameter of the main line, has been used in determining the calculated flowrate and is to be used for D in determining the correction factor when making use of the values shown.

Where the carrier is oversize, experimental results indicate that for $\beta = 0{,}74$ a carrier 11 % oversize and extending 0,05D upstream from the plate increased the discharge coefficient by approximately 0,5 %. However, for a similar geometry but with $\beta = 0{,}63$, no effect was found.



a) Orifice plate

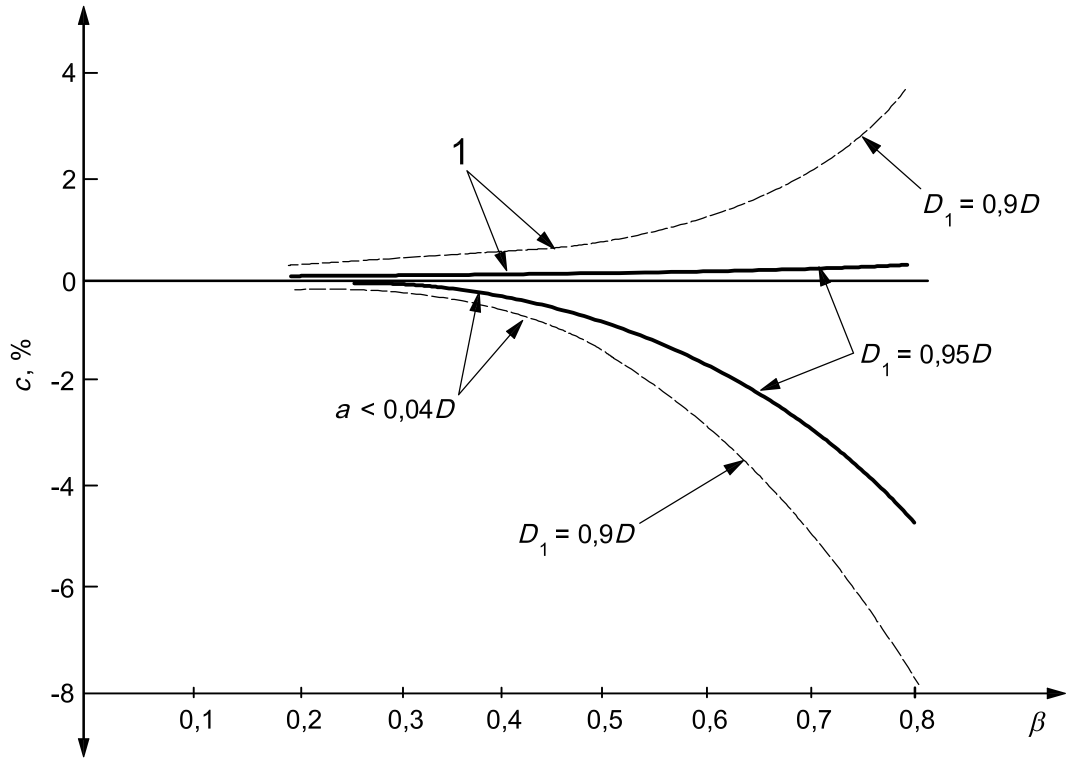


b) Nozzle

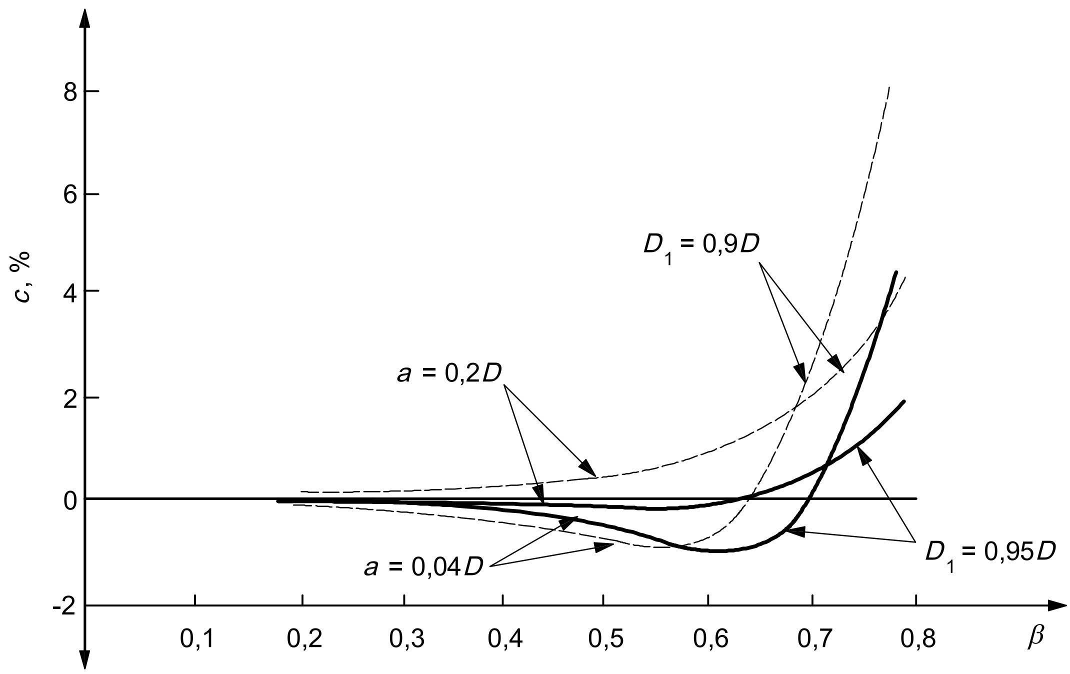
Key

1 flow

Figure 3 — Carrier having internal diameter, D_1, less than pipe diameter, D



a) Orifice plate



b) Nozzle

Key

1 $a = 0{,}2D$ to $0{,}3D$

c change in discharge coefficient

β diameter ratio

Figure 4 — Effect of incorrect carrier diameter

7.4 Undersize joint rings

When the inside diameter of a joint ring or gasket is smaller than the pipe diameter, especially on the upstream side of an orifice plate or nozzle, very large flow-measurement errors may occur. The magnitude and sign of the effect in relation to the measurement of flowrate is dependent on the combination of a number of variables, e.g. the thickness of the joint ring upstream of the orifice plate, the extent of its protrusion into the flow, its position relative to the orifice plate and pressure tappings, and the degree of roughness of the upstream pipe.

7.5 Protruding welds

The effect of an undressed circumferential weld protruding into the pipe bore adjacent to the primary device will be similar to that of an undersize joint ring. Such an effect may arise from the fitting of a weld-neck flange, and the magnitude of the effect will depend on the height uniformity, or otherwise, of the protruding weld, and its position in relation to the single or multiple pressure tapping arrangement employed to measure the differential pressure across the primary device. To quantify the resulting error in a specific situation is difficult without a direct calibration.

It should be noted that seamed pipe may be used, provided that the internal weld bead is parallel to the pipe axis throughout the entire length of the pipe required, to satisfy the installation requirements for the primary device being used. Any weld bead shall not have a height greater than the permitted step in diameter. Unless an annular slot is used, the seam shall not be situated within any sector of ± 30° centred on any individual pressure tapping to be used in conjunction with the primary device. If an annular slot is used, the location of the seam is not significant. If spirally wound pipe is used, then it shall be machined to a smooth bore. (See 7.1.4 of ISO 5167-1:2003.)

7.6 Eccentricity

The requirements for concentric mounting of the device are given in 6.5.3 and 6.5.4 of ISO 5167-2:2003, 6.5.3 and 6.5.4 of ISO 5167-3:2003 and 6.4.3 of ISO 5167-4:2003. The geometric measure of eccentricity is the distance between the pipe and orifice-plate centrelines and is often expressed as a percentage of the pipe diameter, D. Deviations from the permitted eccentricity values for the mounting of an orifice plate relative to the upstream and downstream pipe sections will result in errors in the measurement of flowrate. Figure 5 shows the eccentric mounting of an orifice plate in a sideways direction relative to the upstream pipeline. The displacement is to the right and the eccentricity is a combination of the dimensional tolerances arising from the bolt-hole pitch-circle diameter, the bolt diameter, the bolt-hole diameter and the outer diameter of the orifice plate.

Experimental evidence on the effects of eccentricity is limited, but it has been shown that for orifice plates, the effect on discharge coefficient is a function of β, pipe size and roughness, pressure-tapping type, location and magnitude, as well as the position of the orifice centre relative to the pressure tapping.

Experimental work indicates that the errors due to eccentricity increase in general with β. For $\beta = 0,2$ and eccentricity up to 5 % of D, discharge coefficient increases are unlikely to exceed 0,1 %. For larger β, the changes are best shown graphically as in Figure 6.

Below 3 % eccentricity, the error varies with type of tappings and direction of eccentricity. The meter is least sensitive to eccentricity perpendicular to the tappings. Above 3 % eccentricity, errors for all tappings and directions increase rapidly.

NOTE No data are available for corner tappings, but the errors are probably similar to those for flange tappings since the above data were obtained from a test line with $D = 150$ mm.

