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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

Mesure de débit des fluides au moyen d'appareils déprimogènes —

Partie 1: Diaphragmes, tuyères et tubes de Venturi insérés dans des conduites en charge de section circulaire

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Contents

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Annexes

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.

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.

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

This first edition of ISO 5167-1 cancels and replaces ISO 5167:1980, of which it constitutes a technical revision.

ISO 5167 consists of the following parts, under the general title *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*

— *Part 2: Diaphragms or nozzles installed at the inlet of a conduit*

Annexes A, B, C, D and E of this part of ISO 5167 are for information only.

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

1 Scope

This part of ISO 5167 specifies the geometry and method of use (installation and operating conditions) of orifice plates, nozzles and Venturi tubes when they are inserted in a conduit running full to determine the flow-rate of the fluid flowing in the conduit. It also gives necessary information for calculating the flow-rate and its associated uncertainty.

It applies only to pressure differential devices in which the flow remains subsonic throughout the measuring section and is steady or varies only slowly with time and where the fluid can be considered as single-phase. In addition, each of these devices can only be used within specified limits of pipe size and Reynolds number. Thus this part of ISO 5167 cannot be used for pipe sizes less than 50 mm or more than 1 200 mm or for pipe Reynolds numbers below 3 150.

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

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

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

The different primary devices dealt with in this part of ISO 5167 are as follows:

a) orifice plates, which can be used with corner pressure tappings, D and $D/2$ pressure tappings[2], and flange pressure tappings;

b) ISA 1932 nozzles[3], and long radius nozzles, which differ in shape and in the position of the pressure tappings;

c) classical Venturi tubes[4], and Venturi nozzles, which differ in shape and in the position of the pressure tappings.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 5167. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 5167 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 468:1982, *Surface roughness — Parameters, their values and general rules for specifying requirements*.

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

ISO 5168:—[5], *Measurement of fluid flow — Evaluation of uncertainties*.

3 Definitions

For the purposes of this part of ISO 5167, the definitions given in ISO 4006 apply.

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

3.1 Pressure measurement

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

The hole is usually circular but in certain cases may be an annular slot.

3.1.2 static pressure of a fluid flowing through a straight pipeline, p: Pressure which can be measured by connecting a pressure gauge to a wall pressure tapping. Only the value of the absolute static pressure is considered in this part of ISO 5167.

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

In this part of ISO 5167 the term "differential pressure" is used only if the pressure tappings are in the positions specified for each standard primary device.

3.1.4 pressure ratio, τ: Ratio of the absolute (static) pressure at the downstream pressure tapping to the absolute (static) pressure at the upstream pressure tapping.

2) Orifice plates with *vena contracta* pressure tappings are not considered in this part of ISO 5167.

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

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

5) To be published. (Revision of ISO 5168:1978)

3.2 Primary devices

3.2.1 orifice; throat: Opening of minimum cross-sectional area of a primary device.

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

3.2.2 orifice plate: Thin plate in which a circular aperture has been machined.

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

3.2.3 nozzle: Device which consists of a convergent inlet connected to a cylindrical section generally called the "throat".

3.2.4 Venturi tube: Device which consists of a convergent inlet connected to a cylindrical part called the "throat" and an expanding section called the "divergent" which is conical.

If the convergent inlet is a standardized ISA 1932 nozzle, the device is called a "Venturi nozzle". If the convergent inlet is conical, the device is called a "classical Venturi tube".

3.2.5 diameter ratio of a primary device used in a given pipe, β: Ratio of the diameter of the orifice (or throat) of the primary device to the internal diameter of the measuring pipe upstream of the primary device.

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

3.3 Flow

3.3.1 rate of flow of fluid passing through a primary device, q: Mass or volume of fluid passing through the orifice (or throat) per unit time; in all cases it is necessary to state explicitly whether the mass rate of flow q_m, expressed in mass per unit time, or the volume rate of flow q_V, expressed in volume per unit time, is being used.

3.3.2 Reynolds number, Re: Dimensionless parameter expressing the ratio between the inertia and viscous forces.

The Reynolds number used in this part of ISO 5167 is referred to

— either the upstream condition of the fluid and the upstream diameter of the pipe, i.e.

$$Re_D = \frac{U_1 D}{\nu_1} = \frac{4 q_m}{\pi \mu_1 D}$$

— or the orifice or throat diameter of the primary device, i.e.

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

3.3.3 isentropic exponent, κ: Ratio of the relative variation in pressure to the corresponding relative variation in density under elementary reversible adiabatic (isentropic) transformation conditions.

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

There are many gases and vapours for which no values for κ have been published so far. In such a case, for the purposes of this part of ISO 5167, the ratio of the specific heat capacities of ideal gases can be used in place of the isentropic exponent.

3.3.4 discharge coefficient, C: Coefficient, defined for an incompressible fluid flow, which relates the actual flow-rate to the theoretical flow-rate through a device. It is given by the formula

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

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

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

The equations for the numerical values of C given in this part of ISO 5167 are based on data determined experimentally.

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

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

is called the "flow coefficient".

3.3.5 expansibility [expansion] factor, ε: Coefficient used to take into account the compressibility of the fluid. It is given by the formula

$$\varepsilon = \frac{q_m\sqrt{1-\beta^4}}{\frac{\pi}{4}d^2C\sqrt{2\Delta p\varrho_1}}$$

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

$$\frac{q_m\sqrt{1-\beta^4}}{\frac{\pi}{4}d^2\sqrt{2\Delta p\varrho_1}}$$

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

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

ε is equal to unity when the fluid is incompressible and is less than unity when the fluid is compressible.

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

The numerical values of ε for orifice plates given in this part of ISO 5167 are based on data determined experimentally. For nozzles and Venturi tubes they are based on the thermodynamic general energy equation.

3.3.6 arithmetical mean deviation of the (roughness) profile, R_a: Arithmetic mean deviation from the mean line of the profile being measured. The mean line is such that the sum of the squares of the distances between the effective surface and the mean line is a minimum. In practice R_a can be measured with standard equipment for machined surfaces but can only be estimated for rougher surfaces of pipes. (See also ISO 468.)

For pipes, the uniform equivalent roughness k is used. This value can be determined experimentally (see 8.3.1) or taken from tables (see annex E).

4 Symbols and subscripts

4.1 Symbols

Symbol	Quantity	Dimension[1)]	SI unit
C	Coefficient of discharge	dimensionless	—
d	Diameter of orifice (or throat) of primary device at working conditions	L	m
D	Upstream internal pipe diameter (or upstream diameter of a classical Venturi tube) at working conditions	L	m
e	Relative uncertainty	dimensionless	—
k	Uniform equivalent roughness	L	m
l	Pressure tapping spacing	L	m
L	Relative pressure tapping spacing $L = \frac{l}{D}$	dimensionless	—
p	Absolute static pressure of the fluid	$ML^{-1}T^{-2}$	Pa
q_m	Mass rate of flow	MT^{-1}	kg/s
q_V	Volume rate of flow	L^3T^{-1}	m^3/s
R	Radius	L	m
R_a	Arithmetical mean deviation of the (roughness) profile	L	m
Re	Reynolds number	dimensionless	—
Re_D	Reynolds number referred to D	dimensionless	—
Re_d	Reynolds number referred to d	dimensionless	—
t	Temperature of the fluid	Θ	°C
U	Mean axial velocity of the fluid in the pipe	LT^{-1}	m/s
β	Diameter ratio $\beta = \frac{d}{D}$	dimensionless	—
γ	Ratio of specific heat capacities[2)]	dimensionless	—
δ	Absolute uncertainty	[3)]	[3)]
Δp	Differential pressure	$ML^{-1}T^{-2}$	Pa
$\Delta\varpi$	Pressure loss	$ML^{-1}T^{-2}$	Pa
ε	Expansibility [expansion] factor	dimensionless	—
κ	Isentropic exponent[2)]	dimensionless	—
μ	Dynamic viscosity of the fluid	$ML^{-1}T^{-2}$	Pa·s
ν	Kinematic viscosity of the fluid $\nu = \frac{\mu}{\varrho}$	L^2T^{-1}	m^2/s
ξ	Relative pressure loss	dimensionless	—
ϱ	Density of the fluid	ML^{-3}	kg/m^3
τ	Pressure ratio $\tau = \frac{p_2}{p_1}$	dimensionless	—
φ	Total angle of the divergent section	dimensionless	rad

1) M = mass, L = length, T = time, Θ = temperature.

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

3) The dimensions and units are those of the corresponding quantity.

4.2 Subscripts

Subscript	Meaning
1	Upstream
2	Downstream

5 Principle of the method of measurement and computation

5.1 Principle of the method of measurement

The principle of the method of measurement is based on the installation of a primary device (such as an orifice plate, a nozzle or a Venturi tube) into a pipeline in which a fluid is running full. The installation of the primary device causes a static pressure difference between the upstream side and the throat or downstream side of the device. The rate of flow can be determined from the measured value of this pressure difference and from the knowledge of the characteristics of the flowing fluid as well as the circumstances under which the device is being used. It is assumed that the device is geometrically similar to one on which calibration has been carried out and that the conditions of use are the same, i.e. that it is in accordance with this part of ISO 5167.

The mass rate of flow can be determined, since it is related to the differential pressure within the uncertainty limits stated in this part of ISO 5167, by one of the following formulae:

$$q_m = \frac{C}{\sqrt{1-\beta^4}} \varepsilon_1 \frac{\pi}{4} d^2 \sqrt{2 \Delta p \varrho_1} \qquad \ldots (1)$$

or

$$q_m = \frac{C}{\sqrt{1-\beta^4}} \varepsilon_2 \frac{\pi}{4} d^2 \sqrt{2 \Delta p \varrho_2} \qquad \ldots (2)$$

where ϱ_2 and ε_2 are referred to the downstream conditions.

Note that

$$\varepsilon_2 = \varepsilon_1 \sqrt{1 + \frac{\Delta p}{p_2}}$$

Similarly, the value of the volume rate of flow can be calculated since

$$q_V = \frac{q_m}{\varrho} \qquad \ldots (3)$$

where ϱ is the fluid density at the temperature and pressure for which the volume is stated.

5.2 Method of determination of the diameter ratio of the selected standard primary device

In practice, when determining the diameter ratio of a primary element to be installed in a given pipeline, C and ε used in the basic formulae (1) and (2) are, in general, not known. Hence the following shall be selected a priori:

— the type of primary device to be used;

— a rate of flow and the corresponding value of the differential pressure.

The related values of q_m and Δp are then inserted in the basic formulae rewritten in the form

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

in which ϱ and ε can be inserted for either upstream or downstream conditions (ϱ_1 and ε_1, or ϱ_2 and ε_2) and the diameter ratio of the selected primary device can be determined by iteration (see annex D).

5.3 Computation of rate of flow

Tables A.1 to A.16 are given for convenience: tables A.1 to A.13 give the values of C as a function of β, Re_D and D for orifice plates and nozzles, tables A.14 and A.15 give orifice, nozzle and Venturi tube expansibility factors ε_1, and table A.16 gives values of Venturi nozzle discharge coefficients. They are not intended for precise interpolation. Extrapolation is not permitted.

Computation of the rate of flow, which is a purely arithmetic process, is effected by replacing the different terms on the right-hand side of the basic formula (1) or (2) by their numerical values.

NOTES

2 Except for the case of Venturi tubes, C may be dependent on Re, which is itself dependent on q_m. In such cases the final value of C, and hence of q_m, has to be obtained by iteration. See annex D for guidance regarding the choice of the iteration procedure and initial estimates.

3 Δp represents the differential pressure, as defined in 3.1.3.

4 The diameters d and D mentioned in the formulae are the values of the diameters at the working conditions. Measurements taken at any other conditions should be corrected for any possible expansion or contraction of the primary device and the pipe due to the values of the temperature and pressure of the fluid during the measurement.

5 It is necessary to know the density and the viscosity of the fluid at the working conditions.

5.4 Determination of density

It is necessary to know the density of the fluid at the plane of the upstream or downstream pressure tapping; it can either be measured directly or be calculated from a knowledge of the static pressure, temperature and characteristics of the fluid at the appropriate plane. However, it is considered that the upstream pressure tapping will provide the most consistent results.

5.4.1 The static pressure of the fluid shall be measured in the plane of the upstream or downstream pressure tapping by means of an individual pipe-wall pressure tapping (as described in 8.2.1) or by means of carrier ring tappings (see figure 6).

5.4.1.1 The static pressure tapping shall preferably be separate from the tappings provided for measuring the components of the differential pressure, unless the intention is to measure upstream and downstream pressures separately.

It is, however, permissible to link simultaneously one pressure tapping with a differential pressure measuring device and a static pressure measuring device, provided that it is verified that this double connection does not lead to any distortion of the differential pressure measurement.

5.4.1.2 The static pressure value to be used in subsequent computations is that existing at the level of the centre of the measuring cross-section, which may differ from the pressure measured at the wall.

5.4.2 The temperature of the fluid shall preferably be measured downstream of the primary device. The thermometer well or pocket shall take up as little space as possible. The distance between it and the primary device shall be at least equal to $5D$ (and at most $15D$ when the fluid is a gas) if the pocket is located downstream, and in accordance with the values given in table 1, columns 10 and 11, if the pocket is located upstream.

Within the limits of application of this part of ISO 5167 it may generally be assumed that the downstream and upstream temperatures of the fluid are the same at the differential pressure tappings.

However, if the fluid is a gas, its upstream temperature may be calculated from the temperature measured downstream (at a distance of $5D$ to $15D$) of the primary device.

5.4.3 Any method of determining reliable values of the density, static pressure, temperature and viscosity of the fluid is acceptable if it does not interfere with the distribution of the flow in any way at the measuring cross-section.

5.4.4 The temperature of the primary device and that of the fluid upstream of the primary device are assumed to be the same (see 7.1.9).

6 General requirements for the measurements

In order to comply with this part of ISO 5167 the following requirements shall be met.

6.1 Primary device

6.1.1 The primary device shall be manufactured, installed and used in accordance with this part of ISO 5167.

When the manufacturing characteristics and conditions of use of the primary devices are outside the limits given in this part of ISO 5167, it is necessary to calibrate the primary device separately under the actual conditions of use.

6.1.2 The condition of the primary device shall be checked after each measurement or after each series of measurements, or at intervals close enough to each other so that conformity with this part of ISO 5167 is maintained.

It should be noted that even apparently neutral fluids may form deposits or encrustations on primary devices. Resulting changes in the discharge coefficient which can occur over a period of time can lead to values outside the uncertainties given in this part of ISO 5167.

6.1.3 The primary device shall be manufactured from material the coefficient of expansion of which is known, except if the user decides that the variations in the dimensions due to the temperature changes may be neglected.

6.2 Nature of the fluid

6.2.1 The fluid may be either compressible (gas) or considered as being incompressible (liquid).

6.2.2 The fluid shall be such that it can be considered as being physically and thermally homogeneous and single-phase. Colloidal solutions with a high degree of dispersion (such as milk), and only those solutions, are considered to behave as a single-phase fluid.

6.2.3 To carry out the measurement, it is necessary to know the density and viscosity of the fluid at the working conditions.

6.3 Flow conditions

6.3.1 The rate of flow shall be constant or, in practice, shall vary only slightly and slowly with time. This part of ISO 5167 does not provide for the measurement of pulsating flow, which is the subject of ISO/TR 3313[6].

6.3.2 The uncertainties specified in this part of ISO 5167 are valid only when there is no change of phase through the primary device. Increasing the bore or throat of the primary element will reduce the differential pressure, which may prevent a change of phase. To determine whether or not there is a change of phase, the flow computation shall be carried out on the assumption that the expansion is isothermal for liquids or isentropic for gases.

6.3.3 If the fluid is a gas, the pressure ratio as defined in 3.1.4 shall be greater than or equal to 0,75.

7 Installation requirements

7.1 General

7.1.1 The method of measurement applies only to fluids flowing through a pipeline of circular cross-section.

7.1.2 The pipe shall run full at the measuring section.

7.1.3 The primary device shall be installed in the pipeline at a position such that the flow conditions immediately upstream approach those of a fully developed profile and are free from swirl (see 7.4). Such conditions can be expected to exist if the installation conforms to requirements given in this clause.

7.1.4 The primary device shall be fitted between two sections of straight cylindrical pipe of constant cross-sectional area, in which there is no obstruction or branch connection (whether or not there is flow into or out of such connections during measurement) other than those specified in this part of ISO 5167.

The pipe is considered as straight when it appears so by visual inspection. The required minimum straight lengths of pipe, which conform to the description above, vary according to the nature of the fittings, the type of primary device and the diameter ratio. They are specified in tables 1 and 2.

7.1.5 The pipe bore shall be circular over the entire minimum length of straight pipe required. The cross-section is taken to be circular if it appears so by visual inspection. The circularity of the outside of the pipe can be taken as a guide, except in the immediate vicinity of the primary device where special requirements shall apply according to the type of primary device used (see 7.5.1 and 7.6.1).

Seamed pipe may be used provided that the internal weld bead is parallel to the pipe axis throughout the length of the pipe and satisfies the special requirements for the type of primary element. The seam shall not be situated in any sector of $\pm$ 30° centred on any pressure tapping.

7.1.6 The internal diameter D of the measuring pipe shall comply with the values given for each type of primary device.

7.1.7 The inside surface of the measuring pipe shall be clean and free from encrustations, pitting and deposits, and shall conform with the roughness criterion for at least a length of $10D$ upstream and $4D$ downstream of the primary device.

7.1.8 The pipe may be provided with drain holes and/or vent holes for the removal of solid deposits and fluids other than the measured fluid. However, there shall be no flow through the drain holes and vent holes during the measurement of the flow.

The drain holes and vent holes shall not be located near to the primary device, unless it is unavoidable to do so. In such a case, the diameter of these holes shall be smaller than $0,08D$ and their location shall be such that the distance, measured on a straight line from one of these holes to a pressure tapping of the primary device placed on the same side of this primary device, is always greater than $0,5D$. The axial planes of the pipe containing respectively the centre-line of a pressure tapping and the centre-line of a drain hole or vent hole shall be offset by at least 30°.

6) ISO/TR 3313:1974, *Measurement of pulsating fluid flow in a pipe by means of orifice plates, nozzles or Venturi tubes, in particular in the case of sinusoidal or square wave intermittent periodic-type fluctuations.*

7.1.9 The pipe and the pipe flanges shall be lagged. It is, however, unnecessary to lag the pipe when the temperature of the fluid, between the inlet of the minimum straight length of the upstream pipe and the outlet of the minimum straight length of the downstream pipe, does not exceed any limiting value for the accuracy of flow measurement required.

7.2 Minimum upstream and downstream straight lengths required for installation between various fittings and the primary device

7.2.1 The minimum straight lengths are given in tables 1 and 2.

The minimum straight lengths specified in table 2 for classical Venturi tubes are less than those specified in table 1 for orifice plates, nozzles and Venturi nozzles for the following reasons:

a) they are derived from different experimental results and different correlation approaches;

b) the convergent portion of the classical Venturi tube is designed to obtain a more uniform velocity profile at the throat of the device. Tests have shown that with identical diameter ratios, the minimum straight lengths upstream of the classical Venturi tube may be less than those required for orifice plates, nozzles and Venturi nozzles.

7.2.2 The straight lengths given in tables 1 and 2 are minimum values, and the use of straight lengths longer than those indicated is always recommended. For research work in particular, straight lengths of at least twice the upstream values given in tables 1 and 2 are recommended for "zero additional uncertainty"[7].

7.2.3 When the straight lengths are equal to or longer than the values given in tables 1 and 2 for "zero additional uncertainty"[7], there is no need to add any additional deviation to the discharge coefficient uncertainty to take account of the effect of such installation conditions.

7.2.4 When the upstream **or** downstream straight length is shorter than the "zero additional uncertainty"[7] values and equal to or greater than the "0,5 % additional uncertainty"[8] values, as given in tables 1 and 2, an additional uncertainty of 0,5 % shall be added arithmetically to the uncertainty on the discharge coefficient.

7.2.5 If the straight lengths are shorter than the "0,5 % additional uncertainty"[8] values given in tables 1 and 2, this part of ISO 5167 gives no information by which to predict the value of any additional uncertainty to be taken into account; this is also the case when the upstream **and** downstream straight lengths are both shorter than the "zero additional uncertainty"[7] values.

7.2.6 The valves mentioned in tables 1 and 2 shall be fully open. It is recommended that control of the flow-rate be effected by valves located downstream of the primary device. Isolating valves located upstream shall be fully open and shall be preferably of the "gate" type.

7.2.7 After a single change of direction (bend or tee), it is recommended that if pairs of single tappings are used they be installed so that their axes are perpendicular to the plane of the bend or tee.

7.2.8 The values given in tables 1 and 2 were obtained experimentally with a very long straight length upstream of the particular fitting in question and so it could be assumed that the flow upstream of the disturbance was virtually fully developed and swirl-free. Since in practice such conditions are difficult to achieve, the following information may be used as a guide for normal installation practice.

a) If the primary device is installed in a pipe leading from an upstream open space or large vessel, either directly or through any fitting, the total length of pipe between the open space and the primary device shall never be less than $30D$[9]. If any fitting is installed, then the straight lengths given in table 1 or 2 shall also apply between this fitting and the primary device.

b) If several fittings other than 90° bends[10] are placed in series upstream from the primary device, the following rule shall be applied: between the fitting (1) closest to the primary device and the primary device itself, there shall be a minimum straight length such as is indicated for the fitting (1) in question and for the actual values of β in table 1 or 2. But, in addition, between this fitting (1) and the preceding one (2) there shall be a straight length equal to one-half of the value

7) Values without parentheses in tables 1 and 2.

8) Values in parentheses in tables 1 and 2.

9) In the absence of experimental data, it seemed wise to adopt for classical Venturi tubes the conditions required for orifice plates and nozzles.

10) In the case of several 90° bends, refer to tables 1 and 2 which can be applied whatever the length between two consecutive bends.

Table 1 — Required straight lengths for orifice plates, nozzles and Venturi nozzles

Values expressed as multiples of D

Diameter ratio	Upstream (inlet) side of the primary device																				Downstream (outlet) side of the primary device	
β	Single 90° bend or tee (flow from one branch only)		Two or more 90° bends in the same plane		Two or more 90° bends in different planes		Reducer $2D$ to D over a length of $1,5D$ to $3D$		Expander $0,5D$ to D over a length of D to $2D$		Globe valve fully open		Full bore ball or gate valve fully open		Abrupt symmetrical reduction having a diameter ratio ⩾ 0,5		Thermometer pocket or well*) of diameter ⩽ $0,03D$		Thermometer pocket or well*) of diameter between $0,03D$ and $0,13D$		Fittings (columns 2 to 8)	
1	2		3		4		5		6		7		8		9		10		11		12	
0,20	10	(6)	14	(7)	34	(17)	5		16	(8)	18	(9)	12	(6)							4	(2)
0,25	10	(6)	14	(7)	34	(17)	5		16	(8)	18	(9)	12	(6)							4	(2)
0,30	10	(6)	16	(8)	34	(17)	5		16	(8)	18	(9)	12	(6)							5	(2,5)
0,35	12	(6)	16	(8)	36	(18)	5		16	(8)	18	(9)	12	(6)							5	(2,5)
0,40	14	(7)	18	(9)	36	(18)	5		16	(8)	20	(10)	12	(6)							6	(3)
0,45	14	(7)	18	(9)	38	(19)	5		17	(9)	20	(10)	12	(6)							6	(3)
0,50	14	(7)	20	(10)	40	(20)	6	(5)	18	(9)	22	(11)	12	(6)	30	(15)	5	(3)	20	(10)	6	(3)
0,55	16	(8)	22	(11)	44	(22)	8	(5)	20	(10)	24	(12)	14	(7)							6	(3)
0,60	18	(9)	26	(13)	48	(24)	9	(5)	22	(11)	26	(13)	14	(7)							7	(3,5)
0,65	22	(11)	32	(16)	54	(27)	11	(6)	25	(13)	28	(14)	16	(8)							7	(3,5)
0,70	28	(14)	36	(18)	62	(31)	14	(7)	30	(15)	32	(16)	20	(10)							7	(3,5)
0,75	36	(18)	42	(21)	70	(35)	22	(11)	38	(19)	36	(18)	24	(12)							8	(4)
0,80	46	(23)	50	(25)	80	(40)	30	(15)	54	(27)	44	(22)	30	(15)							8	(4)

*) The installation of thermometer pockets or wells will not alter the required minimum upstream straight lengths for the other fittings.

NOTES

1 The minimum straight lengths required are the lengths between various fittings located upstream or downstream of the primary device and the primary device itself. All straight lengths shall be measured from the upstream face of the primary device.

2 Values without parentheses are "zero additional uncertainty" values (see 7.2.3).

3 Values in parentheses are "0,5 % additional uncertainty" values (see 7.2.4).

Table 2 — Required straight lengths for classical Venturi tubes

Values expressed as multiples of D

Diameter ratio β	Single 90° bend*)	Two or more 90° bends in the same plane*)	Two or more 90° bends in different planes*) **)	Reducer $3D$ to D over a length of $3,5D$	Expander $0,75D$ to D over a length of D	Full bore ball or gate valve fully open
0,30	0,5***)	1,5 (0,5)	(0,5)	0,5***)	1,5 (0,5)	1,5 (0,5)
0,35	0,5***)	1,5 (0,5)	(0,5)	1,5 (0,5)	1,5 (0,5)	2,5 (0,5)
0,40	0,5***)	1,5 (0,5)	(0,5)	2,5 (0,5)	1,5 (0,5)	2,5 (1,5)
0,45	1,0 (0,5)	1,5 (0,5)	(0,5)	4,5 (0,5)	2,5 (1)	3,5 (1,5)
0,50	1,5 (0,5)	2,5 (1,5)	(8,5)	5,5 (0,5)	2,5 (1,5)	3,5 (1,5)
0,55	2,5 (0,5)	2,5 (1,5)	(12,5)	6,5 (0,5)	3,5 (1,5)	4,5 (2,5)
0,60	3,0 (1,0)	3,5 (2,5)	(17,5)	8,5 (0,5)	3,5 (1,5)	4,5 (2,5)
0,65	4,0 (1,5)	4,5 (2,5)	(23,5)	9,5 (1,5)	4,5 (2,5)	4,5 (2,5)
0,70	4,0 (2,0)	4,5 (2,5)	(27,5)	10,5 (2,5)	5,5 (3,5)	5,5 (3,5)
0,75	4,5 (3,0)	4,5 (3,5)	(29,5)	11,5 (3,5)	6,5 (4,5)	5,5 (3,5)

*) The radius of curvature of the bend shall be greater than or equal to the pipe diameter.

**) As the effect of these fittings may still be present after $40D$, no values without parentheses can be given.

***) Since no fitting can be placed closer than $0,5D$ to the upstream pressure tapping in the Venturi tube, the "zero additional uncertainty" values are the only ones applicable in this case.

NOTES

1 The minimum straight lengths required are the lengths between various fittings located upstream of the classical Venturi tube and the classical Venturi tube itself. All straight lengths shall be measured from the upstream pressure tapping plane of the classical Venturi tube. The pipe roughness, at least over the length indicated in this table, shall not exceed that of a smooth, commercially available pipe (approximately $k/D \leqslant 10^{-3}$).

2 Values without parentheses are "zero additional uncertainty" values (see 7.2.3).

3 Values in parentheses are "0,5 % additional uncertainty" values (see 7.2.4).

4 For downstream straight lengths, fittings or other disturbances (as indicated in this table) situated at least four throat diameters downstream of the throat pressure tapping plane do not affect the accuracy of the measurement.

given in table 1 or 2 for fitting (2) for a primary device of diameter ratio $\beta = 0,7$ whatever the actual value of β may be. This requirement does not apply when the fitting (2) is an abrupt symmetrical reduction, the case of which is covered by a) above.

If one of the minimum straight lengths so adopted appears in parentheses, a 0,5 % additional uncertainty shall be added arithmetically to the discharge coefficient uncertainty.

7.3 Flow conditioners

The use of flow conditioners of the types described in 7.3.2 and shown in figures 1 to 3 is recommended to permit the installation of primary devices downstream of fittings not included in table 1 or 2. When a large diameter ratio primary device is to be used, the inclusion of such devices sometimes permits the use of shorter installation lengths upstream of the primary device than are given in table 1.

When installed as described in 7.3.1, the use of a flow conditioner does not introduce any additional uncertainty in the discharge coefficient.

7.3.1 Installation

Any flow conditioner used shall be installed in the upstream straight length between the primary device and the disturbance or fitting closest to the primary device. Unless it can be verified that the flow conditions at the inlet of the primary device conform with the requirements of 7.1.3, the straight length between this fitting and the conditioner itself shall be equal to at least $20D$, and the straight length between the conditioner and the primary device shall be equal to at least $22D$. These lengths are measured from the upstream face and the downstream face respectively of the conditioner. Conditioners are only fully effective if their installation is such that the smallest possible gaps are left around the resistive elements of the device, therefore permitting no by-pass flows which would prevent their proper functioning.

When correctly built conditioners are used with the pipe length combinations described above, they can be used in conjunction with any entrance velocity profile.

7.3.2 Types of flow conditioners

The five standardized types of flow conditioners are shown in figures 1 to 3. The choice of a conditioner is dependent on the nature of the velocity distribution which has to be corrected and on the pressure loss which can be tolerated. The devices described below create a pressure loss of approximately

for type A: $5\varrho_1 U_1^2/2$
for type B with inlet bevel: $11\varrho_1 U_1^2/2$
for type B without inlet bevel: $14\varrho_1 U_1^2/2$
for type C: $5\varrho_1 U_1^2/2$
for type D: $0{,}25\varrho_1 U_1^2/2$
for type E: $0{,}25\varrho_1 U_1^2/2$

For types A, B and C, the pressure loss may vary as a function of the ratio of the area of the holes to the total area.

7.3.2.1 Type A: "Zanker" conditioner

The "Zanker" conditioner consists of a perforated plate with holes of certain specified sizes followed by a number of channels (one for each hole) formed by the intersection of a number of plates (see figure 1).

The various plates shall be as thin as possible but shall provide adequate strength.

7.3.2.2 Type B: "Sprenkle" conditioner

The "Sprenkle" conditioner consists of three perforated plates in series with a length equal to one pipe diameter between successive plates. The perforations shall preferably be chamfered on the upstream side, and the total area of the holes in each plate shall be greater than 40 % of the cross-sectional area of the pipe. The ratio of plate thickness to hole diameter shall be at least 1 and the diameter of the holes shall be less than or equal to $0{,}05D$. (See figure 2.)

The three plates shall be held together by bars or studs, which shall be located around the periphery of the pipe bore, and which shall be of as small a diameter as possible but shall provide the required strength.

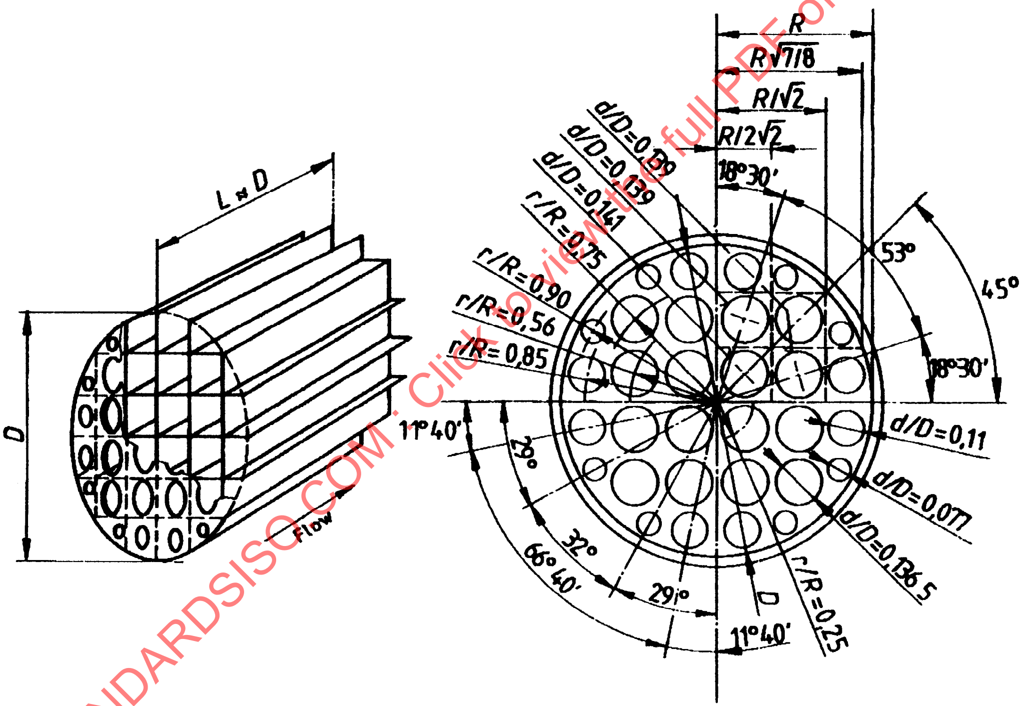


Figure 1 — Type A "Zanker" conditioner

7.3.2.3 Type C: Tube bundle conditioner

The tube bundle conditioner consists of a bundle of parallel and tangential tubes fixed together and held rigidly in the pipe (see figure 2). It is important to ensure that the various tubes are parallel with each other and with the pipe axis since, if this requirement is not complied with, the conditioner itself might introduce disturbances in the flow.

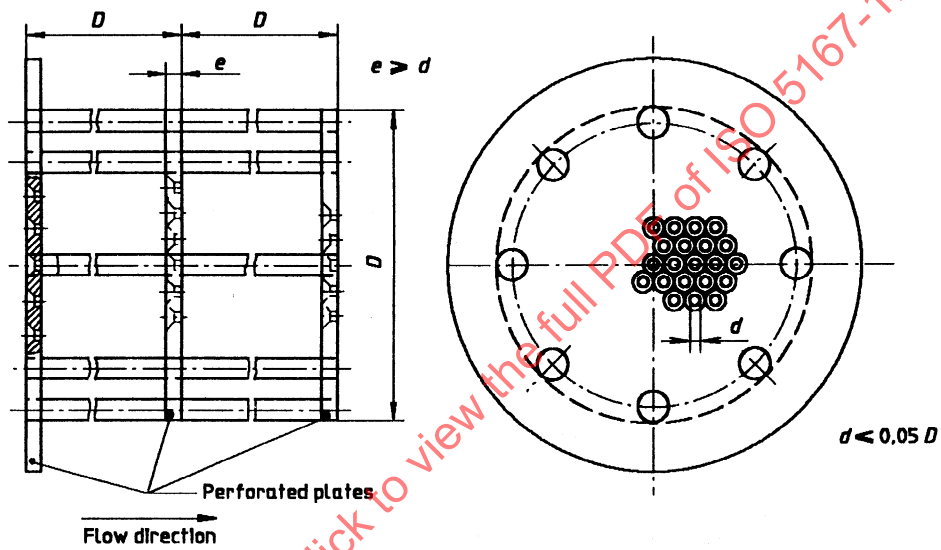
There shall be at least 19 tubes. Their length shall be greater than or equal to $10d$. The tubes shall be joined together and the bundle shall rest against the pipe.

7.3.2.4 Type D: AMCA straightener

The AMCA straightener consists of a honeycomb with square meshes the dimensions of which are shown on figure 3. The vanes shall be as thin as possible but shall provide adequate strength.

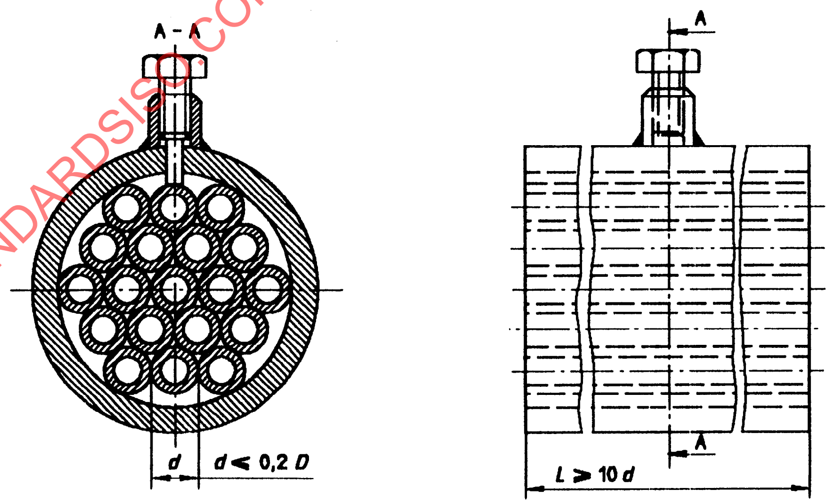
7.3.2.5 Type E: "Étoile" straightener

The "étoile" straightener consists of eight radial vanes at equal angular spacing with a length equal to twice the diameter of the pipe (see figure 3). The vanes shall be as thin as possible but shall provide adequate strength.



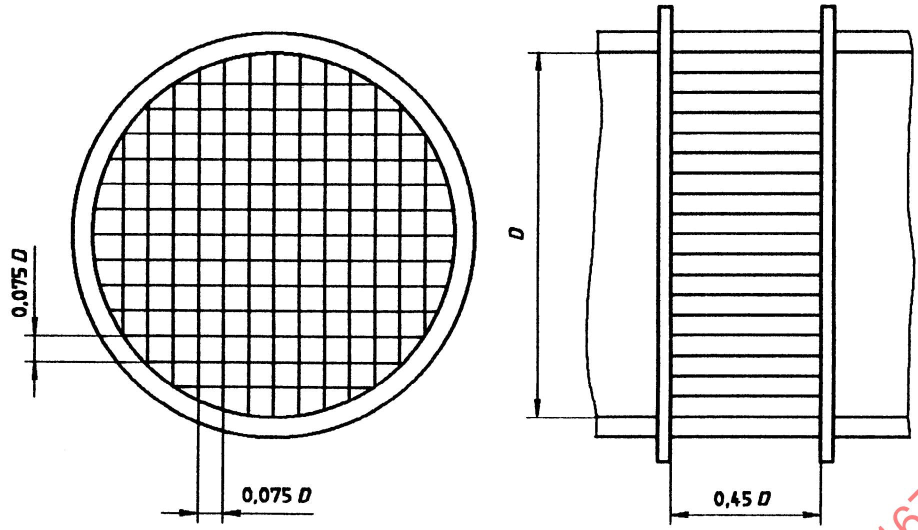
NOTE – In order to decrease the pressure loss the entrance of the holes may be bevelled at 45°.

Type B: "Sprenkle" conditioner

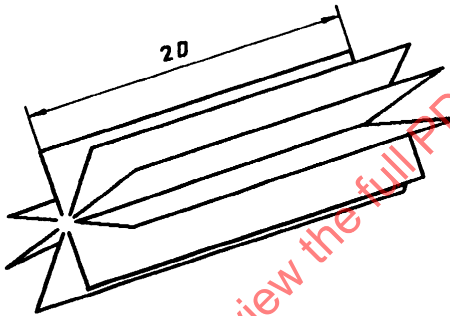


Type C: Tube bundle conditioner

Figure 2 — Type B and type C conditioners



Type D: AMCA straightener



Type E: Etoile straightener

Figure 3 — Type D and type E straighteners

7.4 General requirements for flow conditions at the primary device

If the specified installation conditions given in tables 1 and 2 or in 7.3 cannot be met this part of ISO 5167 still remains valid if the flow conditions immediately upstream of the primary device conform to 7.1.3.