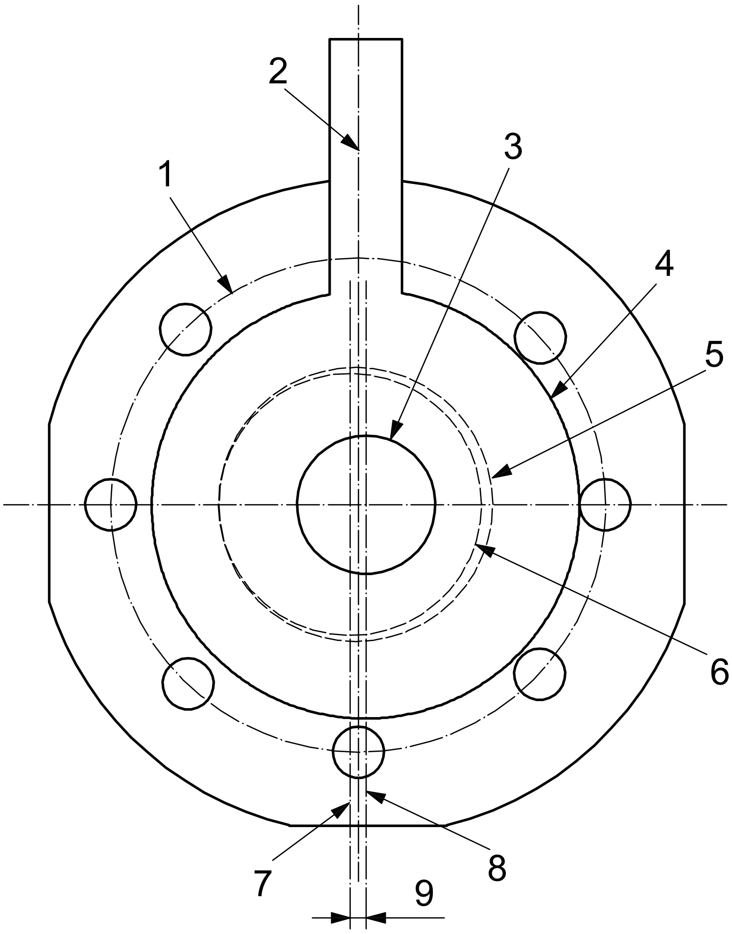
A further effect of eccentric positioning of an orifice plate is an increased unsteadiness of the differential pressure signal obtained. Observations have shown, for example, a marked increase in differential pressure reading fluctuations with increasing eccentricity for all values of β between 0,4 and 0,7.

Because of the number of variants contributing to the effect of eccentricity on the measurement of flow, the effect is difficult to quantify. Every effort should be made to restrict eccentricity to less than 3 % of D, particularly in the direction of the tappings.

The effect may be minimized by employing four equally-spaced upstream and downstream tappings on the flowmeter, as illustrated in Figure 1 of ISO 5167-1:2003. The pressure lines from these are then coupled in the widely used triple-T tapping arrangement in order to obtain an average differential pressure reading.

As a general guide, it may be assumed that the effects of eccentric mounting for multi-tapped nozzles will be less than those for orifice plates of equivalent β. Venturi tubes are less likely to be installed off-centre.

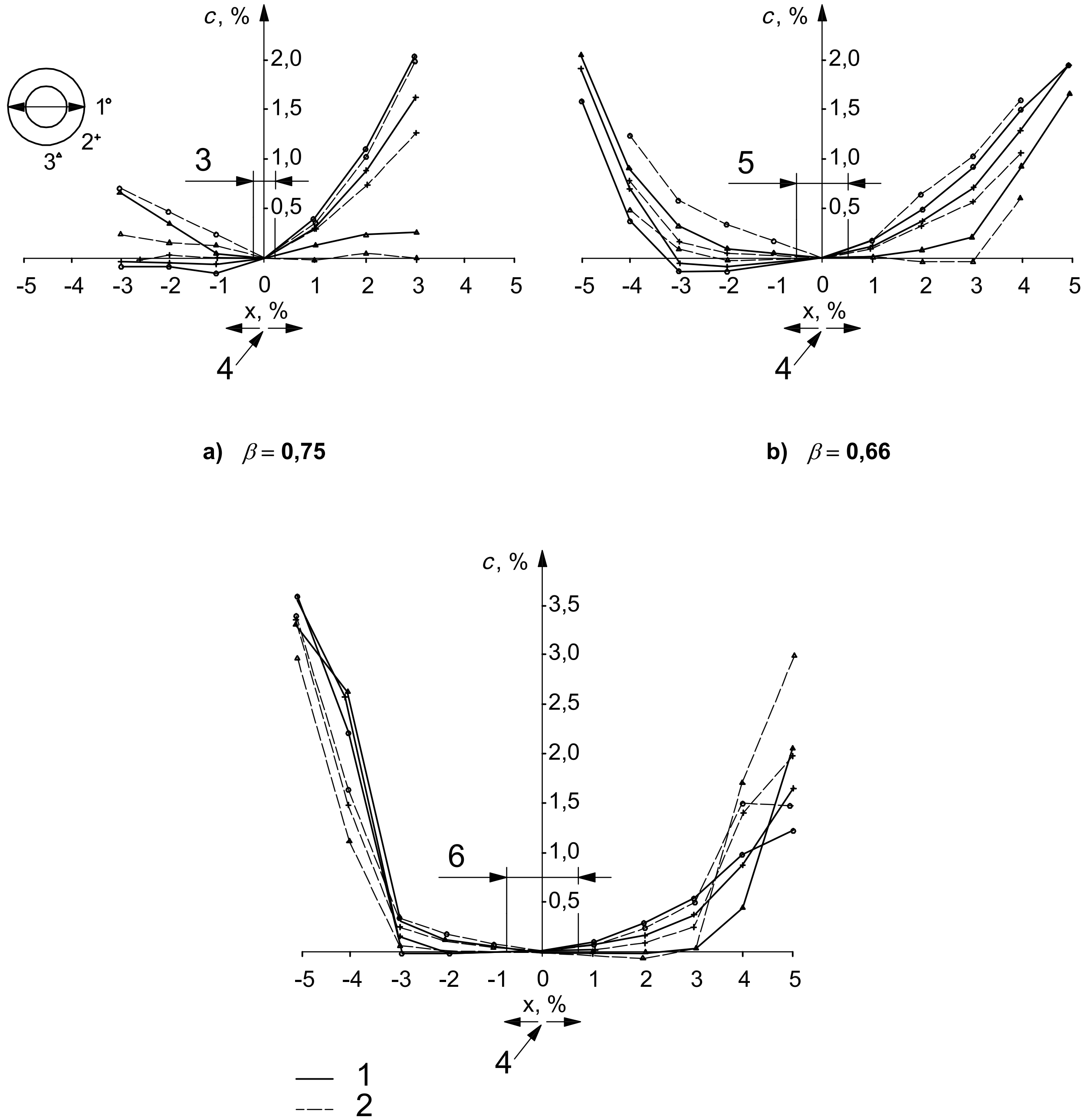
NOTE Combined installation faults: it is recommended that errors arising from the combined effects of eccentricity, carrier ring steps, etc., are not taken into account additively. The total possible error will be governed by the strongest of the effects present.



Key

1 bolt-hole pitch circle
2 flange centreline
3 orifice bore
4 orifice-plate outside diameter
5 flange bore
6 pipe inside diameter
7 pipe centreline
8 orifice centreline
9 eccentricity

Figure 5 — Possible orifice-plate eccentricity resulting from specified tolerances on bolt hole, bolt hole pitch circle, pipe outside diameter and flange bore



a) $\beta = 0{,}75$

b) $\beta = 0{,}66$

c) $\beta = 0{,}57$

Key

1 *D* and *D*/2 tappings

2 flange tappings

3 ± 0,3 %

4 (away from tapping 1) ← → (towards tapping 1)

5 ± 0,5 %

6 ± 0,7 %

c change in discharge coefficient

x eccentricity

Figure 6 — Discharge coefficient error vs. eccentricity for an orifice plate with *D* and *D*/2 and flange tappings

8 Effects of pipe layout

8.1 General

Minimum values of the straight lengths required between the primary device and various upstream fittings are given in 6.2 of ISO 5167-2:2003, 6.2 of ISO 5167-3:2003, and 6.2 of ISO 5167-4:2003. Minimum straight lengths are given both for zero additional uncertainty and for 0,5 % additional uncertainty in the discharge coefficient.

When the minimum requirements for even 0,5 % additional uncertainty cannot be satisfied, the user should make a correction to compensate for the change in the discharge coefficient and should also increase the value of the percentage uncertainty.

Corrections and additional uncertainties for square-edged orifice plates with corner, flange and D and $D/2$ tappings are given in Tables 3 and 4 for a variety of upstream pipe bends and fittings. Shifts in columns 4 and 5 are particularly variable, depending on the exact details of the double bend.

Additional data on shifts in orifice-plate discharge coefficients for a large number of upstream fittings are given in References [3-6].

8.2 Discharge coefficient compensation

8.2.1 Corrections

The discharge coefficient can be corrected using the data in Table 3 as illustrated in the following examples:

a) percentage change in coefficient is + 1,1 %, therefore the coefficient should be multiplied by 1,011;

b) percentage change in coefficient is – 2,3 %, therefore the coefficient should be multiplied by 0,977.

Table 3 — Percentage change in discharge coefficient, c, when the straight pipe lengths before the orifice are less than those specified in ISO 5167-2

Upstream straight length	β	Type of fitting (for details of nomenclature, see key)																
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
4D	0,5	−1,4	−1,4	−0,5	+2,9	+2,9	−0,4	+8,2	—	+0,2	+0,2	−1,0	−0,8	+0,3	+0,5	+0,2	—	—
	0,6	−2,3	−2,2	−1,1	+1,7	+1,3	−1,2	+8,5	—	−0,2	−0,3	−2,4	−1,7	+0,3	0	−0,2	—	—
	0,7	−3,8	−3,2	−1,8	+0,1	+0,4	−2,1	+8,2	—	−0,9	−0,7	−4,4	−2,3	+0,3	−0,6	0	—	—
	0,8	−5,6	— [b]	−2,6	−2,4	— [b]	−3,1	+3,4	—	−2,2	— [b]	−7,5	— [b]	+0,3	−1,3	— [b]	—	—
8D	0,5	−0,7	−0,7	−0,3	+2,4	+2,4	0	+6,3	+6,4	−0,2	−0,2	−0,6	−0,4	— [a]	−0,2	−0,2	−0,8	−0,7
	0,6	−1,4	−1,2	−0,7	+1,4	+1,2	−0,7	+5,6	+6,1	−0,6	−0,4	−1,3	−1,2	— [a]	−0,7	−0,8	−1,3	−1,2
	0,7	−2,2	−1,9	−1,2	+0,3	+0,4	−1,3	+4,4	+6,1	−1,1	−0,8	−2,1	−1,9	+0,1	−1,2	−1,2	−1,7	−1,7
	0,8	−3,2	— [b]	−1,8	−1,7	— [b]	−2,0	+2,3	— [b]	−1,9	— [b]	−3,1	— [b]	+0,1	−1,8	— [b]	−2,0	−2,1
12D	0,5	— [a]	— [a]	— [a]	+2,0	+2,0	0	+5,5	+5,5	−0,2	−0,1	−0,4	−0,3	— [a]	−0,3	−0,2	—	— [c]
	0,6	−0,8	−0,8	−0,4	+1,2	+1,0	−0,4	+3,9	+4,3	−0,4	−0,3	−0,9	−0,9	— [a]	−0,7	−0,6	−0,8	−0,8 [c]
	0,7	−1,4	−1,4	−0,8	+0,3	+0,3	−0,8	+2,6	+3,2	−0,8	−0,7	−1,3	−1,3	— [a]	−1,1	−1,0	−1,2	−1,1
	0,8	−2,0	— [b]	−1,3	−1,3	— [b]	−1,3	+1,5	— [b]	−1,3	— [b]	−1,7	— [b]	—	−1,5	— [b]	−1,5	−1,4
16D	0,5	— [a]	— [a]	— [a]	+1,7	+1,7	0	+5,1	+5,0	−0,1	0	−0,2	−0,2	— [a]	−0,2	−0,2	—	—
	0,6	— [a]	— [a]	−0,3	+1,1	+0,9	−0,3	+3,5	+3,6	−0,3	−0,2	−0,6	−0,6	— [a]	−0,4	−0,4	—	—
	0,7	−0,8	−0,8	−0,5	+0,3	+0,3	−0,5	+2,1	+2,4	−0,5	−0,5	−0,9	−1,0	— [a]	−0,7	−0,6	−0,9	—
	0,8	−1,3	— [b]	−0,7	−1,1	— [b]	−0,8	+0,8	— [b]	−0,8	— [b]	−1,0	— [b]	—	−1,0	— [b]	−1,2	—