Swirl-free conditions can be taken to exist when the swirl angle over the pipe is less than 2°.

Acceptable velocity profile conditions can be presumed to exist when, at each point across the pipe cross-section, the ratio of the local axial velocity to the maximum axial velocity at the cross-section agrees to within 5 % with that which would be achieved in swirl-free flow at the same radial position at a cross-section located at the end of a very long straight length (over $100D$) of similar pipe (fully developed flow).

7.5 Additional specific installation requirements for orifice plates, nozzles and Venturi nozzles

7.5.1 Circularity of the pipe

In the immediate vicinity of the primary device the following requirements shall apply.

7.5.1.1 The length of the upstream pipe section adjacent to the primary device (or to the carrier ring if there is one) shall be at least $2D$ and cylindrical. The pipe is said to be cylindrical when no diameter in any plane differs by more than 0,3 % from the mean value of D obtained from the measurements specified in 7.5.1.2.

7.5.1.2 The value for the pipe diameter D shall be the mean of the internal diameters over a length of $0,5D$ upstream of the upstream pressure tapping. The internal mean diameter shall be the arithmetic mean of measurements of at least twelve diameters, namely four diameters positioned at approximately equal angles to each other, distributed in each of at least three cross-sections evenly distributed over a length of $0{,}5D$, two of these sections being at distance 0 and $0{,}5D$ from the upstream tapping and one being in the plane of the weld in the case of a weld-neck construction. If there is a carrier ring [see figure 6a)] this value of $0{,}5D$ shall be measured from the upstream edge of the carrier ring.

7.5.1.3 Beyond $2D$ from the primary device, the upstream pipe run between the primary device and the first upstream fitting or disturbance may be made up of one or more sections of pipe.

No additional uncertainty in the discharge coefficient is involved provided that the diameter step between any two sections does not exceed 0,3 % of the mean value of D obtained from the measurements specified in 7.5.1.2.

7.5.1.4 An additional uncertainty of 0,2 % shall be added arithmetically to the uncertainty for the discharge coefficient if the diameter step ΔD between any two sections exceeds the limits given in 7.5.1.3, but complies with the following relationships:

$$\frac{\Delta D}{D} \leqslant 0{,}002\left(\frac{\frac{s}{D}+0{,}4}{0{,}1+2{,}3\beta^4}\right)$$

and

$$\frac{\Delta D}{D} \leqslant 0{,}05$$

where s is the distance of the step from the upstream pressure tapping or carrier ring.

7.5.1.5 If a step is greater than any one of the limits given in the inequalities above, the installation is not in accordance with this part of ISO 5167.

7.5.1.6 No diameter of the downstream straight length, considered along a length of at least $2D$ from the upstream face of the primary device, shall differ from the mean diameter of the upstream straight length by more than 3 %. This can be judged by checking a single diameter of the downstream straight length.

This requirement is not valid for Venturi tubes, which may be truncated and to which the requirements of 7.6.1.3 apply.

7.5.2 Location of primary device and carrier rings

7.5.2.1 The primary device shall be placed in the pipe in such a way that the fluid flows from the upstream face towards the downstream face.

7.5.2.2 The primary device shall be perpendicular to the centre-line of the pipe to within 1°.

7.5.2.3 The primary device shall be centred in the pipe or, if applicable, in the carrier rings. The distance e_x between the centre-line of the orifice and the centre-lines of the pipe on the upstream and downstream sides shall be less than or equal to

$$\frac{0{,}002\,5D}{0{,}1+2{,}3\beta^4}$$

If

$$\frac{0{,}002\,5D}{0{,}1+2{,}3\beta^4} < e_x \leqslant \frac{0{,}005D}{0{,}1+2{,}3\beta^4}$$

an additional uncertainty of 0,3 % shall be added arithmetically to the uncertainty on the discharge coefficient C.

In the case where

$$e_x > \frac{0{,}005D}{0{,}1+2{,}3\beta^4}$$

this part of ISO 5167 gives no information by which to predict the value of any additional uncertainty to be taken into account.

7.5.2.4 When carrier rings are used, they shall be centred such that they do not protrude into the pipe at any point.

7.5.3 Method of fixing and gaskets

7.5.3.1 The method of fixing and tightening shall be such that once the primary device has been installed in the proper position, it remains so.

It is necessary, when holding the primary device between flanges, to allow for its free thermal expansion and to avoid buckling and distortion.

7.5.3.2 Gaskets or sealing rings shall be made and inserted in such a way that they do not protrude at any point inside the pipe or across the pressure tappings or slots when corner tappings are used. They shall be as thin as possible, with due consideration taken in maintaining the relationship as defined in 8.2 for orifice plates.

7.5.3.3 If gaskets are used between the primary device and the annular chamber rings, they shall not protrude inside the annular chamber.

7.6 Additional specific installation requirements for classical Venturi tubes

7.6.1 Circularity of the pipe

In the immediate vicinity of the classical Venturi tube, the following requirements shall apply.

7.6.1.1 Over an upstream length of at least $2D$ measured from the upstream end of the entrance cylinder of the Venturi tube, the pipe shall be cylindrical.

7.6.1.2 The mean diameter of the pipe where it joins the classical Venturi tube shall be within 1 % of the classical Venturi tube entrance cylinder diameter D, as defined in 10.1.2.1. Moreover, no single diameter of this inlet pipe section shall differ from the mean of the measured diameters by more than 2 % for a distance of two pipe diameters upstream of the classical Venturi tube.

7.6.1.3 The diameter of the pipe immediately downstream of the Venturi tube need not be measured accurately but it shall be checked that the downstream pipe diameter is not less than 90 % of the diameter at the end of the Venturi tube divergent section. This means that, in most cases, pipes having the same nominal bore as that of the Venturi tube can be used.

7.6.2 Roughness of the upstream pipe

The upstream pipe shall have a relative roughness of $k/D \leqslant 10^{-3}$ on a length at least equal to $2D$ measured upstream from the classical Venturi tube.

7.6.3 Alignment of the classical Venturi tube

The offset or distance between the centre-lines of the upstream pipe and of the Venturi tube, as measured in the connecting plane of the upstream pipe and entrance cylinder A (see 10.1.2), shall be less than $0{,}005D$. The angular alignment uncertainty of the Venturi tube centre-line with respect to the upstream pipe centre-line shall be less than 1°. Finally the sum of the offset and half the diameter deviation (see 7.6.1.2) shall be less than $0{,}007\,5D$.

8 Orifice plates

The various types of standard orifice plates are similar and therefore only a single description is needed. Each type of standard orifice plate is characterized by the arrangement of the pressure tappings.

All types of orifice plates shall conform with the following description under working conditions.

Limits of use are given in 8.3.1.

8.1 Description

The axial plane cross-section of a standard orifice plate is shown in figure 4.

The letters given in the following text refer to the corresponding references in figure 4.

8.1.1 General shape

8.1.1.1 The part of the plate inside the pipe shall be circular and concentric with the pipe centre-line. The faces of the plate shall always be flat and parallel.

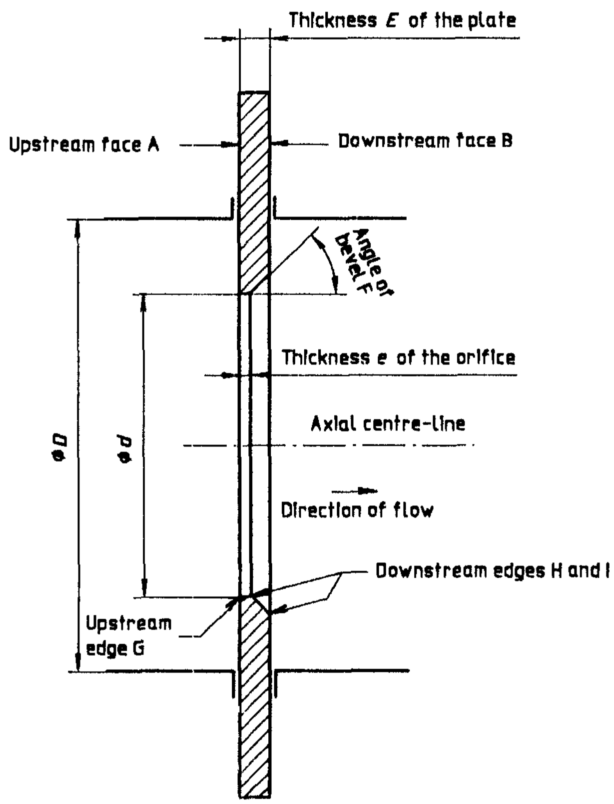


Figure 4 — Standard orifice plate

8.1.1.2 Unless otherwise stated, the following requirements apply only to that part of the plate located within the pipe.

8.1.1.3 Care shall be taken in the design of the orifice plate and its installation to ensure that plastic buckling and elastic deformation of the plate, due to the magnitude of the differential pressure or of any other stress, do not cause the slope of the straight line defined in 8.1.2.1 to exceed 1 % under working conditions.

8.1.2 Upstream face A

8.1.2.1 The upstream face A of the plate shall be flat when the plate is installed in the pipe with zero differential pressure across it. Provided that 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 to be flat if the slope of a straight line connecting any two points of its surface in relation to a plane perpendicular to the centre-line of the orifice plate bore is less than 0,5 %. This criterion ignores the inevitable local defects of the surface which are invisible to the naked eye.

8.1.2.2 The upstream face of the orifice plate shall have a roughness criterion $R_a \leqslant 10^{-4}d$ within a circle of diameter not less than D and which is concentric with the orifice bore. If in the working conditions the plate does not fulfill the specified conditions, it shall be repolished or cleaned to a diameter of at least D.

8.1.2.3 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.

8.1.3 Downstream face B

8.1.3.1 The downstream face B shall be flat and parallel with the upstream face. (See also 8.1.4.4.)

8.1.3.2 Although it may be convenient to manufacture the orifice plate with the same surface finish on each face, it is unnecessary to provide the same high quality finish for the downstream face as for the upstream face (but see 8.1.8).

8.1.3.3 The flatness and surface condition of the downstream face may be judged by visual inspection.

8.1.4 Thicknesses E and e

8.1.4.1 The thickness e of the orifice shall be between $0{,}005D$ and $0{,}02D$.

8.1.4.2 The difference between the values of e measured at any point on the orifice shall not be greater than $0{,}001D$.

8.1.4.3 The thickness E of the plate shall be between e and $0{,}05D$.

However, when 50 mm $\leqslant D \leqslant$ 64 mm, a thickness E up to 3,2 mm is acceptable.

8.1.4.4 The difference between the values of E measured at any point of the plate shall not be greater than $0{,}001D$.

8.1.5 Angle of bevel F

8.1.5.1 If the thickness E of the plate exceeds the thickness e of the orifice, the plate shall be bevelled on the downstream side. The bevelled surface shall be well finished. (See 8.1.2.2.)

8.1.5.2 The angle of bevel F shall be 45° ± 15°.

8.1.6 Edges G, H and I

8.1.6.1 The upstream edge G shall not have wire-edges, burrs, or any peculiarities visible to the naked eye.

8.1.6.2 The upstream edge G shall be sharp. It is considered so if the edge radius is not greater than $0{,}000\,4d$.

This requirement cannot be met unless the edge complies with the requirements of 8.1.6.1.

If $d \geqslant$ 25 mm this requirement can generally be considered as satisfied by visual inspection, by checking that the edge does not seem to reflect a beam of light when viewed with the naked eye.

If $d <$ 25 mm visual inspection is not sufficient.

If there is any doubt as to whether this requirement is met, the edge radius shall be measured.

8.1.6.3 The downstream edges H and I are within the separated flow region and hence the requirements for their quality are less stringent than those for edge G. This being the case, small defects are acceptable.

8.1.7 Diameter of orifice d

8.1.7.1 The diameter d shall in all cases be greater than or equal to 12,5 mm. The diameter ratio $\beta = d/D$ is always greater than or equal to 0,20 and less than or equal to 0,75.

Within these limits, the value of β may be chosen by the user.

8.1.7.2 The value d of the diameter of the orifice shall be taken as the mean of the measurements of at least four diameters at approximately equal angles to each other.

8.1.7.3 The orifice shall be cylindrical, and perpendicular to the upstream face.

No diameter shall differ by more than 0,05 % from the value of the mean diameter. This requirement is deemed to be satisfied when the difference in the length of any of the measured diameters complies with the said requirement in respect of the mean of the measured diameters. In all cases the roughness of the orifice bore cylindrical section shall not be such that it affects the edge sharpness measurement.

8.1.8 Symmetrical plates

8.1.8.1 If the orifice plate is intended to be used for measuring reverse flows the following requirements shall be fulfilled:

a) the plate shall not be bevelled;

b) the two faces shall comply with the specifications for the upstream face given in 8.1.2;

c) the thickness E of the plate shall be equal to the thickness e of the orifice specified in 8.1.4; consequently it may be necessary to limit the differential pressure to prevent plate distortion (see 8.1.1.3);

d) the two edges of the orifice shall comply with the specifications for the upstream edge specified in 8.1.6.

8.1.8.2 Furthermore, for orifice plates with D and $D/2$ tappings (see 8.2), two sets of upstream and downstream pressure taps shall be provided and used according to the direction of the flow.

8.1.9 Material and manufacture

The plate may be manufactured from any material and in any way, provided that it is and remains in accordance with the foregoing description during the flow measurements.

In particular, the plate shall be clean when the measurements are made.

8.2 Pressure tappings

For each primary device, at least one upstream pressure tapping and one downstream pressure tapping shall be installed in one or other of the standard locations.

A single orifice plate may be used with several sets of pressure tappings suitable for different types of standard orifice plates, but to avoid mutual interference, several tappings on the same side of the orifice plate shall not be in the same axial plane.

The location of the pressure tappings characterizes the type of standard orifice plate.

8.2.1 Details of pressure tappings for D and $D/2$ tap orifice plates and flange tap orifice plates

8.2.1.1 The spacing l of a pressure tapping is the distance between the centre-line of the pressure tapping and the plane of a specified face of the orifice plate. When installing the pressure tappings, due account shall be taken of the thickness of the gaskets and/or sealing material.

8.2.1.2 For orifice plates with D and $D/2$ tappings (see figure 5), the spacing l_1 of the upstream pressure tapping is nominally equal to D, but may be between 0,9D and 1,1D without altering the discharge coefficient.

The spacing l_2 of the downstream pressure tapping is nominally equal to 0,5D but may be between the following values without altering the discharge coefficient:

between 0,48D and 0,52D when $\beta \leqslant 0,6$

between 0,49D and 0,51D when $\beta > 0,6$

Both l_1 and l_2 spacings are measured from the **upstream** face of the orifice plate.

8.2.1.3 For orifice plates with flange tappings (see figure 5), the spacing l_1 of the upstream pressure tapping is nominally 25,4 mm and is measured from the **upstream** face of the orifice plate.

The spacing l'_2 of the downstream pressure tapping is nominally 25,4 mm and is measured from the **downstream** face of the orifice plate.

These upstream and downstream spacings l_1 and l'_2 may be within the following ranges without altering the discharge coefficient:

25,4 mm ± 0,5 mm when $\beta > 0,6$ and $D < 150$ mm

25,4 mm ± 1 mm in all other cases, i.e. $\beta \leqslant 0{,}6$ or $\beta > 0{,}6$ but 150 mm $\leqslant D \leqslant$ 1 000 mm

8.2.1.4 The centre-line of the tapping shall meet the pipe centre-line and be at an angle of 90° to it.

8.2.1.5 At the point of break-through the hole shall be circular. The edges shall be flush with the internal surface of the pipe wall and as sharp as possible. To ensure the elimination of all burrs or wire edges at the inner edge, rounding is permitted but shall be kept as small as possible and, where it can be measured, its radius shall be less than one-tenth of the pressure tapping diameter. No irregularity shall appear inside the connecting hole, on the edges of the hole drilled in the pipe wall, or on the pipe wall close to the pressure tapping.

8.2.1.6 Conformity of the pressure tappings with the requirements specified in 8.2.1.4 and 8.2.1.5 may be judged by visual inspection.

8.2.1.7 The diameter of pressure tappings shall be less than $0{,}13D$ and less than 13 mm.

No restriction is placed on the minimum diameter, which is determined in practice by the need to prevent accidental blockage and to give satisfactory dynamic performance. The upstream and downstream tappings shall have the same diameter.

8.2.1.8 The pressure tappings shall be circular and cylindrical over a length of at least 2,5 times the internal diameter of the tapping, measured from the inner wall of the pipeline.

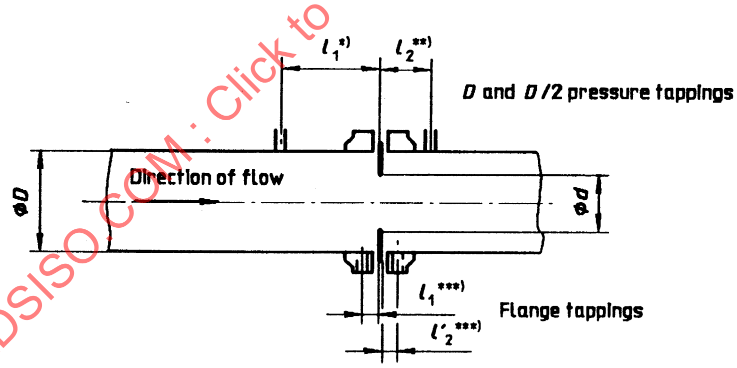
8.2.1.9 The centre-lines of the pressure tappings may be located in any axial plane of the pipeline (see also 3.1.3 and 7.2.7).

8.2.1.10 The axis of the upstream tapping and that of the downstream tapping may be located in different axial planes (see also 3.1.3 and 7.2.7).

8.2.2 Orifice plate with corner tappings (see figure 6)

8.2.2.1 The spacing between the centre-lines of the tappings and the respective faces of the plate is equal to half the diameter or to half the width of the tappings themselves, so that the tapping holes break through the wall flush with the faces of the plate (see also 8.2.2.5).

8.2.2.2 The pressure tappings may be either single tappings or annular slots. Both types of tappings may be located either in the pipe or its flanges or in carrier rings as shown in figure 6.