[a] Refer to Table 3 of ISO 5167-2:2003.

[b] For D and D/2 tappings, discharge coefficient changes measured for $\beta > 0{,}75$ should not be used for interpolation to give discharge coefficient changes for $\beta \leqslant 0{,}75$, as the downstream tapping is in the pressure recovery region if $L_2' > 2(1 - \beta)$.

[c] For a concentric expander 0,5D to D over a length of D to 2D refer to Table 3 of ISO 5167-2:2003.

Key

No.	Type of upstream fitting	Type of tappings	No.	Type of upstream fitting	Type of tappings
1	Single short radius 90° bend	Corner, flange	10	Butterfly valve, fully open	D and D/2
2	Single short radius 90° bend	D and D/2	11	Butterfly valve, 52° open	Corner, flange
3	Two 90° bends in the same plane, U- or S-configuration, 0D to 10D spacer	All	12	Butterfly valve, 52° open	D and D/2
4	Two 90° bends at right angles, no spacer	Corner, flange	13	Gate valve, fully open	All
5	Two 90° bends at right angles, no spacer	D and D/2	14	Gate valve, ⅔ open	Corner, flange
6	Two 90° bends at right angles, 5D to 11D spacer	All	15	Gate valve, ⅔ open	D and D/2
7	Two 90° mitre bends at right angles, no spacer	Corner, flange	16	Gate valve, ¼ open and globe valve	All
8	Two 90° mitre bends at right angles, no spacer	D and D/2	17	Symmetrical enlargement, tapered or abrupt	All
9	Butterfly valve, fully open	Corner, flange			

Table 4 — Formulae for additional uncertainty in the orifice discharge coefficient, to be used with the percentage changes given in Table 3, for all tapping arrangements

Type of upstream fitting	Additional uncertainty formulae	
	Piezometer ring e.g. Triple-T	**Single tapping** [a]
Single short radius 90° bend. Bend radii $1D$ to $1{,}5D$	$0{,}5(1 + 0{,}6\lvert c \rvert)$	$0{,}5 + 0{,}6\lvert c \rvert$
Two 90° bends, U- or S-configuration, in same plane	$0{,}5(1 + \lvert c \rvert)$	$0{,}5 + \lvert c \rvert$
Two 90° bends at right angles, no spacer (where X is the distance from the orifice plate to the nearest bend)	$0{,}5(1 + \lvert c \rvert) + (10D/X)$	$0{,}5 + \lvert c \rvert + (10D/X)$
Two 90° bends at right angles, $5D$ to $11D$ spacer	$0{,}5 + \lvert c \rvert$	$0{,}5(1 + 3\lvert c \rvert)$
Two 90° mitre bends at right angles, no spacer	$0{,}5 + \lvert c \rvert$	$0{,}5(1 + 3\lvert c \rvert)$
Butterfly valve, fully open	$0{,}5 + \lvert c \rvert$	$0{,}5(1 + 3\lvert c \rvert)$
Butterfly valve, 52° open	$0{,}5 + \lvert c \rvert$	$0{,}5(1 + 3\lvert c \rvert)$
Gate valve, fully open	$0{,}5(1 + \lvert c \rvert)$	$0{,}5 + \lvert c \rvert$
Gate valve, ⅔ open	$0{,}5(1 + \lvert c \rvert)$	$0{,}5 + \lvert c \rvert$
Gate valve, ¼ open and globe valve	$0{,}5 + \lvert c \rvert$	$0{,}5 + \lvert c \rvert$
Symmetrical restriction or enlargement, tapered or abrupt	$0{,}5 + \lvert c \rvert$	$0{,}5 + \lvert c \rvert$

[a] The tapping axis should be at right angles to the plane of the nearest upstream bend.

8.2.2 Additional uncertainty

The formulae for calculating the additional percentage uncertainty in discharge coefficient are given in Table 4 for each type of fitting. This is in addition to the basic uncertainty in the discharge coefficient of: 0,5 % for $0{,}2 \leqslant \beta \leqslant 0{,}6$, $(1{,}667\beta - 0{,}5)$ % for $0{,}6 < \beta \leqslant 0{,}75$. In deriving the formulae, the quantity of data, its consistency and corroboration from different sources have been taken into account. Their use is illustrated in the following examples.

a) If the equation to be applied is:

$$e = 0{,}5\left(1 + \lvert c \rvert\right) \qquad (5)$$

where $\lvert c \rvert$ is the modulus of percentage change (i.e. the magnitude irrespective of sign) and if the change in the coefficient is $+$ 1,4 %, then $e = 1{,}2$ %.

b) If the equation to be applied is:

$$e = 0{,}5 + \lvert c \rvert \qquad (6)$$

and if $c = -2{,}8$ %, then $e = 3{,}3$ %.

8.3 Pressure tappings

It is emphasized that the change in the coefficient when D and $D/2$ tappings are used is often different from those obtained with corner or flange tappings.

When the upstream straight pipe length is less than that required for zero additional uncertainty, it is recommended that multiple tappings with triple-T connections, as shown in Figure 1 of ISO 5167-1:2003, be used. If single tappings are used, their axes should be at right angles to the plane of the nearest upstream bend.

8.4 Devices for improving flow conditions

Flow conditioners should be used where asymmetric or swirling flow has to be measured. Descriptions of various flow conditioners are provided in Annex B of ISO 5167-2:2003. Even where the installation requirements of ISO 5167-2:2003 [6.3 or Annex B (informative)] cannot be met, the use of a flow conditioner may reduce errors especially in swirling flow.

9 Operational deviations

9.1 General

Metering systems that conform to ISO 5167 when new or recently maintained may be subject to a significant degradation in accuracy over the passage of time.

This degradation may result from several causes:

a) deformation of the orifice plate;

b) deposition on the upstream face of an orifice plate;

c) deposition in the meter tube;

d) rounding of the orifice-plate edge;

e) deposition in the pressure tappings;

f) deposition and increase of surface roughness in a Venturi tube.

An indication of the effect of sources of error a) to d) and f) is given in 9.2 to 9.6.

It cannot be emphasized too strongly that the continued achievement of high accuracy requires the expenditure of considerable effort. In particular, regular inspection and maintenance are essential. Inspection periods depend on the nature of the fluid being metered and on the manner of operation of the system in which the meter is installed, and can only be determined from experience.

9.2 Deformation of an orifice plate

9.2.1 General

An orifice plate may be said to be deformed when it deviates beyond the 0,5 % value specified in 5.1.3.1 of ISO 5167-2:2003. The deformation may be in the upstream or downstream direction, and possible causes are defects in manufacture, poor installation or incorrect use. Manufacturing and installation faults should be rectified before use.

Deformation arising from the manner of use may be either temporary (elastic) or permanent (buckling). This is discussed in References [7-9]. Information regarding the necessary thickness of orifice plates when metering systems are being designed is given in 8.1.1.3 of ISO/TR 9464:1998[10].

9.2.2 Elastic deformation

Elastic deformation arises when the differential pressure due to flow deforms the plate by a small amount in the downstream direction, such that the induced stresses remain within the elastic limit of the plate material. For a plate simply supported at its rim, a first approximation to the percentage increase in discharge coefficient is given by:

$$c = \frac{100\,\Delta p}{Y}\left(\frac{D_2}{E}\right)^2\left(\frac{a_1 D_2}{E} - a_2\right) \quad (7)$$

where

$a_1 = \beta\,(0{,}135 - 0{,}155\beta)$

$a_2 = 1{,}17 - 1{,}06\,\beta^{1{,}3}$

For American Iron and Steel Institute grades 304 or 316 stainless steel (ISO/TS 15510[11]), Y can be taken as 193×10^9 Pa.

In virtually all cases, the result of the deformation is to cause an increase in the discharge coefficient.

Errors due to elastic bending may be additional to those arising from initial lack of flatness. Only when the combination of both effects results in a slope greater than 1 % under flowing conditions does the plate depart from the requirements of ISO 5167-2.