*) $l_1 = D \pm 0{,}1D$

**) $l_2 = \begin{cases} 0{,}5D \pm 0{,}02D \text{ for } \beta \leqslant 0{,}6 \\ 0{,}5D \pm 0{,}01D \text{ for } \beta > 0{,}6 \end{cases}$

***) $l_1 = l'_2 = \begin{cases} (25{,}4 \pm 0{,}5) \text{ mm for } \beta > 0{,}6 \text{ and } D < 150 \text{ mm} \\ (25{,}4 \pm 1) \text{ mm for } \beta \leqslant 0{,}6 \\ (25{,}4 \pm 1) \text{ mm for } \beta > 0{,}6 \text{ and } 150 \text{ mm} \leqslant D \leqslant 1\,000 \text{ mm} \end{cases}$

Figure 5 — Spacing of pressure tappings for orifice plates with D and $D/2$ pressure tappings or flange tappings

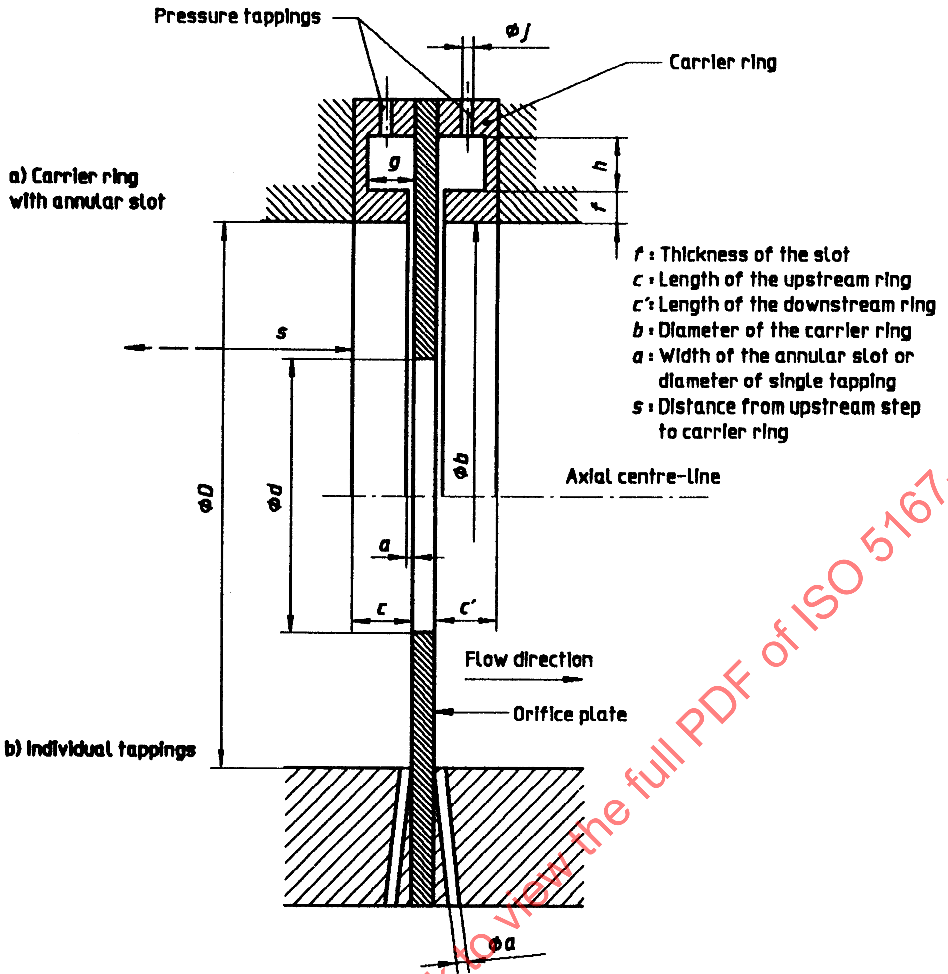


Figure 6 — Corner tappings

8.2.2.3 The diameter a of a single tapping and the width a of annular slots are specified below. The minimum diameter is determined in practice by the need to prevent accidental blockage and to give satisfactory dynamic performance.

For clean fluids and vapours:

for $\beta \leqslant 0,65$: $0,005D \leqslant a \leqslant 0,03D$

for $\beta > 0,65$: $0,01D \leqslant a \leqslant 0,02D$

For any value of β:

for clean fluids: 1 mm $\leqslant a \leqslant$ 10 mm

for vapours, in the case of annular chambers: 1 mm $\leqslant a \leqslant$ 10 mm

for vapours and for liquefied gases, in the case of single tappings: 4 mm $\leqslant a \leqslant$ 10 mm

8.2.2.4 The annular slots usually break through the pipe over the entire perimeter, with no break in continuity. If not, each annular chamber shall connect with the inside of the pipe by at least four openings, the axes of which are at equal angles to one another and the individual opening area of which is at least 12 mm^2.

8.2.2.5 If individual pressure tappings, as shown in figure 6b), are used, the centre-line of the tappings shall meet the centre-line of the pipe at as near an angle of 90° as possible.

If there are several individual pressure tappings in the same upstream or downstream plane, their centre-lines shall form equal angles with each other. The diameters of individual pressure tappings are specified in 8.2.2.3.

The pressure tappings shall be circular and cylindrical over a length of at least 2,5 times the internal diameter of the tappings, measured from the inner wall of the pipeline.

8.2.2.6 The internal diameter b of the carrier rings shall be greater than or equal to the diameter D of the pipe, to ensure that they do not protrude into the pipe, but shall be less than or equal to $1{,}04D$. Moreover, the following condition shall be met:

$$\frac{b-D}{D} \times \frac{c}{D} \times 100 \leqslant \frac{0{,}1}{0{,}1 + 2{,}3\beta^4}$$

The lengths c and c' of the upstream and downstream rings (see figure 6) shall not be greater than $0{,}5D$.

The thickness f of the slot shall be greater than or equal to twice the width a of the annular slot. The area of the cross-section of the annular chamber, gh, shall be greater than or equal to half the total area of the opening connecting this chamber to the inside of the pipe.

8.2.2.7 All surfaces of the ring which are in contact with the measured fluid shall be clean and shall have a well-machined finish.

8.2.2.8 The pressure tappings connecting the annular chambers to the secondary devices are pipe-wall tappings, circular at the point of break-through and with a diameter j between 4 mm and 10 mm (see 8.2.1.5).

8.2.2.9 The upstream and downstream carrier rings need not necessarily be symmetrical in relation to each other, but they shall both conform with the preceding requirements.

8.2.2.10 The diameter of the pipe shall be measured as specified in 7.5.1.2, the carrier ring being regarded as part of the primary device. This also applies to the distance requirement given in 7.5.1.4 so that s shall be measured from the upstream edge of the recess formed by the carrier ring.

8.3 Coefficients and corresponding uncertainties of orifice plates

8.3.1 Limits of use

Standard orifice plates shall only be used in accordance with this part of ISO 5167 under the following conditions.

For orifice plates with corner tappings:

$d \geqslant 12{,}5$ mm

$50 \text{ mm} \leqslant D \leqslant 1\,000 \text{ mm}$

$0{,}2 \leqslant \beta \leqslant 0{,}75$

$Re_D \geqslant 5\,000$ for $0{,}2 \leqslant \beta \leqslant 0{,}45$

$Re_D \geqslant 10\,000$ for $\beta > 0{,}45$

For orifice plates with flange tappings or with D and $D/2$ pressure tappings:

$d \geqslant 12{,}5$ mm

$50 \text{ mm} \leqslant D \leqslant 1\,000 \text{ mm}$

$0{,}2 \leqslant \beta \leqslant 0{,}75$

$Re_D \geqslant 1\,260\beta^2 D$

where D is expressed in millimetres.

In addition, the relative roughness shall conform with the values in table 3.

The value of the uniform equivalent roughness, k, expressed in length units, depends on several factors such as height, distribution, angularity and other geometric aspects of the roughness elements of the pipe wall.

A full-scale pressure loss test of a sample length of the particular pipe should be carried out to determine the value of k.

However, approximate values of k for different materials can be obtained from the various tables given in reference literature, and table E.1 gives values of k for a variety of materials, as derived from the Colebrook formula.

Most of the experiments on which the values of C given in this part of ISO 5167 are based were carried out in pipes with a relative roughness

$k/D \leqslant 3{,}8 \times 10^{-4}$

as regards corner tappings, or

$k/D \leqslant 10 \times 10^{-4}$

as regards flange tappings or D and $D/2$ pressure tappings.

Table 3 — Upper limits of relative roughness of the upstream pipeline for orifice plates

β	≤ 0,3	0,32	0,34	0,36	0,38	0,4	0,45	0,5	0,6	0,75
$10^4\, k/D$	25	18,1	12,9	10,0	8,3	7,1	5,6	4,9	4,2	4,0

Pipes with higher relative roughness may be used if the relative roughness is within the limits given above for at least $10D$ upstream of the orifice plate.

8.3.2 Coefficients

8.3.2.1 Discharge coefficient, C

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

$$C = 0{,}595\,9 + 0{,}031\,2\beta^{2,1} - 0{,}184\,0\beta^{8} + $$
$$+ 0{,}002\,9\beta^{2,5}\left(\frac{10^{6}}{Re_D}\right)^{0,75} +$$
$$+ 0{,}090\,0L_1\beta^4(1-\beta^4)^{-1} - 0{,}033\,7L'_2\beta^3$$

where

$\beta = d/D$ is the diameter ratio;

Re_D is the Reynolds number related to D;

$L_1 = l_1/D$ is the quotient of the distance of the upstream tapping from the **upstream** face of the plate and the pipe diameter;

$L'_2 = l'_2/D$ is the quotient of the distance of the downstream tapping from the **downstream** face of the plate, and the pipe diameter. (L'_2 denotes the reference of the downstream spacing from the **downstream** face, while L_2 would denote the reference of the downstream spacing from the **upstream** face.)

NOTE 6 When $L_1 \geqslant 0{,}039\,0/0{,}090\,0$ $(= 0{,}433\,3)$, take 0,039 0 as the value of the coefficient of $\beta^4(1-\beta^4)^{-1}$.

The values of L_1 and L'_2 to be used in this equation, when the spacings are in accordance with the requirements of 8.2.1.2, 8.2.1.3 or 8.2.2, are as follows:

— for corner tappings:

$$L_1 = L'_2 = 0$$

— for D and $D/2$ tappings:

$$L_1 = 1$$

$$L'_2 = 0{,}47$$

[since L_1 is always greater than or equal to 0,433 3, the value 0,039 0 shall be used for the coefficient of $\beta^4(1-\beta^4)^{-1}$]

— for flange tappings:

$$L_1 = L'_2 = \frac{25{,}4}{D}$$

where D is expressed in millimetres.

In pipelines with $D \leqslant 58{,}62$ mm, $L_1 \geqslant 0{,}433\,3$ and the value 0,039 0 will be used for the coefficient of $\beta^4(1-\beta^4)^{-1}$.

The Stolz equation is only valid for the tapping arrangements defined in 8.2.1 or 8.2.2. In particular, it is not permitted to enter into the equation pairs of values of L_1 and L'_2 which do not match one of the three standardized tapping arrangements.

This formula, as well as the uncertainties given in 8.3.3, is only valid when the measurement meets all the limits of use specified in 8.3.1 and the general installation requirements specified in clause 7.

Values of C as a function of β, Re_D and D are given for convenience in tables A.1 to A.11. These values are not intended for precise interpolation. Extrapolation is not permitted.

8.3.2.2 Expansibility [expansion] factor, ε_1

For the three types of tapping arrangement, the empirical formula for computing the expansibility [expansion] factor, ε_1, is as follows:

$$\varepsilon_1 = 1 - \left(0{,}41 + 0{,}35\beta^4\right)\frac{\Delta p}{\kappa p_1}$$

This formula is applicable only within the range of the limits of use specified in 8.3.1.

Test results for the determination of ε_1 are only known for air, steam and natural gas. However, there is no known objection to using the same formula for other gases and vapours the isentropic exponent of which is known.

Meanwhile, the formula is applicable only if $p_2/p_1 \geqslant 0{,}75$.

Values of the expansibility [expansion] factor as a function of the isentropic exponent, the pressure ratio and the diameter ratio are given for convenience in table A.14. These values are not intended for precise interpolation. Extrapolation is not permitted.

Note that

$$\varepsilon_2 = \varepsilon_1 \sqrt{1 + \frac{\Delta p}{p_2}}$$

8.3.3 Uncertainties

8.3.3.1 Uncertainty of discharge coefficient C

For all three types of tappings, when β, D, Re_D and k/D are assumed to be known without error, the relative uncertainty of the value of C is equal to

0,6 % for $\beta \leqslant 0,6$

β % for $0,6 < \beta \leqslant 0,75$

8.3.3.2 Uncertainty of expansibility [expansion] factor ε_1

When β, $\Delta p/p_1$ and κ are assumed to be known without error, the relative uncertainty, in per cent, of the value of ε_1 is equal to

$$4 \frac{\Delta p}{p_1}$$

8.4 Pressure loss, $\Delta\varpi$

8.4.1 The pressure loss, $\Delta\varpi$, for the orifice plates described in this part of ISO 5167 is approximately related to the differential pressure Δp by the equation

$$\Delta\varpi = \frac{\sqrt{1-\beta^4} - C\beta^2}{\sqrt{1-\beta^4} + C\beta^2} \Delta p$$

This pressure loss is the difference in static pressure between the pressure measured at the wall on the upstream side of the primary device at a section where the influence of the approach impact pressure adjacent to the plate is still negligible (approximately D upstream of the primary device) and that measured on the downstream side of the primary device where the static pressure recovery by expansion of the jet may be considered as just completed (approximately $6D$ downstream of the primary device).

8.4.2 For orifice plates, another approximate value of $\Delta\varpi/\Delta p$ is

$$\frac{\Delta\varpi}{\Delta p} = 1 - \beta^{1,9}$$

9 Nozzles

There are two types of standard nozzle,

— the ISA 1932 nozzle, and

— the long radius nozzle,

which are different and are described separately.

Limits of use are given in 9.1.6.1 and 9.2.6.1.

9.1 ISA 1932 nozzle

Figure 7 shows the cross-section of an ISA 1932 nozzle at a plane passing through the centre-line of the throat.

The letters in the following text refer to those shown on figure 7.

9.1.1 General shape

The part of the nozzle inside the pipe is circular. The nozzle consists of a convergent section, of rounded profile, and a cylindrical throat.

9.1.2 Nozzle profile

9.1.2.1 The profile of the nozzle may be characterized by distinguishing

— a flat inlet part A, perpendicular to the centre-line,

— a convergent section defined by two arcs of circumference B and C,

— a cylindrical throat E, and

— a recess F which is required only if damage to the edge f is feared.

9.1.2.2 The flat inlet part A is limited by a circumference centred on the axis of revolution, with a diameter of $1,5d$, and by the inside circumference of the pipe, of diameter D.

When $d = 2D/3$, the radial width of this flat part is zero.

When d is greater than $2D/3$, the upstream face of the nozzle does not include a flat inlet part within the pipe. In this case, the nozzle is manufactured as if D is greater than $1,5d$ and the inlet flat part is then faced off so that the largest diameter of the convergent profile is just equal to D [see 9.1.2.7 and figure 7b)].

9.1.2.3 The arc of circumference B is tangential to the flat inlet part A when $d < 2D/3$ while its radius R_1 is equal to $0,2d \pm 10$ % for $\beta < 0,5$ and to $0,2d \pm 3$ % for $\beta \geqslant 0,5$. Its centre is at $0,2d$ from the inlet plane and at $0,75d$ from the axial centre-line.

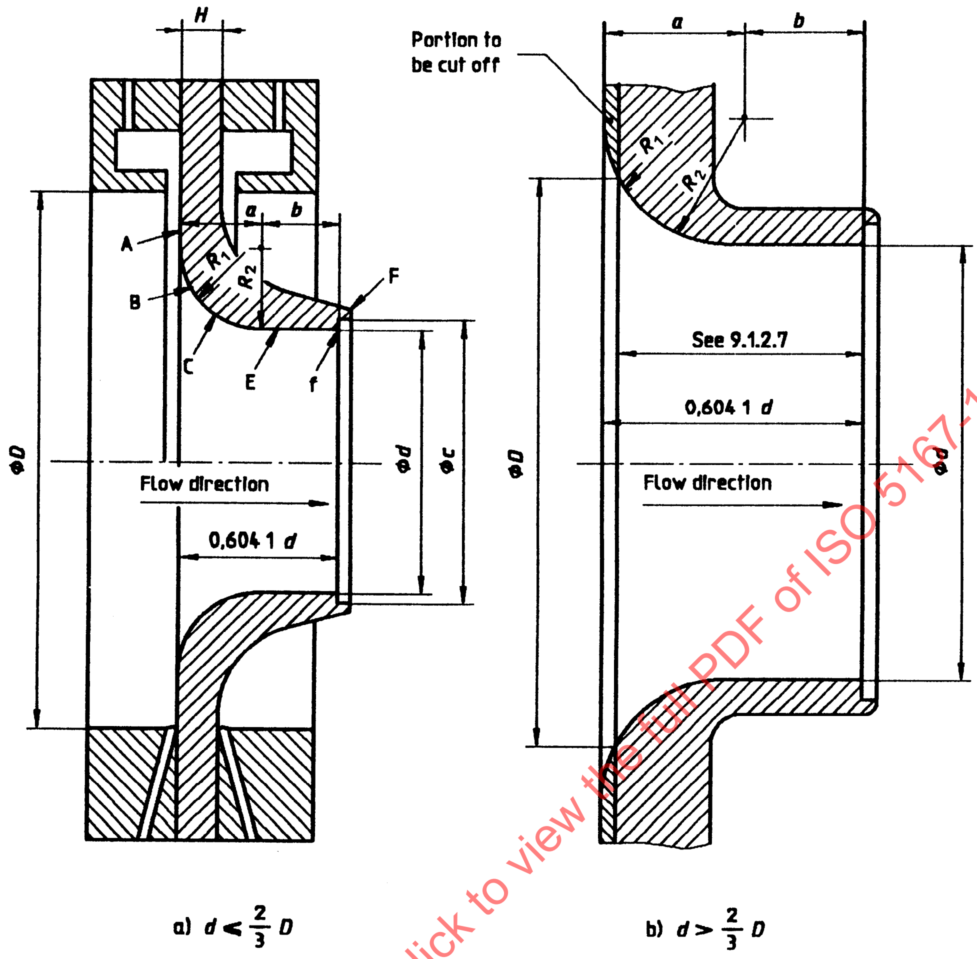


Figure 7 — ISA 1932 nozzle

9.1.2.4 The arc of circumference C is tangential to the arc of circumference B and to the throat E. Its radius R_2 is equal to $d/3 \pm 10$ % for $\beta < 0,5$ and to $d/3 \pm 3$ % for $\beta \geqslant 0,5$. Its centre is at $d/2 + d/3 = 5d/6$ from the axial centre-line and at

$$a = \frac{12 + \sqrt{39}}{60} d = 0,304\,1d$$

from the flat inlet part A.

9.1.2.5 The throat E has a diameter d and a length $b = 0,3d$.

The value d of the diameter of the throat shall be taken as the mean of the measurements of at least four diameters distributed in axial planes and at approximately equal angles to each other.

The throat shall be cylindrical. No diameter of any cross-section shall differ by more than 0,05 % from the value of the mean diameter. This requirement is considered to be satisfied when the deviations in the length of any of the measured diameters comply with the said requirement in respect of deviation from the mean.

9.1.2.6 The recess F has a diameter c equal to at least $1,06d$ and a length less than or equal to $0,03d$. The ratio of the height $(c - d)/2$ of the recess to its axial length shall not be greater than 1,2.

The outlet edge f shall be sharp.

9.1.2.7 The total length of the nozzle, excluding the recess F, is $0,604\,1d$ when d is less than or equal to $2D/3$ and is shorter, due to the inlet profile, if d is greater than $2D/3$.

The total length of the nozzle, excluding the recess, as a function of β is equal to

$$0{,}604\ 1d \quad \text{for} \quad 0{,}3 \leqslant \beta \leqslant \frac{2}{3}$$

and

$$\left[0{,}404\ 1 + \left(\frac{0{,}75}{\beta} - \frac{0{,}25}{\beta^2} - 0{,}522\ 5\right)^{1/2}\right]d$$

for $\frac{2}{3} < \beta \leqslant 0{,}8$

9.1.2.8 The profile of the convergent inlet shall be checked by means of a template.

Two diameters of the convergent inlet in the same plane perpendicular to the axial centre-line shall not differ from each other by more than 0,1 % of their mean value.

9.1.2.9 The surface of the upstream face and the throat shall be polished such that they have a roughness criterion $R_a \leqslant 10^{-4}d$.

9.1.3 Downstream face

9.1.3.1 The thickness H shall not exceed $0{,}1D$.

9.1.3.2 Apart from the above condition, the profile and the surface finish of the downstream face are not specified (see 9.1.1).

9.1.4 Material and manufacture

The requirements given in 8.1.9 apply equally to the manufacture of the ISA 1932 nozzle.