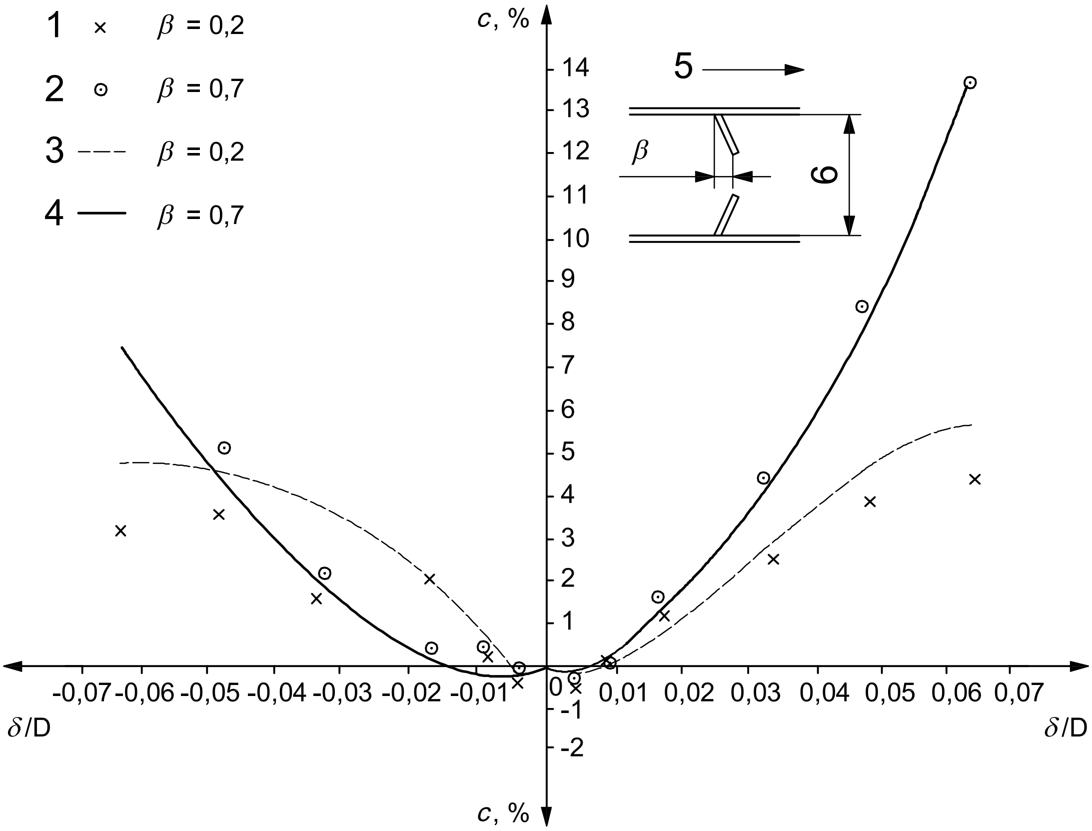
Since the plate will return to its undeformed state when the flow is zero, elastic bending cannot be detected during routine inspection of a metering system.

9.2.3 Plastic deformation

Where an orifice plate has been subjected to excessive differential pressures it may deform permanently. When the deformation is known, the error may be estimated from Figure 7. Such deformation may occur during over-rapid pressurization or venting of a line containing a compressible fluid, or through an abnormal flow condition. It should be emphasized that a permanently deformed plate should be discarded.

The differential pressure required to reach orifice-plate yield stress, Δp_y, may be estimated from:

$$\Delta p_y = \sigma_y \left(\frac{E}{D_2}\right)^2 \left(\frac{1}{0{,}681 - 0{,}651\beta}\right) \quad (8)$$



Key

1 experimental
2 experimental
3 theoretical
4 theoretical
5 flow
6 $D = 200$ mm

c change in discharge coefficient
δ/D ratio of deflection to upstream internal pipe diameter

Figure 7 — Effect of orifice-plate deformation on flow-measurement accuracy

9.3 Deposition on the upstream face of an orifice plate

The effect of deposits on the upstream face of an orifice plate is similar to that of upstream face roughness and always causes the discharge coefficient to increase.

Table 5 shows the effect of a uniform layer of sand one grain thick (grain size 0,4 mm) and the effect of grease spots (each nominally 6,3 mm diameter and 2,5 mm high) on an orifice plate in a 100 mm diameter meter tube measuring air at atmospheric pressure. Table 5 shows the importance of the annular region around the entrance to the orifice bore. As this region is usually scrubbed by the flow, the actual errors are probably smaller than those indicated.

Table 6 shows the effect of a layer of Audco[1)] grease on an orifice plate of thickness 6 mm and of diameter ratio 0,6 in a 300 mm pipe. The pressure tappings were in the horizontal plane on the left of the drawings. The pipe Reynolds number was approximately 10^7. For the tests, the orifice plate was removed from the carrier and moved into a laboratory area where contamination was added with the plate in a horizontal position. The

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

contamination level given in Table 6 is that applied in the laboratory. The plate was then moved to a vertical position to allow any liquid to drain off before being reinserted into the carrier in the test line. During the subsequent 2 h test over a range of flowrates, the maximum increase in discharge coefficient (around the beginning of the test) and the saturation increase in discharge coefficient once the increase had become constant were recorded. Further information on the effect of contamination is given in References [12], [13].

Table 5 — Effect of deposits on $\beta = 0{,}2$ and $\beta = 0{,}7$ orifice plates

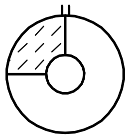
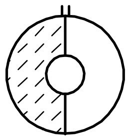
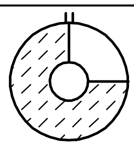
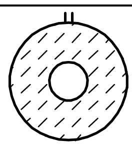
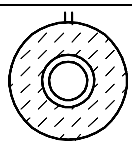
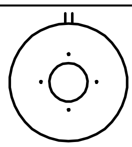
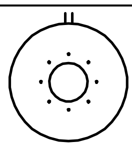
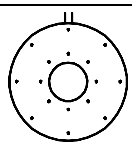
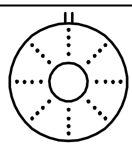
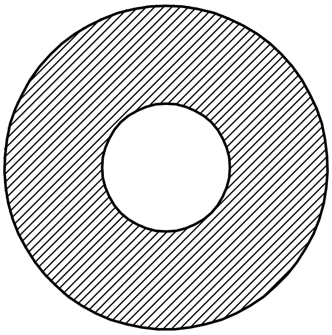
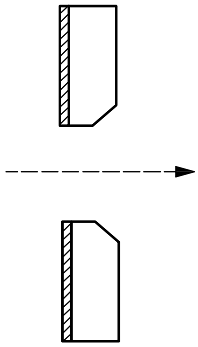
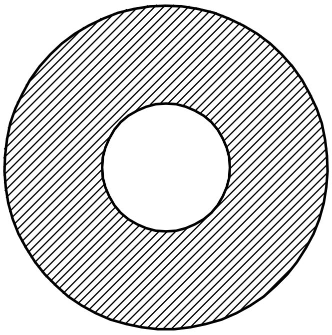
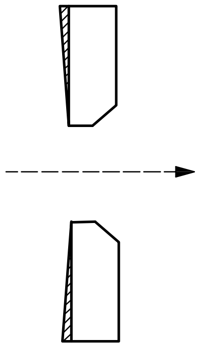
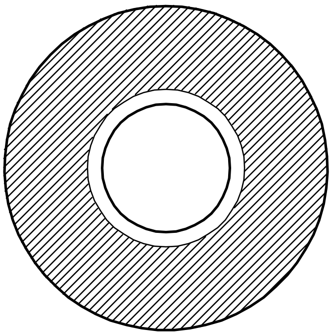
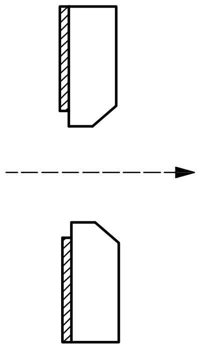
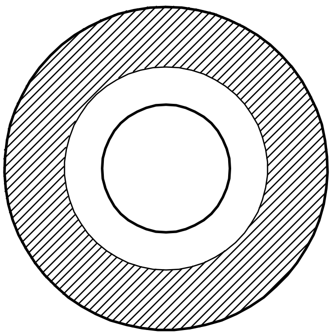
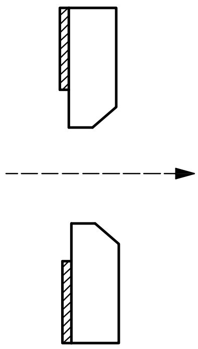
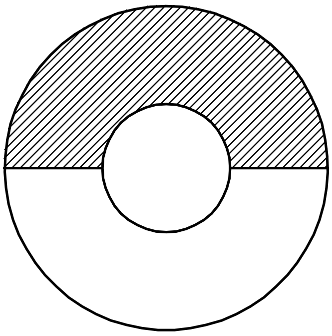
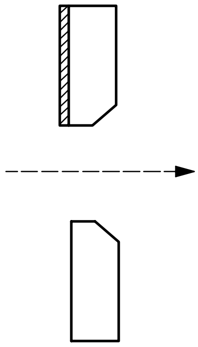
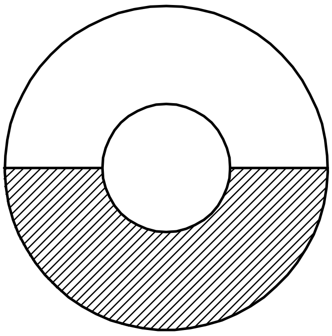
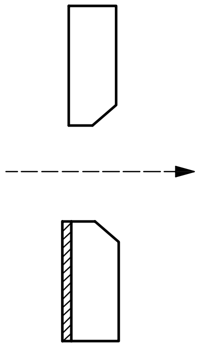
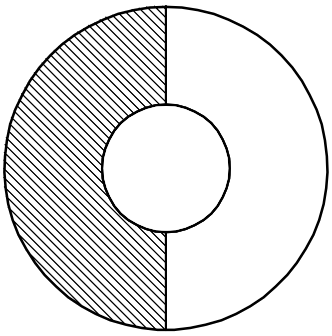
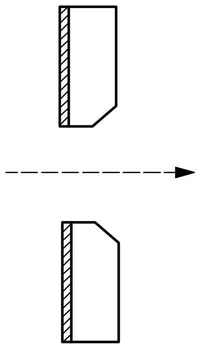
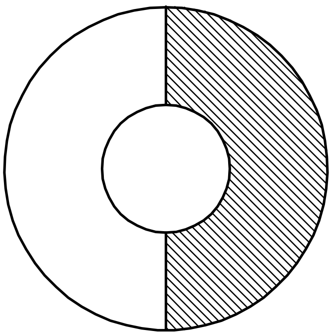
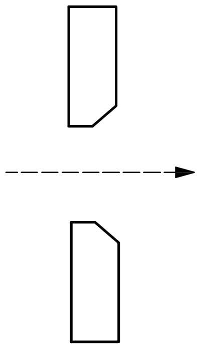
Deposit			Change in discharge coefficient, c	
			$\beta = 0{,}2$	$\beta = 0{,}7$
			%	
Sand	1 sand quadrant		+ 1,0	+ 0,8
	2 sand quadrants		+ 2,8	+ 1,9
	3 sand quadrants		+ 3,9	+ 2,4
	4 sand quadrants		+ 6,2	+ 3,0
	4 sand quadrants with 6 mm ring removed from around orifice bore		+ 0,3	+ 0,3
Grease	4 grease deposits		+ 1,0	+ 0,1
	8 grease deposits		+ 2,8	+ 1,3
	16 grease deposits		+ 2,1	+ 1,2
	32 grease deposits		+ 2,6	+ 0,6