9.1.5 Pressure tappings

9.1.5.1 Corner pressure tappings shall be used upstream of the nozzle.

9.1.5.2 The upstream corner tappings shall comply with the requirements in 8.2.2.

9.1.5.3 The downstream pressure tappings may or may not be corner tappings, but in all cases the distance between the centre of the tapping and the upstream face of the nozzle shall be

$\leqslant 0{,}15D$ for $\beta \leqslant 0{,}67$

$\leqslant 0{,}2D$ for $\beta > 0{,}67$

9.1.5.4 The diameter of the downstream tappings shall be in accordance with 8.2.1.7. Corner tappings as described in 8.2.2 may also be used.

9.1.6 Coefficients of ISA 1932 nozzles

9.1.6.1 Limits of use

This type of nozzle shall only be used in accordance with this part of ISO 5167 when

$50\ \text{mm} \leqslant D \leqslant 500\ \text{mm}$

$0{,}3 \leqslant \beta \leqslant 0{,}8$

and when Re_D is within the following limits:

for $0{,}30 \leqslant \beta < 0{,}44$ $\quad 7 \times 10^4 \leqslant Re_D \leqslant 10^7$

for $0{,}44 \leqslant \beta \leqslant 0{,}80$ $\quad 2 \times 10^4 \leqslant Re_D \leqslant 10^7$

In addition, the relative roughness of the pipe shall conform with the values given in table 4.

Most of the experiments on which the values of the discharge coefficient C given in this part of ISO 5167 are based were carried out in pipes with a relative roughness $k/D \leqslant 3{,}8 \times 10^{-4}$. Pipes with higher relative roughness may be used if the roughness for a distance of at least $10D$ upstream of the nozzle is within the limits given in table 4 (see 8.3.1 for the estimation of k/D).

9.1.6.2 Discharge coefficient, C

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

$$C = 0{,}990\ 0 - 0{,}226\ 2\beta^{4{,}1} - \\ - (0{,}001\ 75\beta^2 - 0{,}003\ 3\beta^{4{,}15})\left(\frac{10^6}{Re_D}\right)^{1{,}15}$$

Values of C as a function of β and Re_D are given for convenience in table A.12. These values are not intended for precise interpolation. Extrapolation is not permitted.

Table 4 — Upper limits of relative roughness of the upstream pipe for ISA 1932 nozzles

β	$\leqslant 0{,}35$	0,36	0,38	0,40	0,42	0,44	0,46	0,48	0,50	0,60	0,70	0,77	0,80
$10^4\ k/D$	25	18,6	13,5	10,6	8,7	7,5	6,7	6,1	5,6	4,5	4,0	3,9	3,9

9.1.6.3 Expansibility [expansion] factor, ε_1

The expansibility [expansion] factor, ε_1, is calculated by means of the following formula:

$$\varepsilon_1 = \left[\left(\frac{\kappa\tau^{2/\kappa}}{\kappa-1}\right)\left(\frac{1-\beta^4}{1-\beta^4\tau^{2/\kappa}}\right)\times\left(\frac{1-\tau^{(\kappa-1)/\kappa}}{1-\tau}\right)\right]^{1/2}$$

This formula is applicable only for values of β, D and Re_D as specified in 9.1.6.1. Test results for determination of ε_1 are only known for air, steam and natural gas. However, there is no known objection to using the same formula for other gases and vapours for which the isentropic exponent is known.

However, the formula is applicable only if $p_2/p_1 \geqslant 0{,}75$.

Values of the expansibility [expansion] factor for a range of isentropic exponents, pressure ratios and diameter ratios are given for convenience in table A.15. These values are not intended for precise interpolation. Extrapolation is not permitted.

Note that

$$\varepsilon_2 = \varepsilon_1\sqrt{1+\frac{\Delta p}{p_2}}$$

9.1.7 Uncertainties

9.1.7.1 Uncertainty of discharge coefficient C

When β, D, Re_D and k/D are assumed to be known without error, the relative uncertainty of the value of C is equal to

0,8 % for $\beta \leqslant 0{,}6$

$(2\beta - 0{,}4)$ % for $\beta > 0{,}6$

9.1.7.2 Uncertainty of expansibility [expansion] factor ε_1

The relative uncertainty, in per cent, of ε_1 is equal to

$$2\frac{\Delta p}{p_1}$$

9.1.8 Pressure loss, $\Delta\varpi$

Subclause 8.4.1 applies equally to the pressure loss of ISA 1932 nozzles (but 8.4.2 does not apply).

9.2 Long radius nozzles

9.2.1 General

There are two types of long radius nozzle, which are called

— high-ratio nozzles ($0{,}25 \leqslant \beta \leqslant 0{,}8$), and

— low-ratio nozzles ($0{,}20 \leqslant \beta \leqslant 0{,}5$).

For β values between 0,25 and 0,5, either design may be used.

Figure 8 illustrates the geometric shapes of long radius nozzles, showing cross-sections passing through the throat centre-lines.

The reference letters used in the text refer to those shown on figure 8.

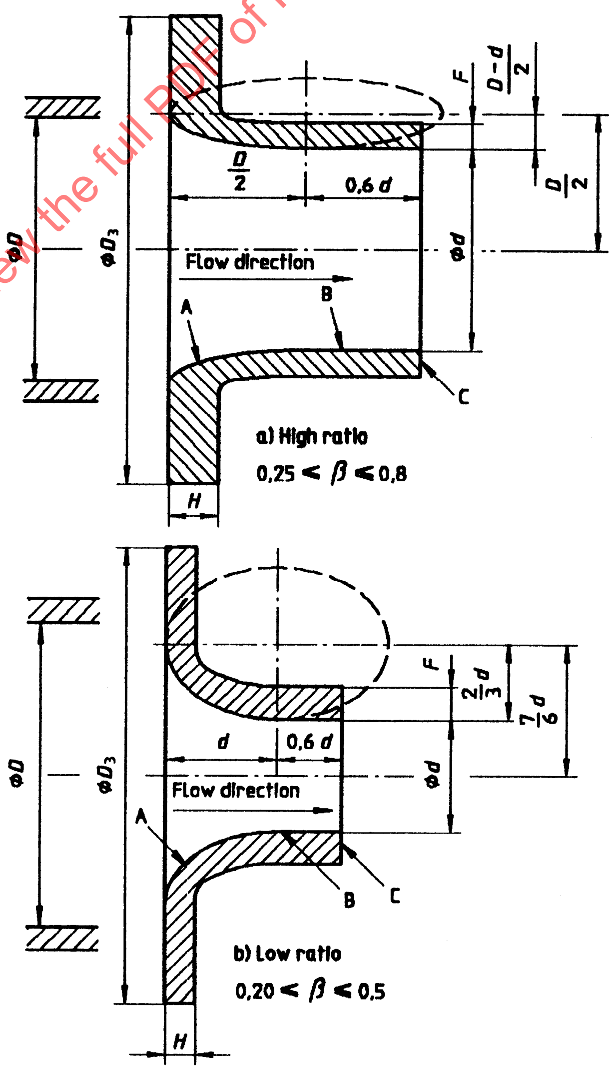


Figure 8 — Long radius nozzles

Both types of nozzle consist of a convergent inlet, whose shape is a quarter ellipse, and a cylindrical throat.

That part of the nozzle which is inside the pipe shall be circular, with the possible exception of the holes of the pressure tappings.

9.2.2 Profile of high-ratio nozzle

9.2.2.1 The inner face can be characterized by

— a convergent section A,

— a cylindrical throat B, and

— a plain end C.

9.2.2.2 The convergent section A has the shape of a quarter ellipse.

The centre of the ellipse is at a distance $D/2$ from the axial centre-line. The major centre-line of the ellipse is parallel to the axial centre-line. The value of half the major axis is $D/2$. The value of half the minor axis is $(D-d)/2$.

The profile of the convergent section shall be checked by means of a template. Two diameters of the convergent section in the same plane perpendicular to the centre-line shall not differ from each other by more than 0,1 % of their mean value.

9.2.2.3 The throat B has a diameter d and a length $0{,}6d$.

The value d of the diameter of the throat shall be taken as the mean of the measurements of at least four diameters distributed in axial planes and at approximately equal angles to each other.

The throat shall be cylindrical. Any diameter of any cross-section shall not differ by more than 0,05 % from the value of the mean diameter. Measurement at a sufficient number of cross-sections shall be made to determine that under no circumstances is the throat divergent in the direction of flow; within the stated uncertainty limits it may be slightly convergent. The section nearest the outlet is particularly important in this respect. This requirement is considered to be satisfied when the deviations in the length of any of the measured diameters comply with the said requirement in respect of its deviation from the mean.

9.2.2.4 The distance between the pipe wall and the outside face of the throat shall be greater than or equal to 3 mm.

9.2.2.5 The thickness H shall be greater than or equal to 3 mm and less than or equal to $0{,}15D$. The thickness F of the throat shall be between 3 mm and 13 mm.

9.2.2.6 The surface of the inner face shall have a roughness criterion $R_a \leqslant 10^{-4}d$.

9.2.2.7 The shape of the downstream (outside) face is not specified but shall comply with 9.2.2.4 and 9.2.2.5 and the last sentence of 9.2.1.

9.2.3 Profile of low-ratio nozzle

9.2.3.1 The requirements given in 9.2.2 for the high-ratio nozzle apply also to the low-ratio nozzle with the exception of the shape of the ellipse itself which is given in 9.2.3.2.

9.2.3.2 The convergent inlet A has the shape of a quarter ellipse. The centre of the ellipse is at a distance $d/2 + 2d/3 = 7d/6$ from the axial centre-line. The major axis of the ellipse is parallel to the axial centre-line. The value of half the major axis is d. The value of half the minor axis is $2d/3$.

9.2.4 Material and manufacture

The requirements given in 8.1.9 apply to the manufacture of long radius nozzles.

9.2.5 Pressure tappings

9.2.5.1 The pressure tappings shall comply with the description given in 8.2.1.

9.2.5.2 The centre-line of the upstream tapping shall be at $1D\,^{+0{,}2D}_{-0{,}1D}$ from the inlet face of the nozzle.

The centre-line of the downstream tapping shall be at $0{,}50D \pm 0{,}01D$ from the inlet face of the nozzle with the condition that it shall not in any case be further downstream than the nozzle outlet.

9.2.5.3 The upstream and downstream pressure tappings break through the inside wall of the pipe.

9.2.6 Coefficients of long radius nozzles

9.2.6.1 Limits of use

The long radius nozzles shall only be used in accordance with this part of ISO 5167 when

$50 \text{ mm} \leqslant D \leqslant 630 \text{ mm}$

$0{,}2 \leqslant \beta \leqslant 0{,}8$

$10^4 \leqslant Re_D \leqslant 10^7$

$k/D \leqslant 10 \times 10^{-4}$

9.2.6.2 Discharge coefficient, C

The discharge coefficients, C, are the same for both types of long radius nozzle when the tappings are in accordance with 9.2.5.

The discharge coefficient, C, is given by the following formula, when referring to the upstream pipe Reynolds number Re_D:

$$C = 0{,}996\,5 - 0{,}006\,53\beta^{0,5}\left(\frac{10^6}{Re_D}\right)^{0,5}$$

When referring to the Reynolds number at the throat Re_d, this formula becomes

$$C = 0{,}996\,5 - 0{,}006\,53\left(\frac{10^6}{Re_d}\right)^{0,5}$$

and, in this case, C is independent of the diameter ratio β.

Values of C as a function of β and Re_D are given for convenience in table A.13. These values are not intended for precise interpolation. Extrapolation is not permitted.

9.2.6.3 Expansibility [expansion] factor, ε_1

The indications given in 9.1.6.3 apply also to the expansibility [expansion] factor for long radius nozzles, but within the limits of use specified in 9.2.6.1.

9.2.7 Uncertainties

9.2.7.1 Uncertainty of discharge coefficient C

When β and Re_d are assumed to be known without error, the relative uncertainty of the value of C is 2,0 % for all values of β between 0,2 and 0,8.

9.2.7.2 Uncertainty of expansibility [expansion] factor ε_1

The relative uncertainty, in per cent, on ε_1 is equal to

$$2\frac{\Delta p}{p_1}$$

9.2.8 Pressure loss, $\Delta\varpi$

Subclause 8.4.1 applies equally to the pressure loss of long radius nozzles (but 8.4.2 does not apply).

10 Venturi tubes

There are two different types of standard Venturi tube,

— the classical Venturi tube, and

— the Venturi nozzle.

They are described in 10.1 and 10.2.

Limits of use are given in 10.1.5.1 and 10.2.4.1.

10.1 Classical Venturi tubes

10.1.1 Field of application

The field of application of the classical Venturi tubes dealt with in this part of ISO 5167 depends on the way in which they are manufactured.

Three types of standard classical Venturi tube are defined according to the method of manufacture of the internal surface of the entrance cone and the profile at the intersection of the entrance cone and the throat. These three methods of manufacture are described in 10.1.1.1 to 10.1.1.3 and have somewhat different characteristics.

10.1.1.1 Classical Venturi tube with an "as cast" convergent section

This is a classical Venturi tube made by casting in a sand mould or by other methods which leave a finish on the surface of the convergent section similar to that produced by sand casting. The throat is machined and the junctions between the cylinders and cones are rounded.

These classical Venturi tubes can be used in pipes of diameter between 100 mm and 800 mm and having diameter ratios β between 0,3 and 0,75 inclusive.

10.1.1.2 Classical Venturi tube with a machined convergent section

This is a classical Venturi tube cast or fabricated as in 10.1.1.1 but in which the convergent section is machined as are the throat and the entrance cylinder. The junctions between the cylinders and cones may or may not be rounded.

These classical Venturi tubes can be used in pipes of diameter between 50 mm and 250 mm and having diameter ratios β between 0,4 and 0,75 inclusive.

10.1.1.3 Classical Venturi tube with a rough-welded sheet-iron convergent section

This is a classical Venturi tube normally fabricated by welding. For the larger sizes it is not machined in any way, but in the smaller sizes the throat is machined.

These classical Venturi tubes can be used in pipes of diameter between 200 mm and 1 200 mm and having diameter ratios β between 0,4 and 0,7 inclusive.

10.1.2 General shape

Figure 9 shows a section through the centre-line of the throat of a classical Venturi tube. The letters used in the text refer to those shown on figure 9.

The classical Venturi tube is made up of an entrance cylinder A connected to a conical convergent section B, a cylindrical throat C and a conical divergent section E. The internal surface of the device is cylindrical and concentric with the pipe centre-line. The coaxiality of the convergent section and the cylindrical throat is assessed by visual inspection.

10.1.2.1 The entrance cylinder A shall have a diameter D which shall not differ from the pipe inside diameter by more than $0{,}01D$.

The minimum cylinder length, measured from the plane containing the intersection of the cone frustum B with the cylinder A, may vary as a result of the manufacturing process (see 10.1.2.7 to 10.1.2.9). It is, however, recommended that it be chosen to be equal to D.

The entrance cylinder diameter D shall be measured in the plane of the upstream pressure tappings. The number of measurements shall be at least equal to the number of pressure tappings (with a minimum of four).

The diameters shall be measured near each pair of pressure tappings, and also between these pairs. The arithmetic mean value of these measurements shall be taken as the value of D in the calculations.

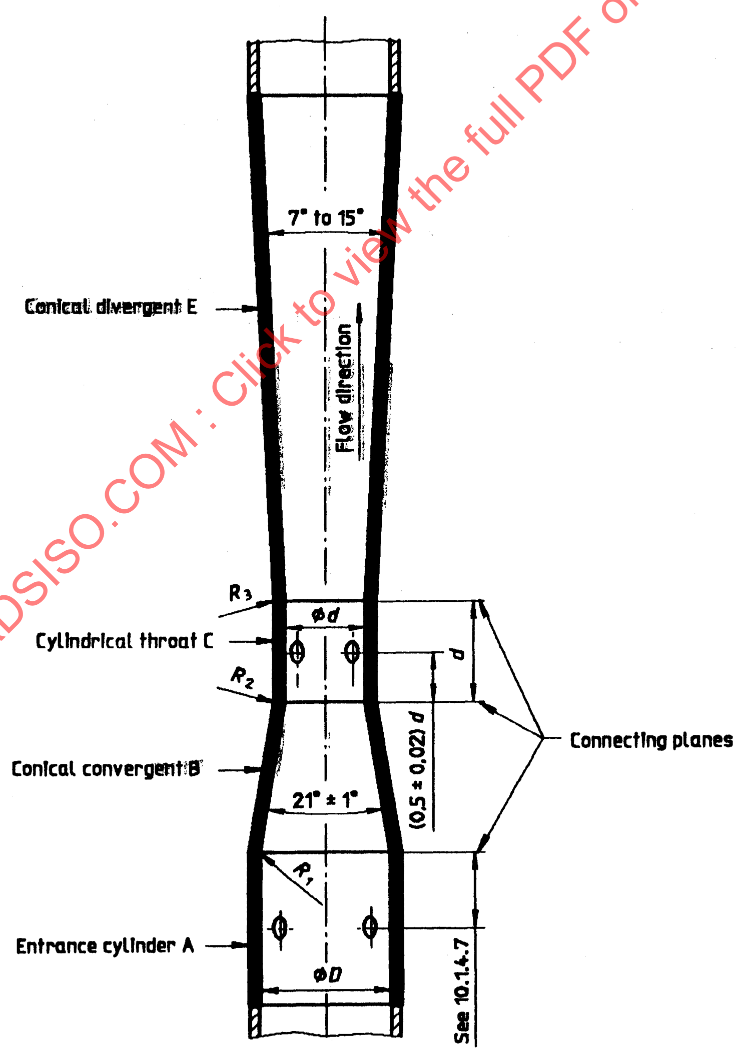


Figure 9 — Geometric profile of the classical Venturi tube

Diameters shall also be measured in planes other than the plane of the pressure tappings.

No diameter along the entrance cylinder shall differ by more than 0,4 % from the value of the mean diameter. This requirement is satisfied when the difference in the length of any of the measured diameters complies with the said requirement in respect of the mean of the measured diameters.

10.1.2.2 The convergent section B shall be conical and shall have an included angle of 21° ± 1° for all types of classical Venturi tube. It is limited upstream by the plane containing the intersection of the cone frustum B with the entrance cylinder A (or their prolongations) and downstream by the plane containing the intersection of the cone frustum B with the throat C (or their prolongations).

The overall length of the convergent B measured parallel to the centre-line of the Venturi tube is therefore approximately equal to 2,7$(D-d)$.

The convergent section B is blended to the entrance cylinder A by a curvature of radius R_1, the value of which depends on the type of classical Venturi tube.

The profile of the convergent section shall be checked by means of a template. The deviation between the template and the conical section of the convergent section shall not exceed, in any place, 0,4 % of D.

The internal surface of the conical section of the convergent section is taken as being a surface of revolution then two diameters situated in the same plane perpendicular to the axis of revolution do not differ from the value of the mean diameter by more than 0,4 %.

It shall be checked in the same way that the joining curvature with a radius R_1 is a surface of revolution.

10.1.2.3 The throat C shall be cylindrical with a diameter d. It is limited upstream by the plane containing the intersection of the cone frustum B with the throat C (or their prolongations) and downstream by the plane containing the intersection of the throat C with the cone frustum E (or their prolongations). The length of the throat C, i.e. the distance between those two planes, shall be equal to d whatever the type of classical Venturi tube.

The throat C is connected to the convergent section B by a curvature of radius R_2 and to the divergent section E by a curvature of radius R_3. The values of R_2 and R_3 depend on the type of classical Venturi tube.

The diameter d shall be measured very carefully in the plane of the throat pressure tappings. The number of measurements shall be at least equal to the number of pressure tappings (with a minimum of four). The diameters shall be measured near each pair of pressure tappings and also between these pairs. The arithmetic mean value of all these measurements shall be taken as the value of d in the calculations.

Diameters shall also be measured in planes other than the plane of the pressure tappings.

No diameter along the throat shall differ by more than 0,1 % of the value of the mean diameter. This requirement is satisfied when the difference in the length of any of the measured diameters complies with the said requirement in respect of the mean of the measured diameters.

The throat of the classical Venturi tube shall be machined or be of equivalent smoothness over the whole of its length to the surface roughness specified in 10.1.2.6.

It shall be checked that the joining curvatures into the throat with radii R_2 and R_3 are surfaces of revolution as described in 10.1.2.2. This requirement is satisfied when two diameters, situated in the same plane perpendicular to the axis of revolution, do not differ from the value of the mean diameter by more than 0,1 %.

The values of the radii of curvature R_2 and R_3 shall be checked by means of a template.

The deviation between the template and the classical Venturi tube shall evolve in a regular way for each curvature so that the single maximum deviation that is measured occurs at approximately mid-way along the template profile. The value of this maximum deviation shall not exceed 0,02d.

10.1.2.4 The divergent section E shall be conical and may have an included angle of between 7° and 15°; it is, however, recommended that an angle between 7° and 8° be chosen. Its smallest diameter shall not be less than the throat diameter.

10.1.2.5 A classical Venturi tube is called "truncated" when the outlet diameter of the divergent section is less than the diameter D and "not truncated" when the outlet diameter is equal to diameter D. The divergent portion may be truncated by about 35 % of its length without notably modifying the pressure loss of the device.

10.1.2.6 The roughness criterion R_a of the throat and that of the adjacent curvature shall be as small as possible and shall always be less than $10^{-5}d$ (see 6.1.2). The divergent section is roughcast. Its internal surface shall be clean and smooth. The roughness of other parts of the classical Venturi tube depends on the type considered.

10.1.2.7 The profile of the classical Venturi tube with an "as cast" convergent section has the following characteristics.

The internal surface of the convergent section B is sand cast and unmachined. It shall be free from cracks, fissures, depressions, irregularities and impurities. The roughness criterion R_a for the surface shall be less than $10^{-4}D$.

The minimum length of the entrance cylinder A shall be equal to the smaller of the following two values: D and $0{,}25D + 250$ mm (see 10.1.2.1).

The internal surface of the entrance cylinder A may be left "as cast" provided that it has the same surface finish as the convergent section B.

The radius of curvature R_1 shall be equal to $1{,}375D \pm 20$ %.

The radius of curvature R_2 shall be equal to $3{,}625d \pm 0{,}125d$.

The length of the cylindrical part of the throat shall be not less than $d/3$. In addition, the length of the cylindrical part between the end of the joining curvature R_2 and the plane of the pressure tappings, as well as the length of the cylindrical part between the plane of the throat pressure tappings and the beginning of the joining curvature R_3, shall be not less than $d/6$ (see also 10.1.2.3 for the throat length).

The radius of curvature R_3 shall lie between $5d$ and $15d$. Its value shall increase as the divergent angle decreases. A value close to $10d$ is recommended.

10.1.2.8 The profile of the classical Venturi tube with a machined convergent section has the following characteristics.

The minimum length of the entrance cylinder A shall be equal to D.

The radius of curvature R_1 shall be less than $0{,}25D$ and preferably equal to zero.

The radius of curvature R_2 shall be less than $0{,}25d$ and preferably equal to zero.

The length of the throat cylindrical part between the end of the curvature R_2 and the plane of the throat pressure tappings shall be not less than $0{,}25d$.

The length of the throat cylindrical part between the plane of the throat pressure tappings and the beginning of the joining curvature R_3 shall be not less than $0{,}3d$.

The radius of curvature R_3 shall be less than $0{,}25d$ and preferably equal to zero.

The entrance cylinder and the convergent section shall have a surface finish equal to that of the throat (see 10.1.2.6).

10.1.2.9 The profile of the classical Venturi tube with a rough-welded sheet-iron convergent section has the following characteristics.

The minimum length of the entrance cylinder A shall be equal to D.

There shall be no joining curvature between the entrance cylinder A and the convergent section B other than that resulting from welding.

There shall be no joining curvature between the convergent section B and the throat C other than that resulting from welding.

There shall be no joining curvature between the throat C and the divergent section E.

The internal surface of the entrance cylinder A and the convergent section B shall be clean and free from encrustation and welding deposits. It may be galvanized. Its roughness criterion R_a shall be about $5 \times 10^{-4}D$.

The internal welded seams shall be flush with the surrounding surfaces. They shall not be located in the vicinity of the pressure tappings.

10.1.3 Material and manufacture

10.1.3.1 The classical Venturi tube may be manufactured from any material, provided that it is in accordance with the foregoing description and will remain so during use.

10.1.3.2 It is also recommended that the convergent section B and the throat C be joined as one part. It is recommended that in the case of a classical Venturi tube with a machined convergent, the throat and the convergent section be manufactured from one piece of material. If, however, they are made in two separate parts they shall be assembled before the internal surface is finally machined.

10.1.3.3 Particular care shall be given to the centring of the divergent section E on the throat. There shall be no step in diameters between the two parts.

This can be established by touch before the classical Venturi tube is installed, but after the divergent section has been assembled with the throat section.

10.1.3.4 When a lining is added in the throat, it shall be machined after being assembled.

10.1.4 Pressure tappings

10.1.4.1 The upstream and throat pressure tappings shall be made in the form of separate pipe wall pressure tappings interconnected by annular chambers or piezometer rings.

10.1.4.2 The diameter of these tappings shall be between 4 mm and 10 mm and moreover shall never be greater than $0{,}1D$ for the upstream tappings and $0{,}13d$ for the throat pressure tappings.

It is recommended that pressure tappings as small as compatible with the fluid be used (for example, with its viscosity and cleanness).

10.1.4.3 At least four pressure tappings shall be provided for the upstream and throat pressure measurements. The centre-lines of the pressure tappings shall meet the centre-line of the classical Venturi tube, shall form equal angles with each other and shall be contained in planes perpendicular to the centre-line of the classical Venturi tube.

10.1.4.4 At the point of break-through, the hole of the pressure tapping shall be circular. The edges shall be flush with the pipe wall, free from burrs and generally have no peculiarities. If joining curvatures are required the radius shall not exceed one-tenth of the diameter of the pressure tapping.

10.1.4.5 The pressure tappings shall be cylindrical over a length at least 2,5 times the internal diameter of the tapping, measured from the inner wall of the pipeline.

10.1.4.6 Conformity of the pressure tappings with the two foregoing requirements is assessed by visual inspection.

10.1.4.7 The spacing of a pressure tapping is the distance, measured on a straight line parallel to the centre-line of the classical Venturi tube, between the centre-line of the pressure tapping and the reference planes defined below.

For the classical Venturi tube with an "as cast" convergent section, the spacing between the upstream pressure tappings situated on the entrance cylinder and the plane of intersection between the entrance cylinder A and the prolongation of convergent section B shall be

$0{,}5D \pm 0{,}25D$ for D between 100 mm and 150 mm

and

$0{,}5D\,_{-0{,}25D}^{\;\;0}$ for D between 150 mm and 800 mm.

For classical Venturi tubes with a machined convergent section and with a rough-welded sheet-iron convergent, the spacing between the upstream pressure tappings and the plane of intersection between the entrance cylinder A and the convergent section B (or their prolongations) shall be

$0{,}5D \pm 0{,}05D$

For all types of classical Venturi tube, the spacing between the plane containing the axes of the points of break-through of the throat pressure tappings and the intersection plane of the convergent section B and the throat C (or their prolongations) shall be

$0{,}5d \pm 0{,}02d$

10.1.4.8 The area of the free cross-section of the annular chamber of the pressure tappings shall be greater than or equal to half the total area of the tapping holes connecting the chamber to the pipe.

It is recommended, however, that the chamber section mentioned above shall be doubled when the classical Venturi tube is used with a minimum upstream straight length from a fitting causing non-symmetrical flow.

10.1.5 Discharge coefficient, C

10.1.5.1 Limits of use

Whatever the type of classical Venturi tube, a simultaneous use of extreme values for D, β and Re_D shall be avoided as otherwise the uncertainties given in 10.1.7 are likely to be increased.

The effects of Re_D, k/D and β on C are not yet sufficiently known for it to be possible to give reliable values of C outside the limits defined for each type of classical Venturi tube. (See annex B.)

10.1.5.2 Discharge coefficient of the classical Venturi tube with an "as cast" convergent section

Classical Venturi tubes with an "as cast" convergent section can only be used in accordance with this part of ISO 5167 when

$100 \text{ mm} \leqslant D \leqslant 800 \text{ mm}$

$0{,}3 \leqslant \beta \leqslant 0{,}75$

$2 \times 10^5 \leqslant Re_D \leqslant 2 \times 10^6$

Under these conditions the value of the discharge coefficient C is

$C = 0{,}984$

10.1.5.3 Discharge coefficient of the classical Venturi tube with a machined convergent section

Classical Venturi tubes with a machined convergent section can only be used in accordance with this part of ISO 5167 when

$50 \text{ mm} \leqslant D \leqslant 250 \text{ mm}$

$0{,}4 \leqslant \beta \leqslant 0{,}75$

$2 \times 10^5 \leqslant Re_D \leqslant 1 \times 10^6$

Under these conditions the value of the discharge coefficient C is

$C = 0{,}995$

10.1.5.4 Discharge coefficient of the classical Venturi tube with a rough-welded sheet-iron convergent section

Classical Venturi tubes with a rough-welded sheet-iron convergent section can only be used in accordance with this part of ISO 5167 when

$200 \text{ mm} \leqslant D \leqslant 1\,200 \text{ mm}$

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

$2 \times 10^5 \leqslant Re_D \leqslant 2 \times 10^6$

Under these conditions the value of the discharge coefficient C is

$C = 0{,}985$

10.1.6 Expansibility [expansion] factor, ε_1

The indications given in 9.1.6.3 also apply to the expansibility [expansion] factor for the different types of classical Venturi tubes, but within the limits of use specified in 10.1.5.2, 10.1.5.3 or 10.1.5.4 as appropriate.

10.1.7 Uncertainty of the discharge coefficient C

10.1.7.1 Classical Venturi tube with an "as cast" convergent section

The relative uncertainty of the discharge coefficient as given in 10.1.5.2 is equal to 0,7 %[11].

10.1.7.2 Classical Venturi tube with a machined convergent section

The relative uncertainty of the discharge coefficient as given in 10.1.5.3 is equal to 1 %[11].

10.1.7.3 Classical Venturi tube with a rough-welded sheet-iron convergent section

The relative uncertainty of the discharge coefficient as given in 10.1.5.4 is equal to 1,5 %[11].

10.1.8 Uncertainty of the expansibility [expansion] factor ε_1

The relative uncertainty, in per cent, of ε_1 is equal to

$$(4 + 100\beta^8)\frac{\Delta p}{p_1}$$

10.1.9 Pressure loss

10.1.9.1 Definition of the pressure loss (see figure 10)

The pressure loss caused by a classical Venturi tube may be determined by pressure measurements made prior and subsequent to the installation of the Venturi tube in a pipe through which there is a given flow.

If $\Delta p'$ is the difference in pressure, measured prior to the installation of the Venturi tube, between two pressure tappings one of which is situated at least D upstream of the flanges where the Venturi tube will be inserted and the other of which is $6D$ downstream of the same flanges, and if $\Delta p''$ is the difference in pressure measured between the same pressure tappings after installation of the Venturi tube between these flanges, then the pressure loss caused by the Venturi tube is given by $\Delta p'' - \Delta p'$.

10.1.9.2 Relative pressure loss

The relative pressure loss, ξ, is the value of the pressure loss $\Delta p'' - \Delta p'$ related to the differential pressure Δp:

$$\xi = \frac{\Delta p'' - \Delta p'}{\Delta p}$$

It depends, in particular, on

— the diameter ratio (ξ decreases when β increases);

— the Reynolds number (ξ decreases when Re_D increases);

— the manufacturing characteristics of the Venturi tube: angle of the divergent, manufacturing of the convergent, surface finish of the different parts, etc. (ξ increases when φ and k/D increase);

11) The differences between the uncertainties show on the one hand the number of results available for each type of classical Venturi tube and on the other hand the more or less precise definition of the geometric profile.

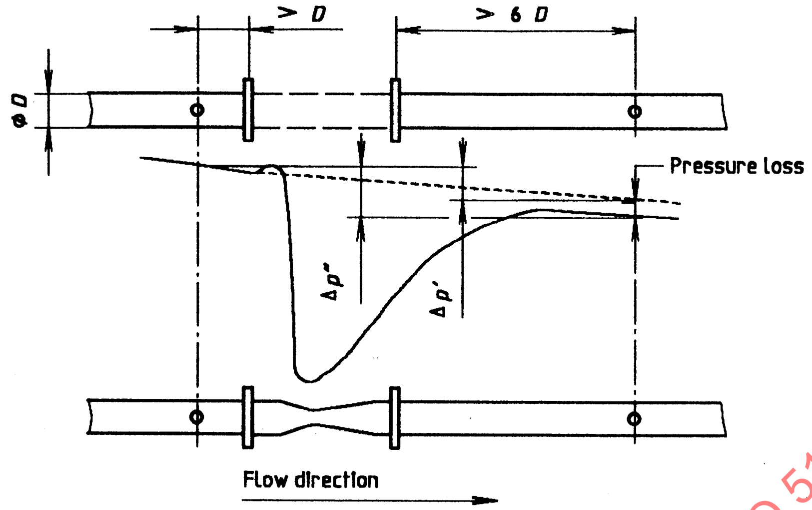


Figure 10 — Pressure loss across a classical Venturi tube

— the installation conditions (good alignment, roughness of the upstream conduit, etc.).

For guidance, the relative value of the pressure loss can be accepted as being generally between 5 % and 20 %.

Annex C gives, for guidance only, some information on the effect of these different factors on the values the pressure loss ξ is likely to have.

10.2 Venturi nozzle

10.2.1 General shape

10.2.1.1 The profile of the Venturi nozzle (see figure 11) is axisymmetric. It consists of a convergent section, with a rounded profile, a cylindrical throat and a divergent section.

10.2.1.2 The upstream face is identical with that of an ISA 1932 nozzle (see figure 7).

The descriptions in 9.1.2.2 to 9.1.2.4 apply equally to the Venturi nozzle.

10.2.1.3 The throat (see figure 11) consists of a part E of length 0,3d which is the same as for the ISA 1932 nozzle (see figure 7) and a part E′ of a length 0,4d to 0,45d.

The value d of the diameter of the throat shall be taken as the mean of measurements of at least four diameters distributed in axial planes and at approximately equal angles to each other.

The throat shall be cylindrical. No diameter of any cross-section shall differ by more than 0,05 % from the value of the mean diameter. This requirement is considered as satisfied when the deviations in the length of any of the measured diameters comply with the said requirement in respect of deviation from the mean.

10.2.1.4 The divergent section (see figure 11) shall be connected with the part E′ of the throat without a rounded part, but any burrs shall be removed.

The included angle of the divergent section, φ, shall be less than or equal to 30°.

The length L of the divergent section has practically no influence on the discharge coefficient C. However, the included angle of the divergent section, and hence the length, does influence the pressure loss.

10.2.1.5 The Venturi nozzle may be truncated in the same way as the classical Venturi tube (see 10.1.2.5).

10.2.1.6 The internal surfaces of the Venturi nozzle shall have a roughness criterion $R_a \leqslant 10^{-4}d$ (see 6.1.2).

10.2.2 Material and manufacture

10.2.2.1 The Venturi nozzle may be manufactured from any material provided that it is in accordance with the description in 10.2.1 and will remain so during use. In particular, the Venturi nozzle shall be clean when the flow measurements are made.

10.2.2.2 The Venturi nozzle is usually made of metal, and shall be erosion and corrosion proof against the fluid with which it is to be used.

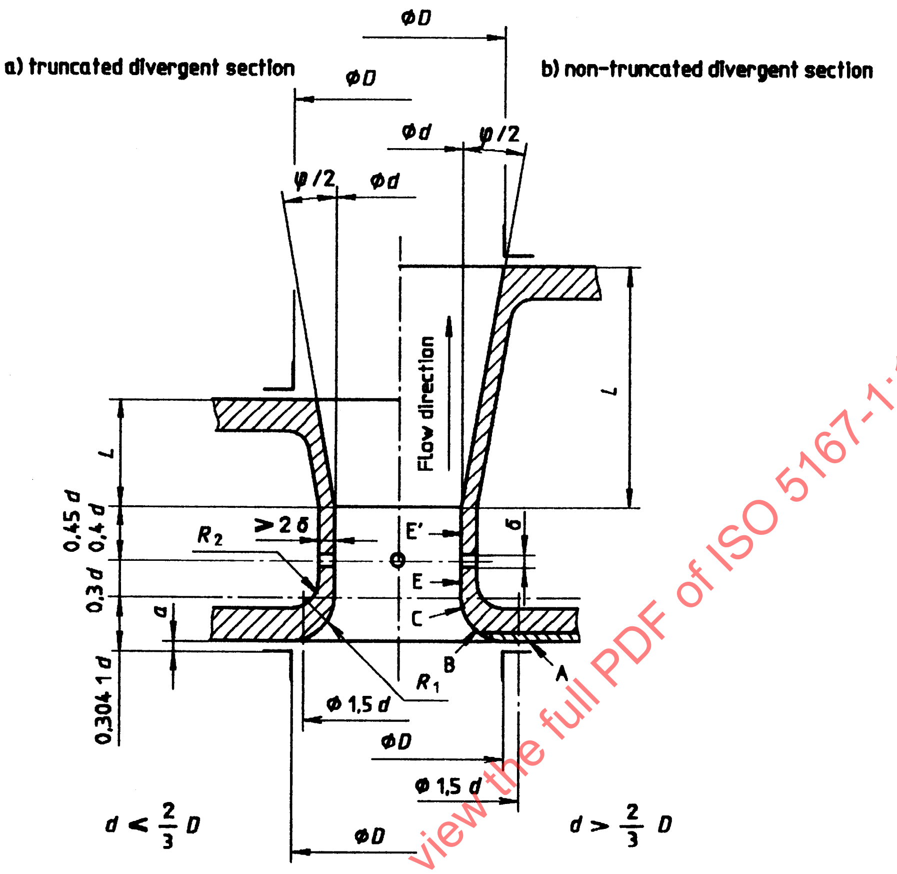


Figure 11 — Venturi nozzles

10.2.3 Pressure tappings

10.2.3.1 Angular position of pressure tappings

The centre-lines of the pressure tappings may be located in any axial sector of the pipe. Attention is drawn to the information given in 8.2.

10.2.3.2 Upstream pressure tappings

The upstream pressure tappings shall be corner tappings identical with those of an ISA 1932 nozzle, as defined in 8.2.2 (see also figures 11 and 12).

10.2.3.3 Throat pressure tapping

The throat pressure tapping shall comprise at least four single pressure tappings leading into an annular chamber or piezometer ring. Annular slots or interrupted slots shall not be used.

The centre-lines of the pressure tappings shall meet the centre-line of the Venturi nozzle, shall be at equal angles to each other, and shall lie in the plane perpendicular to the centre-line of the Venturi nozzle, which is the imaginary border between the parts E and E′ of the cylindrical throat.

The tappings shall always be large enough to ensure that clogging by dirt or gas bubbles is prevented.

The diameter δ_2 of the individual tappings in the throat of Venturi nozzles shall be less than or equal to 0,04d and moreover shall be between 2 mm and 10 mm.

10.2.4 Coefficients

10.2.4.1 Limits of use

Venturi nozzles shall only be used in accordance with this part of ISO 5167 when

$65 \text{ mm} \leqslant D \leqslant 500 \text{ mm}$

$d \geqslant 50 \text{ mm}$

$0{,}316 \leqslant \beta \leqslant 0{,}775$

$1{,}5 \times 10^5 \leqslant Re_D \leqslant 2 \times 10^6$

In addition, the roughness of the pipe shall conform with the values given in table 5.