Table 6 —Increase in discharge coefficient, c, of an orifice plate, D = 300 mm, β = 0,6, due to Audco[2] grease coating

Upstream face profile	Cross-section profile	Contaminant pattern	Maximum increase in discharge coefficient, c %	Saturation increase in discharge coefficient, c %	Coating thickness mm
		Full upstream face	2,85 3,49 5,15	2,15 2,13 3,70	0,6 1,2 2,0
		Full upstream face tapered off towards centre	1,30	1,00	1,2 to 0,0
		Full upstream face with 10 mm clean ring at centre	1,00	0,61	1,2
		Full upstream face with 20 mm clean ring at centre	0,60	0,50	1,2

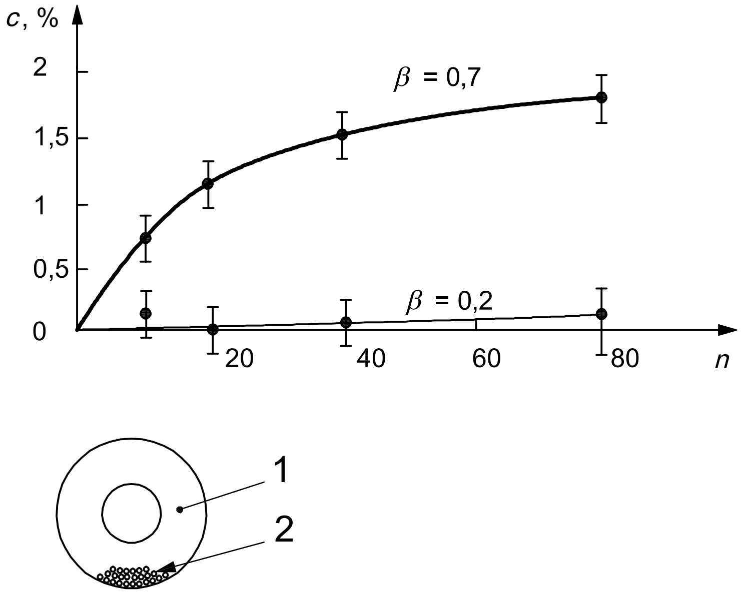
2) Example of a product available commercially. This information is given for the convenience of users of this Technical Report and does not constitute an endorsement by ISO of this product.

Table 6 (*continued*)

Upstream face profile	**Cross-section profile**	**Contaminant pattern**	**Maximum increase in discharge coefficient, c** %	**Saturation increase in discharge coefficient, c** %	**Coating thickness** mm
		Half circle at top of upstream face	1,70	—	1,2
		Half circle at bottom of upstream face	1,80	1,30	1,2
		Half circle vertical near tappings	2,20	0,85	1,2
		Half circle vertical away from tappings	3,70	2,84	1,2

9.4 Deposition in the meter tube

In an exercise to simulate the effect of deposition in the meter tube, welding rods were stacked axially against the upstream face of an orifice plate as shown in Figure 8. The rods caused an increase in the discharge coefficient.



Key

1 orifice plate

2 welding rods laid axially against orifice plate (rod diameter = 0,016D, rod length = 0,5D)

c change in discharge coefficient

n number of welding rods

Figure 8 — Effect of welding rods in meter tube

Figure 9 shows the results of tests carried out to investigate the effect of a smooth horizontal build-up of material in a meter run. When the material is below the dam height, the discharge coefficient increases. When the build-up exceeds the dam height, the orifice bore cross-sectional area is reduced, leading to a decrease in discharge coefficient.

9.5 Orifice-plate edge sharpness

9.5.1 Deterioration

The sharp edge of an orifice plate may deteriorate with time. Possible causes of this deterioration are:

a) erosion;

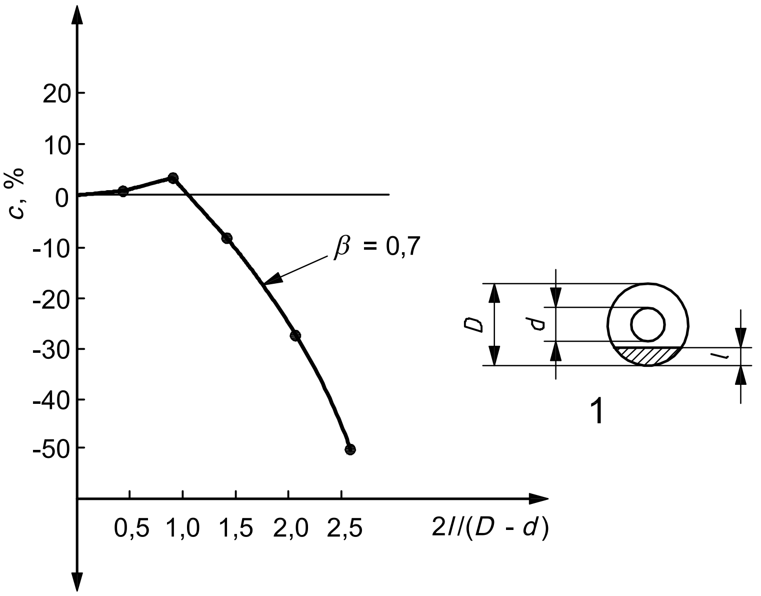
b) cavitation;

c) mechanical damage;

d) careless handling.

Orifice-plate discharge coefficients are sensitive to edge sharpness, and, where any of the above effects may occur, regular quantitative inspection of the edge should be made.

The effect of loss of sharp edge is described in 6.1.



Key

1 fraction of dam height

c change in discharge coefficient

$2l/(D-d)$ obstruction level — fraction of dam height

Figure 9 — Effect of debris in meter tube (on both sides of plate)

9.5.2 Plate reversal

Particular care should be taken to ensure that bevelled orifice plates are inserted into the meter line with the bevel on the downstream face.

In a 100 mm diameter meter, a plate bevelled at 45° and facing upstream can give the following percentage increases in discharge coefficient:

a) 0,25 mm bevel width: $c = 2,0$;

b) 0,5 mm bevel width: $c = 4,0$;

c) 1,25 mm bevel width: $c = 13,0$.

These values should be taken simply as indicative of changes which can occur by incorrect installation and should not be taken as precise.

9.6 Deposition and increase of surface roughness in Venturi tubes

9.6.1 General

Two effects may occur in a Venturi tube which has been in use for a period of time. These are deposition of material in the contraction and the bore, and an increase in the surface roughness. Both effects result in a decrease in the discharge coefficient and both effects may occur together. They are, however, considered separately in 9.6.2 and 9.6.3.

9.6.2 Deposition

If material is deposited smoothly and uniformly in the contraction and bore of a Venturi tube, the change in discharge coefficient, expressed as a percentage, c, may be estimated theoretically from the reduction in area as:

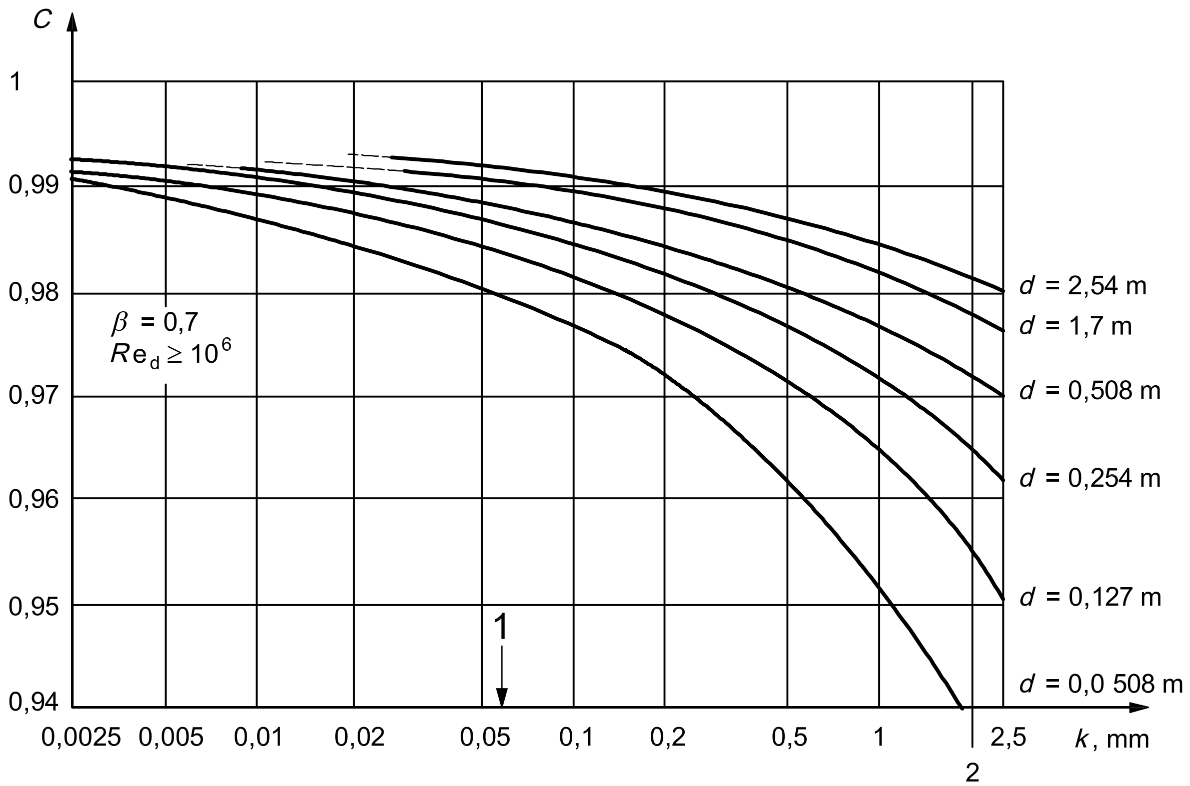
$$c = -400(l/d) \tag{9}$$

where l is the thickness, in metres, of the annular deposit in the bore of the Venturi tube.