Most of the experiments on which the values of the discharge coefficient C are based were carried out on pipes with a relative roughness $k/D \leqslant 3,8 \times 10^{-4}$. Pipes with higher relative roughness may be used if the roughness over a distance of at least $10D$ upstream of the primary device is within the limits of table 5 (see 8.3.1 for the estimation of k/D).

10.2.4.2 Discharge coefficient, C

The discharge coefficient, C, is given by the formula

$$C = 0,985\,8 - 0,196\beta^{4,5}$$

Values of C as a function of β are given for convenience in table A.16. They are not intended for precise interpolation. Extrapolation is not permitted.

NOTE 7 Within the limits specified in 10.2.4.1, C is independent of the Reynolds number and of the pipe diameter D.

10.2.4.3 Expansibility [expansion] factor, ε_1

The indications given in 9.1.6.3 also apply to the expansibility [expansion] factor for Venturi nozzles, but within the limits of use specified in 10.2.4.1.

10.2.5 Uncertainties

10.2.5.1 Uncertainty of discharge coefficient C

Within the limits of use specified in 10.2.4.1 and when β is assumed to be known without error, the relative uncertainty of the values of the discharge coefficient C, in per cent, is equal to

$$(1,2 + 1,5\beta^4)$$

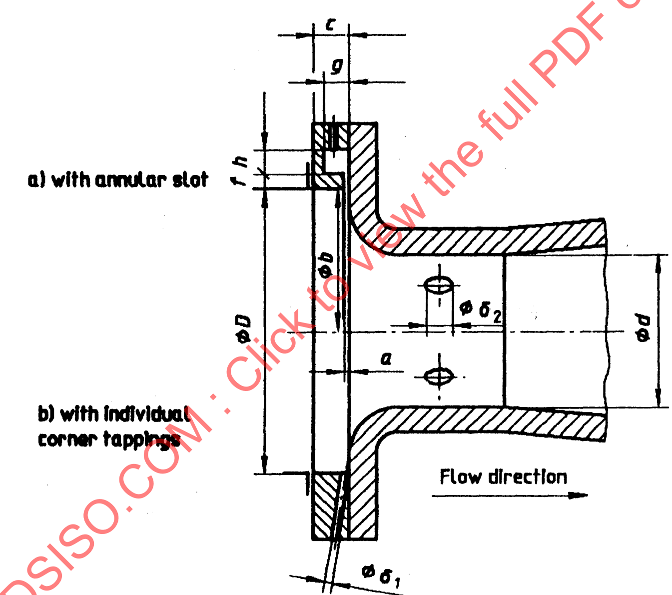


Figure 12 — Venturi nozzle fitted with a carrier ring

Table 5 — Upper limits of relative roughness of the upstream pipe for Venturi nozzles

β	$\leqslant 0,35$	0,36	0,38	0,40	0,42	0,44	0,46	0,48	0,50	0,60	0,70	0,775
$10^4\ k/D$	25	18,6	13,5	10,6	8,7	7,5	6,7	6,1	5,6	4,5	4,0	3,9

10.2.5.2 Uncertainty of expansibility [expansion] factor ε_1

The relative uncertainty, in per cent, of ε_1 is equal to

$$(4 + 100\beta^8)\frac{\Delta p}{p_1}$$

10.2.6 Pressure loss

The indications given in 10.1.9 also apply to Venturi nozzles when the divergent angle is not greater than 15°.

11 Uncertainties on the measurement of flow-rate

Useful general information for calculation of the uncertainty of a measurement of flow-rate, together with an example, are given in ISO 5168.

11.1 Definition of uncertainty

11.1.1 For the purposes of this part of ISO 5167 the uncertainty is defined as a range of values within which the true value of the measurement is estimated to lie at the 95 % probability level.

In some cases, the confidence level which can be associated with this range of values will be greater than 95 %, but this will be so only where the value of a quantity used in the calculation of flow-rate is known with a confidence level in excess of 95 %; in such a case, reference shall be made to ISO 5168.

11.1.2 The uncertainty on the measurement of the flow-rate shall be calculated and given under this name whenever a measurement is claimed to be in conformity with this part of ISO 5167.

11.1.3 The uncertainty can be expressed in absolute or relative terms and the result of the flow measurement can then be given in any one of the following forms:

rate of flow = $q \pm \delta q$

rate of flow = $q(1 \pm e)$

rate of flow = q within $(100e)$ %

where the uncertainty δq shall have the same dimensions as q while $e_q = \delta q/q$ and is dimensionless.

11.1.4 Although for one single measuring device and for coefficients used in one test, some of these partial uncertainties may in reality be the result of systematic errors (of which only an estimation of their maximum absolute value can be known) their combination is permitted as if they were random errors having a distribution conforming to the Laplace-Gauss normal law.

The uncertainty of the flow measurement so defined is, in practice, equivalent to twice the standard deviation used in statistical terminology and it is obtained by combining the partial uncertainties on the individual quantities which are used in the calculation of the flow-rate, assuming them to be small, numerous and independent of each other.

11.1.5 For convenience a distinction is made between the uncertainties linked to measurements made by the user and those linked to quantities specified in this part of ISO 5167. The latter uncertainties are on the discharge coefficient and the expansibility [expansion] factor; they give the minimum uncertainty with which the measurement is unavoidably tainted, since the user has no control over these values. They occur because small variations in the geometry of the device are allowed and because the investigations on which the values have been based could not be made under "ideal" conditions, nor without some uncertainty.

11.2 Practical computation of the uncertainty

11.2.1 The basic formula of computation of the mass rate of flow q_m is

$$q_m = C\varepsilon_1 \frac{\pi}{4} d^2 \frac{\sqrt{2\Delta p \varrho_1}}{\sqrt{1-\beta^4}}$$

In fact, the various quantities which appear on the right-hand side of this formula are not independent, so that it is not correct to compute the uncertainty of q_m directly from the uncertainties of these quantities.

For example, C is a function of d, D, κ, U_1, v_1 and ϱ_1 and ε_1 is a function of d, D, Δp, p_1 and κ.

11.2.1.1 However, it is sufficient, for most practical purposes, to assume that the uncertainties of C, ε_1, d, Δp and ϱ_1 are independent of each other.

11.2.1.2 A practical working formula for δq_m may then be derived, which takes account of the interdependence of C on d and D which enters into the calculation as a consequence of the dependence of C on β. It shall be noted that C may also be dependent on the Reynolds number Re_D. However, the deviations of C due to these influences are of a second order and are included in the uncertainty on C.

Similarly, the deviations of ε_1 which are due to uncertainties in the value of β, the pressure ratio and the isentropic exponent are also of a second order and are included in the uncertainty on ε_1.

11.2.1.3 The uncertainties which shall be included in a practical working formula for δq_m are therefore those of the quantities C, ε_1, d, D, Δp and ϱ_1.

11.2.2 The practical working formula for the uncertainty, δq_m, of the mass rate of flow is as follows:

$$\frac{\delta q_m}{q_m} = \left[\left(\frac{\delta C}{C} \right)^2 + \left(\frac{\delta \varepsilon_1}{\varepsilon_1} \right)^2 + \left(\frac{2\beta^4}{1-\beta^4} \right)^2 \left(\frac{\delta D}{D} \right)^2 + \left(\frac{2}{1-\beta^4} \right)^2 \left(\frac{\delta d}{d} \right)^2 + \frac{1}{4} \left(\frac{\delta \Delta p}{\Delta p} \right)^2 + \frac{1}{4} \left(\frac{\delta \varrho_1}{\varrho_1} \right)^2 \right]^{1/2}$$

In the formula above some of the uncertainties, such as those on the discharge coefficient and expansibility [expansion] factor, are given in this part of ISO 5167 (see 11.2.2.1 and 11.2.2.2) while others have to be determined by the user (see 11.2.2.3 and 11.2.2.4).

11.2.2.1 In the formula above, the values of $\delta C/C$ and of $\delta \varepsilon_1/\varepsilon_1$ shall be taken from the appropriate clauses of this part of ISO 5167.

11.2.2.2 When the straight lengths are such that an additional uncertainty of 0,5 % is to be considered, this additional uncertainty shall be added in accordance with the requirements given in 7.2.4 and not quadratically as with the other uncertainties in the formula above. Other additional uncertainties (see 7.5.1.4 and 7.5.2.3) shall be added in the same way.

11.2.2.3 In the formula above the maximum values of $\delta D/D$ and $\delta d/d$, which can be derived from the specifications given in clause 7 and in 8.1.7, 9.1.2.5, 9.2.2.3, 10.1.2.3 and 10.2.1.3, can be adopted or alternatively the smaller actual values can be computed by the user. (The maximum value for $\delta D/D$ may be taken as 0,4 % while the maximum value for $\delta d/d$ may be taken as 0,07 %.)

11.2.2.4 The values of $\delta \Delta p/\Delta p$ and $\delta \varrho_1/\varrho_1$ shall be determined by the user because this part of ISO 5167 does not specify in detail the method of measurement of the quantities Δp and ϱ_1.

Annex A
(informative)

Tables of discharge coefficients and expansibility [expansion] factors

Table A.1 — Orifice plate with corner tappings — Discharge coefficient, C

Diameter ratio β	Discharge coefficient, C, for Re_D equal to											
	5×10^3	1×10^4	2×10^4	3×10^4	5×10^4	7×10^4	1×10^5	3×10^5	1×10^6	1×10^7	1×10^8	∞
0,20	0,599 7	0,598 6	0,597 9	0,597 7	0,597 5	0,597 3	0,597 3	0,597 1	0,597 0	0,597 0	0,597 0	0,597 0
0,22	0,600 6	0,599 3	0,598 4	0,598 1	0,597 8	0,597 7	0,597 6	0,597 4	0,597 3	0,597 2	0,597 2	0,597 2
0,24	0,601 8	0,600 0	0,599 0	0,598 6	0,598 2	0,598 1	0,597 9	0,597 7	0,597 5	0,597 5	0,597 5	0,597 5
0,26	0,603 1	0,600 9	0,599 6	0,599 1	0,598 7	0,598 5	0,598 3	0,598 0	0,597 8	0,597 8	0,597 7	0,597 7
0,28	0,604 4	0,601 9	0,600 3	0,599 7	0,599 2	0,598 9	0,598 7	0,598 3	0,598 2	0,598 1	0,598 1	0,598 0
0,30	0,606 0	0,602 9	0,601 1	0,600 4	0,599 7	0,599 4	0,599 2	0,598 7	0,598 5	0,598 4	0,598 4	0,598 4
0,32	0,607 7	0,604 0	0,601 9	0,601 1	0,600 3	0,600 0	0,599 7	0,599 1	0,598 9	0,598 8	0,598 7	0,598 7
0,34	0,609 5	0,605 3	0,602 8	0,601 8	0,601 0	0,600 5	0,600 2	0,599 6	0,599 3	0,599 1	0,599 1	0,599 1
0,36	0,611 5	0,606 6	0,603 7	0,602 6	0,601 6	0,601 2	0,600 8	0,600 1	0,599 7	0,599 5	0,599 5	0,599 5
0,38	0,613 6	0,608 1	0,604 8	0,603 5	0,602 4	0,601 8	0,601 4	0,600 5	0,600 2	0,600 0	0,599 9	0,599 9
0,40	0,615 9	0,609 6	0,605 9	0,604 4	0,603 1	0,602 5	0,602 0	0,601 1	0,600 6	0,600 4	0,600 3	0,600 3
0,42	0,618 4	0,611 3	0,607 0	0,605 4	0,603 9	0,603 2	0,602 6	0,601 6	0,601 1	0,600 8	0,600 8	0,600 8
0,44	0,621 0	0,613 0	0,608 2	0,606 4	0,604 7	0,603 9	0,603 3	0,602 1	0,601 6	0,601 3	0,601 2	0,601 2
0,46	0,623 8	0,614 8	0,609 5	0,607 4	0,605 6	0,604 7	0,604 0	0,602 7	0,602 1	0,601 7	0,601 7	0,601 6
0,48	—	0,616 7	0,610 8	0,608 5	0,606 4	0,605 5	0,604 7	0,603 2	0,602 5	0,602 1	0,602 1	0,602 1
0,50	—	0,618 7	0,612 1	0,609 6	0,607 3	0,606 2	0,605 3	0,603 7	0,603 0	0,602 6	0,602 5	0,602 5
0,51	—	0,619 7	0,612 8	0,610 1	0,607 7	0,606 6	0,605 7	0,604 0	0,603 2	0,602 7	0,602 7	0,602 6
0,52	—	0,620 7	0,613 5	0,610 7	0,608 2	0,607 0	0,606 0	0,604 2	0,603 4	0,602 9	0,602 8	0,602 8
0,53	—	0,621 7	0,614 1	0,611 2	0,608 6	0,607 3	0,606 3	0,604 4	0,603 6	0,603 1	0,603 0	0,603 0
0,54	—	0,622 8	0,614 8	0,611 7	0,609 0	0,607 7	0,606 6	0,604 7	0,603 7	0,603 2	0,603 1	0,603 1
0,55	—	0,623 8	0,615 5	0,612 3	0,609 4	0,608 0	0,606 9	0,604 9	0,603 9	0,603 4	0,603 3	0,603 2
0,56	—	0,624 9	0,616 2	0,612 8	0,609 8	0,608 4	0,607 2	0,605 0	0,604 0	0,603 5	0,603 4	0,603 4
0,57	—	0,625 9	0,616 8	0,613 3	0,610 2	0,608 7	0,607 4	0,605 2	0,604 1	0,603 6	0,603 5	0,603 4
0,58	—	0,627 0	0,617 5	0,613 8	0,610 5	0,608 9	0,607 7	0,605 3	0,604 2	0,603 6	0,603 5	0,603 5
0,59	—	0,628 0	0,618 1	0,614 3	0,610 8	0,609 2	0,607 9	0,605 4	0,604 3	0,603 6	0,603 5	0,603 5
0,60	—	0,629 1	0,618 7	0,614 7	0,611 1	0,609 4	0,608 0	0,605 5	0,604 3	0,603 6	0,603 5	0,603 5
0,61	—	0,630 1	0,619 3	0,615 1	0,611 4	0,609 6	0,608 2	0,605 5	0,604 3	0,603 6	0,603 4	0,603 4
0,62	—	0,631 1	0,619 8	0,615 5	0,611 6	0,609 8	0,608 3	0,605 5	0,604 2	0,603 5	0,603 3	0,603 3
0,63	—	0,632 0	0,620 3	0,615 8	0,611 8	0,609 9	0,608 3	0,605 4	0,604 1	0,603 3	0,603 2	0,603 2
0,64	—	0,633 0	0,620 8	0,616 1	0,611 9	0,609 9	0,608 3	0,605 3	0,603 9	0,603 1	0,603 0	0,602 9
0,65	—	0,633 9	0,621 2	0,616 4	0,612 0	0,609 9	0,608 2	0,605 1	0,603 7	0,602 8	0,602 7	0,602 7
0,66	—	0,634 8	0,621 6	0,616 5	0,612 0	0,609 9	0,608 1	0,604 8	0,603 3	0,602 5	0,602 3	0,602 3
0,67	—	0,635 6	0,621 9	0,616 7	0,612 0	0,609 7	0,607 9	0,604 5	0,602 9	0,602 1	0,601 9	0,601 9
0,68	—	0,636 3	0,622 2	0,616 7	0,611 8	0,609 5	0,607 6	0,604 1	0,602 5	0,601 6	0,601 4	0,601 4
0,69	—	0,637 0	0,622 3	0,616 7	0,611 6	0,609 2	0,607 2	0,603 6	0,601 9	0,601 0	0,600 8	0,600 8
0,70	—	0,637 6	0,622 4	0,616 5	0,611 3	0,608 8	0,606 7	0,603 0	0,601 2	0,600 3	0,600 1	0,600 0
0,71	—	0,638 2	0,622 4	0,616 3	0,610 9	0,608 3	0,606 1	0,602 3	0,600 4	0,599 4	0,599 3	0,599 2
0,72	—	0,638 6	0,622 2	0,616 0	0,610 3	0,607 6	0,605 4	0,601 4	0,599 5	0,598 5	0,598 3	0,598 3
0,73	—	0,638 9	0,622 0	0,615 5	0,609 7	0,606 9	0,604 6	0,600 4	0,598 5	0,597 4	0,597 2	0,597 2
0,74	—	0,639 1	0,621 6	0,614 9	0,608 9	0,606 0	0,603 6	0,599 3	0,597 3	0,596 2	0,596 0	0,595 9
0,75	—	0,639 2	0,621 1	0,614 1	0,607 9	0,604 9	0,602 5	0,598 0	0,595 9	0,594 8	0,594 6	0,594 5

NOTE — This table is given for convenience. The values given are not intended for precise interpolation. Extrapolation is not permitted.