9.6.3 Surface roughness

The chemical nature of the fluid and the material of the Venturi tube may be such that the surface roughness of the Venturi tube increases with time (Reference [14]). This increase in roughness leads to a reduction in the discharge coefficient. An indication of the error involved is given in Figure 10.

The rate of increase of surface roughness is dependent on the chemical reactions occurring in the metering system, and is outside the scope of this Technical Report.



Key

1 effective roughness for new meters ($k = 0{,}056$ mm)

C Venturi tube discharge coefficient

k uniform equivalent roughness of Venturi tube

Figure 10 — Variation of Venturi meter coefficient with surface roughness

10 Pipe roughness

10.1 General

The discharge coefficients given in 5.3.2.1 of ISO 5167-2:2003, 5.1.6.2, 5.2.6.2 and 5.3.4.2 of ISO 5167-3:2003, and 5.5 of ISO 5167-4:2003 assume conformity to specified installation conditions. In particular, the velocity profile immediately upstream of a primary device should be similar to that in the experiments on which the equation is based.

The uniform equivalent pipe roughness, k, Reynolds number, Re_D, and friction factor, λ, are interrelated and determine the velocity profile (see Reference [15]). Experimental results suggest that the velocity profile, defined as the ratio of the local axial velocity at y from the pipe wall, u, to the velocity at the centreline ($y/R = 1$), u_{CL}, can be described approximately by:

$$\frac{u}{u_{CL}} = \left(\frac{y}{R}\right)^{1/n} \tag{10}$$

where

y is the distance from the pipe wall;

R is the pipe radius, $D/2$;

n is a number whose reciprocal gives the power (dependent on Re_D and k/D) to which y/R must be raised to give the velocity profile.

The ratio of the mean axial velocity, U, to the velocity at the centreline ($y/R = 1$), u_{CL}, is then given by:

$$\frac{U}{u_{CL}} = \frac{2n^2}{(n+1)(2n+1)} \tag{11}$$

In smooth pipe, n increases with the Reynolds number (see Table 7). In fully rough pipe, n decreases with increasing relative roughness (see Table 8).

A more uniform profile ($U/u_{CL} \to 1$) reduces the discharge coefficient and a more peaked profile (U/u_{CL} decreasing) increases C.

The extent to which the discharge coefficient varies is also influenced by β, being less for smaller β.

Table 7 — Values of n, U/u_{CL} and λ for smooth pipe

Re_D	n	U/u_{CL}	λ
4×10^3	6,0	0,791	0,04
$2,3 \times 10^4$	6,6	0,807	0,025
$1,1 \times 10^5$	7,0	0,817	0,0175
$1,1 \times 10^6$	8,8	0,850	0,0115
2×10^6	10	0,866	0,0105

Table 8 — Values of n, U/u_{CL} and λ for rough pipe

R/k	k/D	n	U/u_{CL}	λ
507	$0{,}986 \times 10^{-3}$	6	0,791	0,020
126	$3{,}97 \times 10^{-3}$	5	0,758	0,028
31	$16{,}1 \times 10^{-3}$	4	0,711	0,045

10.2 Upstream pipe

For an orifice plate the change in discharge coefficient, ΔC, due to pipe roughness is approximately proportional both to the change in friction factor, $\Delta\lambda$, and to $\beta^{3,5}$. The friction factor, λ, can be measured directly, using:

$$\lambda = \frac{2D\Delta p}{\rho U^2 Z} \tag{12}$$

where

D is the pipe diameter, in metres;

Δp is the pressure difference, in pascals, between two tappings;

ρ is the fluid density, in kilograms per cubic metre;

U is the mean axial velocity, in metres per second;

Z is the distance, in metres, between two tappings.

It is simpler to measure the arithmetic mean deviation of the roughness profile, R_a, to deduce the uniform equivalent roughness, $k \approx \pi R_a$, and to calculate λ using the Colebrook-White equation {see 7.4.1.5 of ISO 5167-1:2003 and Equation (20.35a) of Reference [15]}:

$$\frac{1}{\sqrt{\lambda}} = 1{,}74 - 2\lg\left(\frac{2k}{D} + \frac{18{,}7}{Re_D\sqrt{\lambda}}\right) \tag{13}$$

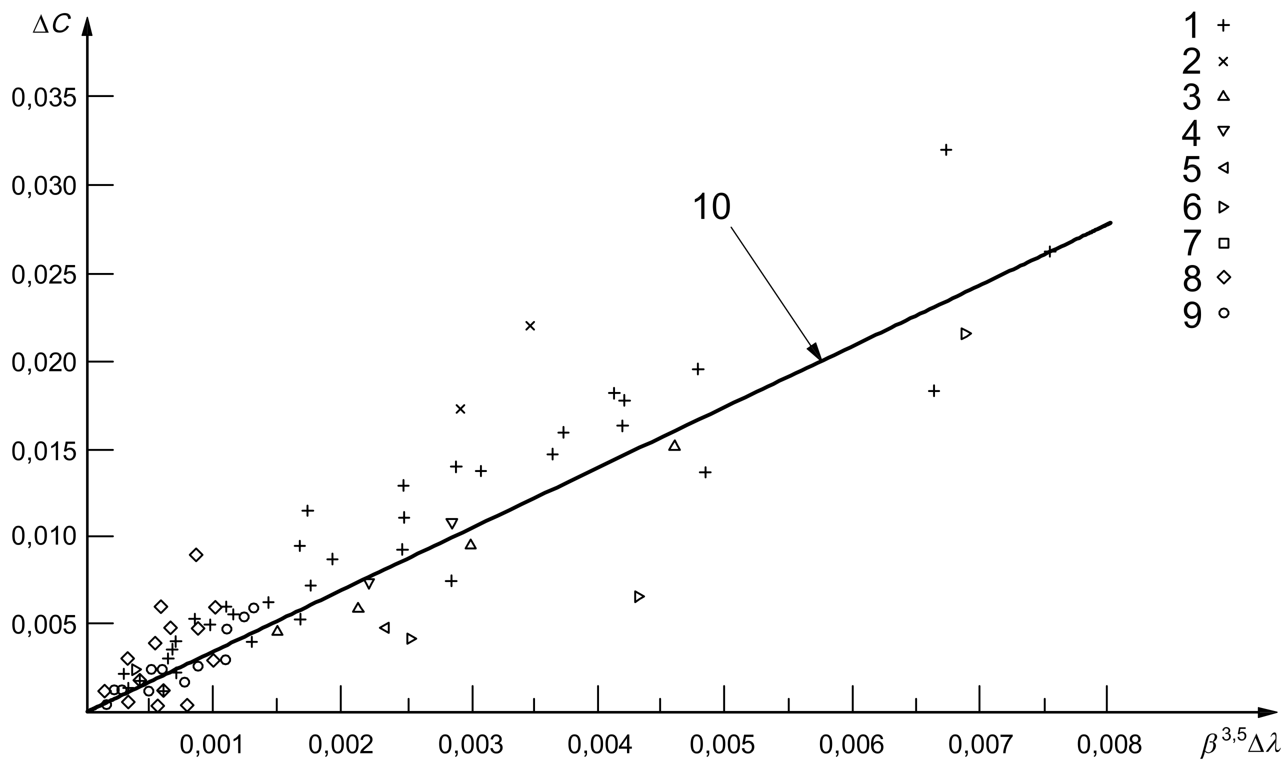
If an estimate of the shift in discharge coefficient from Equation (4) of ISO 5167-2:2003 is desired, it is also necessary to estimate the friction factor for the discharge coefficient equation. This has to be done on the basis of the measured roughness or friction factor of the pipes in which the standard data (to which the discharge coefficient equation was fitted) were collected; these are given in Table 9. Both k/D and λ depend on Re_D; k/D reduces with Re_D because the higher Reynolds numbers generally occur in larger pipes, which are generally relatively smoother.

Table 9 — Values of k/D and λ associated with Equation (4) of ISO 5167-2:2003

Pipe Reynolds No. Re_D	10^4	3×10^4	10^5	3×10^5	10^6	3×10^6	10^7	3×10^7	10^8
Ratio of uniform equivalent roughness to pipe diameter $k/D \times 10^4$	1,75	1,45	1,15	0,9	0,7	0,55	0,45	0,35	0,25
Friction factor λ	0,031	0,024	0,018 5	0,015 5	0,013	0,011 5	0,010 5	0,010	0,009 5

Figure 11 gives measured and computed (using computational fluid dynamics) values of ΔC as a function of $\beta^{3,5}\Delta\lambda$ (see Reference [16] for complete references). The computed values and the European experimental data were obtained using corner tappings. The North American experimental data (References [17-19]) were obtained using flange tappings. For corner tappings, the following approximate equation to calculate the change in discharge coefficient, ΔC, has been plotted:

$$\Delta C = 3{,}5\beta^{3,5}\Delta\lambda \tag{14}$$



Key

1 computed [16]

2 experiment [20]

3 experiment [21]

4 experiment [22]

5 experiment [23]

6 experiment [24]

7 experiment [17]

8 experiment [18]

9 experiment [19]

10 $\Delta C = 3{,}5\beta^{3,5}\Delta\lambda$

β diameter ratio, d/D

λ friction factor

ΔC change in discharge coefficient

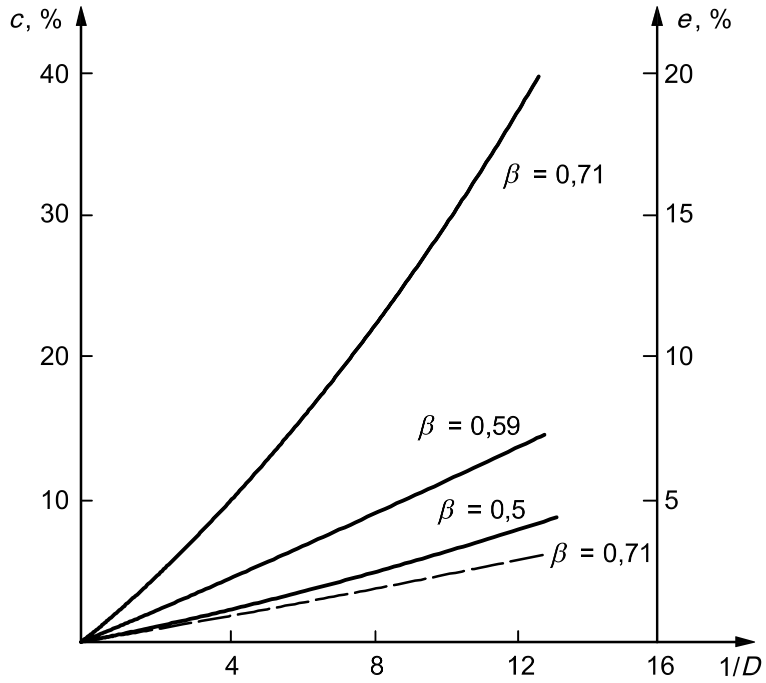
Figure 11 — The effect of rough pipe on discharge coefficient

From computational work, the effect of roughness on discharge coefficients using D and $D/2$ tappings has been found to be about 25 % less than its effect on those using corner tappings. ΔC using flange tappings lies between ΔC using corner tappings and ΔC using D and $D/2$ tappings.

In a swirling flow at a fixed Reynolds number, increasing the roughness of the upstream pipe reduces the swirl at the flowmeter.

In extreme cases, roughness can change the diameter of the pipe and consequently β. The following information (see Reference [20]) is for such an extreme case.

Figure 12 relates to orifice plates with corner tappings and gives the discharge coefficient change for pipes with a roughness corresponding to surfaces encrusted with closely spaced spherical nodules. These averaged 6,3 mm in diameter reducing the effective diameter of the pipe by at least 6,3 mm. The changes shown would be applied to the flow using the larger clean pipe diameter. [The dotted curve for $\beta = 0{,}71$ applies to a sanded surface (0,5 mm to 1,0 mm diameter particles)].



Key

c percentage change in discharge coefficient

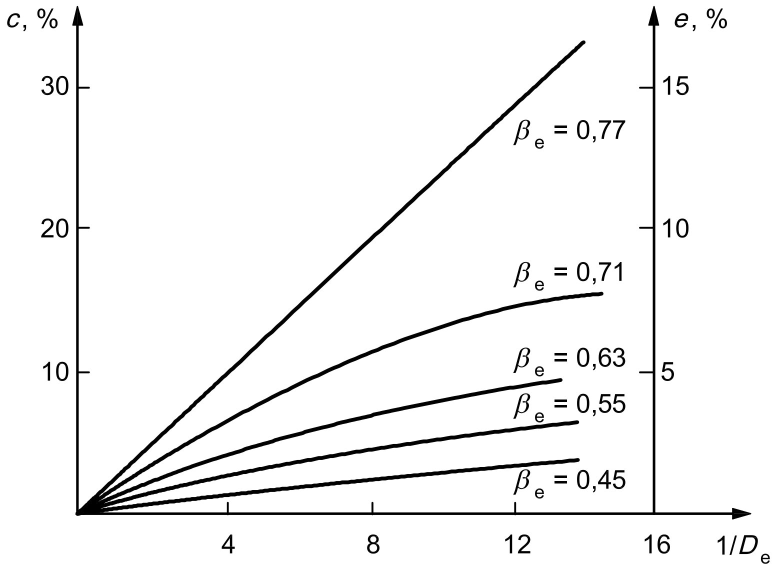
D upstream internal pipe diameter, in metres

e additional uncertainty

Figure 12 — The combined effect of abnormal roughness and diminution in pipe bore

Figure 13 shows the coefficient changes based on similar pipe conditions to those above, but calculated on the smaller effective pipe diameter D_e ($= D - 6{,}3$ mm) and β_e where $\beta_e = d/D_e$. The changes due to sand particles of about 1 mm diameter are about one-third of those given in Figure 12.

If a measurement of the flow needs to be made under such adverse conditions, the corrected discharge coefficients given above should be used with an additional uncertainty of half the percentage change in discharge coefficient.



Key

c percentage change in discharge coefficient

D_e effective upstream internal pipe diameter, in metres

e additional uncertainty

Figure 13 — The effect of abnormal roughness on orifice plates

10.3 Downstream pipe

Even severe encrustation adjacent to the downstream side of an orifice plate has no significant effect on the discharge coefficient.

10.4 Reduction of roughness effects

Experiments have shown that if a relatively short upstream length of pipe adjacent to the orifice plate is cleaned to remove the encrustations, the error is significantly reduced. Table 10 gives recommendations regarding the extent of such cleaning for various pipe sizes, values of β and types of roughness. For pipes of internal diameter greater than 300 mm, fewer diameters of clean upstream pipe may be necessary.

10.5 Maintenance

In all cases of flow measurement by pressure differential meters, a cleaning routine for the pipe, the primary device and the pressure tappings should be established to suit the particular conditions. Where reasonable accuracy is required in the measurement of the flow of dirty fluids, installations should be designed for easy cleaning of the upstream pipe to an extent shown in Table 10.

Table 10 — Recommendations regarding the extent of cleaning

Upstream internal pipe diameter D mm	β	**Type of roughness**	**Approximate change in discharge coefficient without cleaning the pipe**	**Amount of cleaning (in multiples of** D**) to obtain roughness errors not exceeding:**				
				± 3 %	± 2 %	± 1 %	± 0,5 %	Nil
76	0,5 to 0,59	7,0 mm spheres	9 % to 15 %	3 to 4	4 to 5	5 to 15	15 to 20	> 20
	0,71	7,0 mm spheres	40 %	4 to 10	10 to 20	20 to 25	25 to 30	> 30
	0,71	Sand	7 %		3 to 5	5 to 25	25 to 30	> 30
152	0,5 to 0,59	7,0 mm spheres	4 % to 8 %		3 to 5	5 to 12	12 to 20	> 20
	0,71	7,0 mm spheres	17 %	2,5 to 4	4 to 15	15 to 25	25 to 30	> 30
	0,71	Sand	4 %		1 to 3	3 to 4	4 to 20	> 20
305	0,71	7,0 mm spheres	8 %		2,5 to 4	4 to 6	6 to 15	> 15
	0,71	Sand	2 %			1 to 3	3 to 5	> 5

Bibliography

[1] HOBBS, J.M. and HUMPHREYS, J.S. The effect of orifice plate geometry upon discharge coefficient. *Flow Meas. Instrum.*, 1990, **1**(3), pp. 133-140

[2] HUSAIN, Z.D. and TEYSSANDIER, R.G. The effects of plate thickness and bevel angle in a 150 mm line size orifice meter. In: Kinghorn, F.C., Gibson, E.E., editors. *Flow measurement in the mid 80's: International conference: Papers*, paper 5.1, National Engineering Laboratory, Glasgow, 1986

[3] MARTIN, C.N.B. *Effects of upstream bends and valves on orifice plate pressure distributions and discharge coefficients*. National Engineering Laboratory, Glasgow, 1986. 50 p. (NEL Report 702)

[4] STUDZINSKI, W., KARNIK, U., LANASA, P., MORROW, T., GOODSON, D., HUSAIN, Z. and GALLAGHER, J. White paper on "orifice meter installation configurations with and without flow conditioners". American Petroleum Institute, Washington, DC, 1997. 252 p. (Available as GRI Report 99/0262 from Gas Technology Institute, Des Plaines, IL, USA)

[5] STUDZINSKI, W., WEISS, M., ATTIA, J. and GEERLIGS, J. Effect of reducers, expanders, a gate valve, and two elbows in perpendicular planes on orifice meter performance. In: *Flow Measurement 2001: Creating efficiency across industry sectors,* international conference, Peebles, UK, May 2001, paper 3.1. National Engineering Laboratory, Glasgow, 2001

[6] WEISS, M., STUDZINSKI, W. and ATTIA, J. Performance evaluation of orifice meter standards for selected T-junction and elbow installations. In: *Proceedings of the 5th International Symposium on Fluid Flow Measurement*, paper 5.1. Washington, DC, April 2002

[7] JEPSON, P. and CHIPCHASE, R. The effect of plate buckling on orifice meter accuracy, *J. Mech. Eng. Sci.* 1975, **17**(6)

[8] NORMAN, R., RAWAT, M.S. and JEPSON, P. Buckling and eccentricity effects on orifice metering accuracy, In: *Proceedings of the 1983 International Gas Research Conference*, London, UK, 13-6 June 1983, A22-83, 1983

[9] NORMAN, R., RAWAT, M.S. and JEPSON, P. An experimental investigation into the effects of plate eccentricity and elastic deformation on orifice meter accuracy. In: Spencer, E.A., editor. *Proceedings of the International Conference on the Metering of Natural Gas and Liquefied Hydrocarbon Gases,* London, UK, 1-2 February 1984, paper 3.3. Oyez, London, 1984

[10] ISO/TR 9464:1998, *Guidelines for the use of ISO 5167-1:1991*

[11] ISO/TS 15510, *Stainless steels — Chemical composition*

[12] PRITCHARD, M., NIAZI, A. and MARSHALL, D. Assessment of the effect of contamination on orifice plates. In: *Proceedings of the 11th Flomeko Conference on Flow Measurement of Gas and Liquid*, Groningen, 12-4 May 2003, paper 6.2. Gasunie Research, Groningen, 2003 (on CD-ROM)

[13] PRITCHARD, M., MARSHALL, D. and WILSON, J. An assessment of the impact of contamination on orifice plate metering accuracy. In: *Proceedings of the 22nd North Sea Flow Measurement Workshop*, St Andrews, UK, 26-9 October 2004, paper 2.2. National Engineering Laboratory, Glasgow, 2004 (on CD-ROM)

[14] HUTTON, S.P. The prediction of Venturi meter coefficients and their variation with roughness and age. *Inst. Civil Eng. Proc*. 1954, **3**, pp. 216-241; 922-927

[15] SCHLICHTING, H. *Boundary layer theory*, 4th edition. McGraw-Hill, New York, NY, 1960, 647 p.

[16] READER-HARRIS, M.J. Pipe roughness and Reynolds number limits for the orifice plate discharge coefficient equation. In: *Proceedings of the 2nd International Symposium on Fluid Flow Measurement*, Calgary, AB, Canada, 6-9 June 1990, pp. 29-43. American Gas Association, Arlington, VA, 1990

[17] BEAN, H.S. and MURDOCK, J.W. *Effects of pipe roughness on orifice meter accuracy, Report of Supervising Committee on two-inch tests.* American Gas Association, New York, NY, 1959 (American Gas Association Research Project NW-20)

[18] BRENNAN, J.A., MCFADDIN, S.E., SINDT, C.F. and WILSON, R.R. *Effect of pipe roughness on orifice flow measurement.* National Institute of Standards and Technology, Boulder, CO, 1989 (NIST Technical Note 1329)

[19] STUDZINSKI, W., BERG, D., BELL, D. and KARWACKI, L. Effect of meter run roughness on orifice meter accuracy. In: *Proceedings of the 2nd International Symposium on Fluid Flow Measurement*, Calgary, AB, Canada, 6-9 June 1990, pp. 1-15. American Gas Association, Arlington, VA, 1990

[20] CLARK, W.J. and STEPHENS, R.C. Flow measurement by square edged orifice plates: pipe roughness effects. *Proc. Inst. Mech. Eng.* 1957, **171**(33), pp. 895-904

[21] HERNING, F. and LUGT, H. Neue Versuche mit Segmentblenden und Normblenden [New research with segmental diaphragms and standard orifices]. *Brennst. — Wärme — Kraft*, 1958, **10**(5), pp. 219-223

[22] SPENCER, E.A., CALAME, H. and SINGER, J. *Edge sharpness and pipe roughness effects on orifice plate discharge coefficients.* National Engineering Laboratory, Glasgow, 1969 (NEL Report No 427)

[23] THIBESSARD, G. Le coefficient de débit des diaphragmes, la rugosité et le nombre de Reynolds [Diaphragm discharge coefficient, roughness and Reynolds number]. *Chaleur Indust.*, **415**, pp. 33-50, 1960

[24] WITTE, R. Neue Beiträge zur internationalen Normung auf dem Gebiete der Durchflußmessung [New contributions to international standardization in the flow measurement field]. *Brennst. — Wärme — Kraft*, 1953, **5**(6), pp. 185-190

[25] AKASHI, K., WATANABE, H. and KOGA, K. Development of a new rectifier for shortening upstream pipe length of flow meter. In: Yamasaki, H., editor. *Proceedings of the Imeko Symposium on Flow Measurement and Control in Industry*, pp. 279-280, Tokyo, Japan, 13-6 November 1979. Society of Instrument and Control Engineers, Tokyo, 1979

[26] BEAN, H.S. Indications of an orifice meter. *Am. Gas Assoc. Month.*, Jul–Aug 1947, pp. 337-341, 349

[27] BEITLER, S.R. The flow of fluids through orifices in 6 inch pipelines. *Trans. Am. Soc. Mech. Eng.*, 1929, **52**, p. 751

[28] BLAKE, K.A. The design of piezometer rings. *J. Fluid Mech.*, 1979, **78**, pp. 415-428

[29] BRAIN, T.J.S. and REID, J. Measurement of orifice plate edge sharpness. *Meas. Control*, 1973, **6**, pp. 377-384

[30] CLARK, W.J. *Flow measurement by square-edged orifice plate using corner tappings,* Pergamon, Oxford, 1965. 226 p.

[31] DALL, H.E. The effect of roughness of the orifice plate on the discharge coefficient. *Instrum. Eng.*, Apr 1958, **2**(5), pp. 91-92

[32] GALLAGHER, J.E. and LANASA, P.J. Field performance of the Gallagher flow conditioner. In: *Proceedings of the 3rd International Conference on Fluid Flow Measurement,* San Antonio, TX, 1995, section: Flow Conditioning II; paper: 2

[33] GALLAGHER, J.E., LANASA, P.J. and BEATY, R.E. The Gallagher flow conditioner. In: *North Sea Flow Measurement Workshop: Papers and programme,* Peebles, UK, October 1994, paper 2.4. National Engineering Laboratory, Glasgow

[34] HERNING, F. and WOLOWSKI, E. Die Kantenunschärfe von Normblenden und Segmentblenden und das Ähnlichkeitsgesetz [The edge sharpness of standard and segment orifices and the laws of similarity]. *Brennst. — Wärme — Kraft*, 1963, **15**(1), pp. 26-30

[35] IRVING, S.J. *Effect of system layout of the discharge coefficients of orifice plates*. Part II [British Hydromechanics Research Association (BHRA) Report RR 1424, 1977]; Part III (BHRA Report RR 1462, 1978)

[36] JENNER, S.R. An investigation of the influence of upstream fittings on the accuracy of flow measurement using orifice plates. Hatfield Polytechnic, B.Sc. (Eng.) Project Report, 1977

[37] JEPSON, P. and CHAMBERLAIN, D. Operating high pressure orifice metering installations. *Flow-Con 77. Proceedings of a Symposium on the application of flow measuring techniques*, Brighton, UK, April 1977. Institute of Measurement and Control, Gatton and Kent Sections

[38] KRETZSCHMER, F. and WALZHOLZ, G. [Experiments on installation faults of standard orifice plates.] *Forschung*, 1934, **5**(1), pp. 25-35

[39] LAKE, W.T. and REID, J. Optimal flow conditioner. In: *Proceedings of the 10th North Sea Flow Measurement Workshop,* Peebles, UK, 1992, paper 1.3. National Engineering Laboratory, Glasgow

[40] LAWS, E.M. Flow conditioning — A new development. *Flow Meas. Instrum.*, 1990, **1**, pp. 167-170

[41] LAWS, E.M. and OUAZZANE, A.K. Flow conditioning for orifice plate flow meters. In: *Proceedings of the 3rd International Conference on Fluid Flow Measurement,* San Antonio, TX, 1995, section: Flow Conditioning I; paper: 3

[42] MCVEIGH, J.C. Further investigations into the effect of roughness of the orifice plate on the discharge coefficient. *Instrum. Eng.*, 1962, **3**(5), pp. 112-113

[43] MASON, D. and WILSON, M.P.JR. *Measurement error due to the bending of orifice plates,* ASME paper No. 75-WA/FM-6, 1975

[44] MILLER, R.W. and KNEISEL, O. Experimental study of the effects of orifice plate eccentricity on flow coefficients. *Trans Am. Soc. Mech Eng Ser. D: J. Basic Eng.*, 1969, **91**(1), pp. 121-131

[45] NAGASHIO, K. and KOMIYA, K. *Effect of upstream straight length on orifice flowmeters*. Report of the National Research Laboratory of Metrology, 21-1, Japan, 1972

[46] NAGEL, P. and JAUMOTTE, A. Étude expérimentale de l'influence de singularités sur le coefficient de débit d'un diaphragme normalisé [Influence of disturbances on the coefficients of a standardized orifice plate]. *Promoclim A: Appl. Therm. Aéraul.*, 1976, **7**(1), pp. 57-84

[47] ORSI, E. Influence of special parts on the operation of standardized diaphragms. *L'Energica Elettrica* NI, Italy, 1978

[48] READER-HARRIS, M.J. *The effect of pipe roughness on orifice plate discharge coefficients*, National Engineering Laboratory, Glasgow, 1990 (*Progress Report No. 9.*). Also available as Report EUR 13763, Commission of the European Communities, Brussels, 1991 (negative microfiche)

[49] READER-HARRIS, M.J. Computation of flow through orifice plates. In: Taylor, C., Gresho, P., Sani, R.I., Haüser, J., editors. *Numerical methods in laminar and turbulent flow,* Volume 6, *Proceedings of the. 6th International Conference on Numerical Methods in Laminar and Turbulent Flow, Swansea,* Part 2, pp. 1907-1917, Pineridge, Swansea, 1989

[50] READER-HARRIS, M.J., SATTARY, J.A. and SPEARMAN, E.P. *The orifice plate discharge coefficient equation*, National Engineering Laboratory Executive Agency, Glasgow, 1992 (*Progress Report* No. 14)

[51] READER-HARRIS, M.J. SATTARY, J.A. and WOODHEAD, E. The use of flow conditioners to improve flow measurement accuracy downstream of headers. In: *Proceedings of the 3rd International Conference on Fluid Flow Measurement,* San Antonio, TX, 1995, section: Flow Conditioning II; paper: 3

[52] ROARK, R.J. and YOUNG, W.C. *Formulas for stress and strain,* 5th edition, McGraw Hill, New York, NY, 1975. 624 p.

[53] WEST, R.G. Developments in flow metering by means of orifice plates. In: *Flow measurement in closed conduits*, Glasgow, UK, 27-30 September 1960, Paper B-3, HMSO, Edinburgh, 1962

[54] WILCOX, P.L., WEBERG, T. and ERDAL, A. Short gas metering systems using K-Lab flow conditioners. In: *Proceedings of the 8th North Sea Flow Measurement Workshop*, 1990

[55] READER-HARRIS, M.J. and SATTARY, J.A. The orifice plate discharge coefficient equation — The equation for ISO 5167-1. In: *Proceedings of the 14th North Sea Flow Measurement Workshop*, Peebles, UK, October 1996, paper 24. National Engineering Laboratory, Glasgow, 1998

[56] HERNING, F. Untersuchungen zum Problem der Kantenunschärfe bei Normblenden und bei Segmentblenden [Experiments on the problem of the edge sharpness of standard and segmental orifice plates]. *Brennst. — Wärme — Kraft*, 1962, **14**(3), pp. 119-126

[57] CROCKET, K.A. and UPP, E.L. The measurement and effects of edge sharpness on the flow coefficients of standard orifices. *Trans. ASME J. Fluids Eng.*, Paper No 72-WA/FM-4, 1972 (June 1973, pp. 271-275)

[58] BENEDICT, R.P., WYLER, J.S. and BRANDT, G.B. The effect of edge sharpness on the discharge coefficient of an orifice. *Trans. ASME J. Eng. Power*, Paper No 74-WA/FM-4, 1974

ICS 17.120.10

Price based on 35 pages