Table A.2 — Orifice plate with D and $D/2$ tappings — Discharge coefficient, C

Diameter ratio β	Discharge coefficient, C, for Re_D equal to											
	5×10^3	1×10^4	2×10^4	3×10^4	5×10^4	7×10^4	1×10^5	3×10^5	1×10^6	1×10^7	1×10^8	∞
0,20	0,599 7	0,598 5	0,597 9	0,597 6	0,597 4	0,597 3	0,597 2	0,597 0	0,596 9	0,596 9	0,596 9	0,596 9
0,22	0,600 6	0,599 2	0,598 4	0,598 0	0,597 7	0,597 6	0,597 5	0,597 3	0,597 2	0,597 1	0,597 1	0,597 1
0,24	0,601 7	0,600 0	0,598 9	0,598 5	0,598 1	0,598 0	0,597 8	0,597 6	0,597 4	0,597 4	0,597 4	0,597 4
0,26	0,603 0	0,600 8	0,599 5	0,599 0	0,598 6	0,598 4	0,598 2	0,597 9	0,597 7	0,597 7	0,597 6	0,597 6
0,28	0,604 3	0,601 7	0,600 2	0,599 6	0,599 1	0,598 8	0,598 6	0,598 2	0,598 1	0,598 0	0,597 9	0,597 9
0,30	—	0,602 8	0,601 0	0,600 3	0,599 6	0,599 3	0,599 1	0,598 6	0,598 4	0,598 3	0,598 3	0,598 3
0,32	—	0,603 9	0,601 8	0,601 0	0,600 2	0,599 9	0,599 6	0,599 0	0,598 8	0,598 7	0,598 6	0,598 6
0,34	—	0,605 2	0,602 7	0,601 7	0,600 9	0,600 4	0,600 1	0,599 5	0,599 2	0,599 0	0,599 0	0,599 0
0,36	—	0,606 6	0,603 7	0,602 6	0,601 6	0,601 1	0,600 7	0,600 0	0,599 7	0,599 5	0,599 4	0,599 4
0,38	—	0,608 0	0,604 7	0,603 5	0,602 3	0,601 8	0,601 3	0,600 5	0,600 1	0,599 9	0,599 9	0,599 9
0,40	—	0,609 6	0,605 9	0,604 4	0,603 1	0,602 5	0,602 0	0,601 1	0,600 6	0,600 4	0,600 4	0,600 3
0,42	—	—	0,607 1	0,605 4	0,604 0	0,603 3	0,602 7	0,601 7	0,601 2	0,600 9	0,600 9	0,600 8
0,44	—	—	0,608 4	0,606 5	0,604 9	0,604 1	0,603 5	0,602 3	0,601 7	0,601 4	0,601 4	0,601 4
0,46	—	—	0,609 8	0,607 7	0,605 9	0,605 0	0,604 3	0,603 0	0,602 3	0,602 0	0,601 9	0,601 9
0,48	—	—	0,611 2	0,608 9	0,606 9	0,605 9	0,605 1	0,603 6	0,603 0	0,602 6	0,602 5	0,602 5
0,50	—	—	0,612 7	0,610 2	0,607 9	0,606 8	0,606 0	0,604 3	0,603 6	0,603 2	0,603 1	0,603 1
0,51	—	—	0,613 5	0,610 8	0,608 5	0,607 3	0,606 4	0,604 7	0,603 9	0,603 5	0,603 4	0,603 4
0,52	—	—	0,614 3	0,611 5	0,609 0	0,607 8	0,606 8	0,605 1	0,604 2	0,603 8	0,603 7	0,603 7
0,53	—	—	0,615 1	0,612 2	0,609 6	0,608 3	0,607 3	0,605 4	0,604 6	0,604 1	0,604 0	0,604 0
0,54	—	—	0,615 9	0,612 9	0,610 1	0,608 8	0,607 7	0,605 8	0,604 9	0,604 4	0,604 3	0,604 3
0,55	—	—	0,616 8	0,613 6	0,610 7	0,609 3	0,608 2	0,606 1	0,605 2	0,604 7	0,604 6	0,604 5
0,56	—	—	0,617 6	0,614 3	0,611 3	0,609 8	0,608 7	0,606 5	0,605 5	0,604 9	0,604 8	0,604 8
0,57	—	—	—	0,615 0	0,611 8	0,610 3	0,609 1	0,606 9	0,605 8	0,605 2	0,605 1	0,605 1
0,58	—	—	—	0,615 7	0,612 4	0,610 8	0,609 5	0,607 2	0,606 1	0,605 5	0,605 4	0,605 4
0,59	—	—	—	0,616 4	0,613 0	0,611 3	0,610 0	0,607 5	0,606 4	0,605 8	0,605 6	0,605 6
0,60	—	—	—	0,617 1	0,613 5	0,611 8	0,610 4	0,607 9	0,606 7	0,606 0	0,605 9	0,605 9
0,61	—	—	—	0,617 8	0,614 1	0,612 3	0,610 8	0,608 2	0,606 9	0,606 2	0,606 1	0,606 1
0,62	—	—	—	0,618 5	0,614 6	0,612 8	0,611 2	0,608 5	0,607 2	0,606 5	0,606 3	0,606 3
0,63	—	—	—	0,619 2	0,615 1	0,613 2	0,611 6	0,608 7	0,607 4	0,606 7	0,606 5	0,606 5
0,64	—	—	—	0,619 8	0,615 6	0,613 6	0,612 0	0,609 0	0,607 6	0,606 8	0,606 7	0,606 7
0,65	—	—	—	0,620 5	0,616 1	0,614 0	0,612 3	0,609 2	0,607 8	0,607 0	0,606 8	0,606 8
0,66	—	—	—	0,621 1	0,616 6	0,614 4	0,612 7	0,609 4	0,607 9	0,607 1	0,606 9	0,606 9
0,67	—	—	—	0,621 7	0,617 0	0,614 8	0,613 0	0,609 6	0,608 0	0,607 2	0,607 0	0,607 0
0,68	—	—	—	0,622 3	0,617 5	0,615 1	0,613 2	0,609 7	0,608 1	0,607 2	0,607 0	0,607 0
0,69	—	—	—	0,622 9	0,617 8	0,615 4	0,613 4	0,609 8	0,608 1	0,607 2	0,607 0	0,607 0
0,70	—	—	—	—	0,618 2	0,615 7	0,613 6	0,609 9	0,608 1	0,607 1	0,607 0	0,606 9
0,71	—	—	—	—	0,618 5	0,615 9	0,613 8	0,609 9	0,608 1	0,607 1	0,606 9	0,606 8
0,72	—	—	—	—	0,618 7	0,616 1	0,613 9	0,609 8	0,608 0	0,606 9	0,606 7	0,606 7
0,73	—	—	—	—	0,619 0	0,616 2	0,613 9	0,609 7	0,607 8	0,606 7	0,606 5	0,606 5
0,74	—	—	—	—	0,619 1	0,616 3	0,613 9	0,609 6	0,607 6	0,606 5	0,606 3	0,606 2
0,75	—	—	—	—	0,619 3	0,616 3	0,613 8	0,609 4	0,607 3	0,606 2	0,605 9	0,605 9

NOTE — This table is given for convenience. The values given are not intended for precise interpolation. Extrapolation is not permitted.

Table A.3 — Orifice plate with flange tappings — Discharge coefficient, C, for $D = 50$ mm

Diameter ratio β	Discharge coefficient, C, for Re_D equal to										
	5×10^3	1×10^4	2×10^4	3×10^4	5×10^4	7×10^4	1×10^5	3×10^5	1×10^6	1×10^7	1×10^8	∞
0,25	0,602 3	0,600 3	0,599 2	0,598 7	0,598 3	0,598 1	0,598 0	0,597 7	0,597 6	0,597 5	0,597 5	0,597 5
0,26	0,602 9	0,600 8	0,599 5	0,599 0	0,598 6	0,598 4	0,598 2	0,597 9	0,597 7	0,597 6	0,597 6	0,597 6
0,28	0,604 3	0,601 7	0,600 2	0,599 6	0,599 0	0,598 8	0,598 6	0,598 2	0,598 0	0,597 9	0,597 9	0,597 9
0,30	—	0,602 8	0,600 9	0,600 2	0,599 6	0,599 3	0,599 0	0,598 6	0,598 4	0,598 3	0,598 2	0,598 2
0,32	—	0,603 9	0,601 7	0,600 9	0,600 2	0,599 8	0,599 5	0,599 0	0,598 8	0,598 6	0,598 6	0,598 6
0,34	—	0,605 1	0,602 6	0,601 7	0,600 8	0,600 4	0,600 1	0,599 4	0,599 2	0,599 0	0,599 0	0,599 0
0,36	—	0,606 5	0,603 6	0,602 5	0,601 5	0,601 0	0,600 6	0,599 9	0,599 6	0,599 4	0,599 4	0,599 4
0,38	—	0,608 0	0,604 7	0,603 4	0,602 2	0,601 7	0,601 3	0,600 4	0,600 1	0,599 8	0,599 8	0,599 8
0,40	—	—	0,605 8	0,604 3	0,603 0	0,602 4	0,601 9	0,601 0	0,600 6	0,600 3	0,600 3	0,600 3
0,42	—	—	0,607 0	0,605 4	0,603 9	0,603 2	0,602 6	0,601 6	0,601 1	0,600 8	0,600 8	0,600 8
0,44	—	—	0,608 3	0,606 4	0,604 8	0,604 0	0,603 4	0,602 2	0,601 6	0,601 3	0,601 3	0,601 3
0,46	—	—	0,609 6	0,607 6	0,605 7	0,604 9	0,604 1	0,602 8	0,602 2	0,601 9	0,601 8	0,601 8
0,48	—	—	0,611 1	0,608 8	0,606 7	0,605 8	0,605 0	0,603 5	0,602 8	0,602 4	0,602 4	0,602 4
0,50	—	—	0,612 6	0,610 0	0,607 8	0,606 7	0,605 8	0,604 2	0,603 4	0,603 0	0,602 9	0,602 9
0,51	—	—	0,613 3	0,610 7	0,608 3	0,607 2	0,606 2	0,604 5	0,603 7	0,603 3	0,603 2	0,603 2
0,52	—	—	0,614 1	0,611 3	0,608 8	0,607 6	0,606 7	0,604 9	0,604 1	0,603 6	0,603 5	0,603 5
0,53	—	—	0,614 9	0,612 0	0,609 4	0,608 1	0,607 1	0,605 2	0,604 4	0,603 9	0,603 8	0,603 8
0,54	—	—	0,615 7	0,612 7	0,609 9	0,608 6	0,607 5	0,605 6	0,604 7	0,604 2	0,604 1	0,604 1
0,55	—	—	0,616 6	0,613 4	0,610 5	0,609 1	0,608 0	0,605 9	0,605 0	0,604 4	0,604 4	0,604 3
0,56	—	—	0,617 4	0,614 0	0,611 0	0,609 6	0,608 4	0,606 3	0,605 3	0,604 7	0,604 6	0,604 6
0,57	—	—	—	0,614 7	0,611 6	0,610 1	0,608 9	0,606 6	0,605 6	0,605 0	0,604 9	0,604 9
0,58	—	—	—	0,615 4	0,612 1	0,610 6	0,609 3	0,607 0	0,605 9	0,605 3	0,605 1	0,605 1
0,59	—	—	—	0,616 1	0,612 7	0,611 1	0,609 7	0,607 3	0,606 1	0,605 5	0,605 4	0,605 4
0,60	—	—	—	0,616 8	0,613 2	0,611 5	0,610 1	0,607 6	0,606 4	0,605 7	0,605 6	0,605 6
0,61	—	—	—	0,617 5	0,613 8	0,612 0	0,610 5	0,607 9	0,606 6	0,606 0	0,605 8	0,605 8
0,62	—	—	—	0,618 2	0,614 3	0,612 4	0,610 9	0,608 2	0,606 9	0,606 2	0,606 0	0,606 0
0,63	—	—	—	0,618 8	0,614 8	0,612 9	0,611 3	0,608 4	0,607 1	0,606 3	0,606 2	0,606 2
0,64	—	—	—	0,619 5	0,615 3	0,613 3	0,611 7	0,608 7	0,607 3	0,606 5	0,606 3	0,606 3
0,65	—	—	—	0,620 1	0,615 8	0,613 7	0,612 0	0,608 9	0,607 4	0,606 6	0,606 5	0,606 4
0,66	—	—	—	0,620 8	0,616 2	0,614 1	0,612 3	0,609 1	0,607 6	0,606 7	0,606 6	0,606 5
0,67	—	—	—	0,621 4	0,616 7	0,614 4	0,612 6	0,609 2	0,607 6	0,606 8	0,606 6	0,606 6
0,68	—	—	—	0,621 9	0,617 1	0,614 7	0,612 8	0,609 3	0,607 7	0,606 8	0,606 6	0,606 6
0,69	—	—	—	0,622 5	0,617 4	0,615 0	0,613 0	0,609 4	0,607 7	0,606 8	0,606 6	0,606 6
0,70	—	—	—	—	0,617 7	0,615 2	0,613 2	0,609 4	0,607 7	0,606 7	0,606 5	0,606 5
0,71	—	—	—	—	0,618 0	0,615 4	0,613 3	0,609 4	0,607 6	0,606 6	0,606 4	0,606 4
0,72	—	—	—	—	0,618 3	0,615 6	0,613 4	0,609 4	0,607 5	0,606 4	0,606 2	0,606 2
0,73	—	—	—	—	0,618 5	0,615 7	0,613 4	0,609 2	0,607 3	0,606 2	0,606 0	0,606 0
0,74	—	—	—	—	0,618 6	0,615 7	0,613 4	0,609 1	0,607 1	0,605 9	0,605 7	0,605 7
0,75	—	—	—	—	0,618 7	0,615 7	0,613 3	0,608 8	0,606 8	0,605 6	0,605 4	0,605 4

NOTE — This table is given for convenience. The values given are not intended for precise interpolation. Extrapolation is not permitted.

Table A.4 — Orifice plate with flange tappings — Discharge coefficient, C, for $D = 75$ mm

Diameter ratio β	Discharge coefficient, C, for Re_D equal to											
	5×10^3	1×10^4	2×10^4	3×10^4	5×10^4	7×10^4	1×10^5	3×10^5	1×10^6	1×10^7	1×10^8	∞
0,20	0,599 7	0,598 6	0,597 9	0,597 6	0,597 4	0,597 3	0,597 2	0,597 0	0,597 0	0,596 9	0,596 9	0,596 9
0,22	0,600 6	0,599 2	0,598 4	0,598 1	0,597 8	0,597 6	0,597 5	0,597 3	0,597 2	0,597 2	0,597 1	0,597 1
0,24	—	0,600 0	0,598 9	0,598 5	0,598 2	0,598 0	0,597 9	0,597 6	0,597 5	0,597 4	0,597 4	0,597 4
0,26	—	0,600 8	0,599 6	0,599 1	0,598 6	0,598 4	0,598 2	0,597 9	0,597 8	0,597 7	0,597 7	0,597 7
0,28	—	0,601 8	0,600 2	0,599 7	0,599 1	0,598 9	0,598 7	0,598 3	0,598 1	0,598 0	0,598 0	0,598 0
0,30	—	0,602 8	0,601 0	0,600 3	0,599 7	0,599 4	0,599 1	0,598 7	0,598 5	0,598 3	0,598 3	0,598 3
0,32	—	0,604 0	0,601 8	0,601 0	0,600 3	0,599 9	0,599 6	0,599 1	0,598 8	0,598 7	0,598 7	0,598 7
0,34	—	—	0,602 7	0,601 8	0,600 9	0,600 5	0,600 2	0,599 6	0,599 3	0,599 1	0,599 1	0,599 1
0,36	—	—	0,603 7	0,602 6	0,601 6	0,601 1	0,600 8	0,600 0	0,599 7	0,599 5	0,599 5	0,599 5
0,38	—	—	0,604 8	0,603 5	0,602 4	0,601 8	0,601 4	0,600 6	0,600 2	0,600 0	0,599 9	0,599 9
0,40	—	—	0,605 9	0,604 5	0,603 2	0,602 6	0,602 1	0,601 1	0,600 7	0,600 5	0,600 4	0,600 4
0,42	—	—	0,607 1	0,605 5	0,604 0	0,603 3	0,602 8	0,601 7	0,601 2	0,601 0	0,600 9	0,600 9
0,44	—	—	0,608 4	0,606 6	0,604 9	0,604 2	0,603 5	0,602 3	0,601 8	0,601 5	0,601 4	0,601 4
0,46	—	—	0,609 8	0,607 7	0,605 9	0,605 0	0,604 3	0,603 0	0,602 4	0,602 0	0,602 0	0,602 0
0,48	—	—	—	0,608 9	0,606 9	0,605 9	0,605 1	0,603 6	0,603 0	0,602 6	0,602 5	0,602 5
0,50	—	—	—	0,610 2	0,607 9	0,606 8	0,605 9	0,604 3	0,603 6	0,603 2	0,603 1	0,603 1
0,51	—	—	—	0,610 8	0,608 4	0,607 3	0,606 4	0,604 7	0,603 9	0,603 4	0,603 4	0,603 3
0,52	—	—	—	0,611 5	0,609 0	0,607 8	0,606 8	0,605 0	0,604 2	0,603 7	0,603 6	0,603 6
0,53	—	—	—	0,612 1	0,609 5	0,608 2	0,607 2	0,605 4	0,604 5	0,604 0	0,603 9	0,603 9
0,54	—	—	—	0,612 8	0,610 0	0,608 7	0,607 7	0,605 7	0,604 8	0,604 3	0,604 2	0,604 2
0,55	—	—	—	0,613 4	0,610 6	0,609 2	0,608 1	0,606 0	0,605 1	0,604 5	0,604 4	0,604 4
0,56	—	—	—	0,614 1	0,611 1	0,609 7	0,608 5	0,606 4	0,605 4	0,604 8	0,604 7	0,604 7
0,57	—	—	—	—	0,611 6	0,610 1	0,608 9	0,606 7	0,605 6	0,605 0	0,604 9	0,604 9
0,58	—	—	—	—	0,612 2	0,610 6	0,609 3	0,607 0	0,605 9	0,605 3	0,605 2	0,605 1
0,59	—	—	—	—	0,612 7	0,611 1	0,609 7	0,607 3	0,606 1	0,605 5	0,605 4	0,605 4
0,60	—	—	—	—	0,613 2	0,611 5	0,610 1	0,607 6	0,606 4	0,605 7	0,605 6	0,605 6
0,61	—	—	—	—	0,613 7	0,611 9	0,610 5	0,607 8	0,606 6	0,605 9	0,605 8	0,605 7
0,62	—	—	—	—	0,614 2	0,612 3	0,610 8	0,608 0	0,606 8	0,606 0	0,605 9	0,605 9
0,63	—	—	—	—	0,614 6	0,612 7	0,611 1	0,608 3	0,606 9	0,606 2	0,606 0	0,606 0
0,64	—	—	—	—	0,615 1	0,613 1	0,611 4	0,608 4	0,607 0	0,606 3	0,606 1	0,606 1
0,65	—	—	—	—	0,615 5	0,613 4	0,611 7	0,608 6	0,607 1	0,606 3	0,606 2	0,606 2
0,66	—	—	—	—	0,615 9	0,613 7	0,611 9	0,608 7	0,607 2	0,606 4	0,606 2	0,606 2
0,67	—	—	—	—	0,616 2	0,614 0	0,612 1	0,608 8	0,607 2	0,606 3	0,606 2	0,606 1
0,68	—	—	—	—	0,616 5	0,614 2	0,612 3	0,608 8	0,607 2	0,606 3	0,606 1	0,606 1
0,69	—	—	—	—	0,616 8	0,614 4	0,612 4	0,608 8	0,607 1	0,606 1	0,606 0	0,605 9
0,70	—	—	—	—	0,617 0	0,614 5	0,612 4	0,608 7	0,606 9	0,606 0	0,605 8	0,605 8
0,71	—	—	—	—	0,617 2	0,614 6	0,612 4	0,608 6	0,606 7	0,605 7	0,605 6	0,605 5
0,72	—	—	—	—	0,617 3	0,614 6	0,612 4	0,608 4	0,606 5	0,605 4	0,605 2	0,605 2
0,73	—	—	—	—	—	0,614 5	0,612 2	0,608 1	0,606 1	0,605 1	0,604 9	0,604 8
0,74	—	—	—	—	—	0,614 4	0,612 0	0,607 7	0,605 7	0,604 6	0,604 4	0,604 4
0,75	—	—	—	—	—	0,614 2	0,611 8	0,607 3	0,605 2	0,604 1	0,603 9	0,603 8

NOTE — This table is given for convenience. The values given are not intended for precise interpolation. Extrapolation is not permitted.

Table A.5 — Orifice plate with flange tappings — Discharge coefficient, C, for D = 100 mm

Diameter ratio β	Discharge coefficient, C, for Re_D equal to											
	5 × 10^3	1 × 10^4	2 × 10^4	3 × 10^4	5 × 10^4	7 × 10^4	1 × 10^5	3 × 10^5	1 × 10^6	1 × 10^7	1 × 10^8	∞
0,20	—	0,598 6	0,597 9	0,597 6	0,597 4	0,597 3	0,597 2	0,597 1	0,597 0	0,596 9	0,596 9	0,596 9
0,22	—	0,599 2	0,598 4	0,598 1	0,597 8	0,597 6	0,597 5	0,597 3	0,597 2	0,597 2	0,597 2	0,597 2
0,24	—	0,600 0	0,599 0	0,598 5	0,598 2	0,598 0	0,597 9	0,597 6	0,597 5	0,597 4	0,597 4	0,597 4
0,26	—	0,600 9	0,599 6	0,599 1	0,598 6	0,598 4	0,598 3	0,597 9	0,597 8	0,597 7	0,597 7	0,597 7
0,28	—	0,601 8	0,600 3	0,599 7	0,599 1	0,598 9	0,598 7	0,598 3	0,598 1	0,598 0	0,598 0	0,598 0
0,30	—	—	0,601 0	0,600 3	0,599 7	0,599 4	0,599 1	0,598 7	0,598 5	0,598 4	0,598 3	0,598 3
0,32	—	—	0,601 9	0,601 0	0,600 3	0,599 9	0,599 6	0,599 1	0,598 9	0,598 7	0,598 7	0,598 7
0,34	—	—	0,602 8	0,601 8	0,600 9	0,600 5	0,600 2	0,599 6	0,599 3	0,599 1	0,599 1	0,599 1
0,36	—	—	0,603 7	0,602 6	0,601 6	0,601 1	0,600 8	0,600 0	0,599 7	0,599 5	0,599 5	0,599 5
0,38	—	—	0,604 8	0,603 5	0,602 4	0,601 8	0,601 4	0,600 6	0,600 2	0,600 0	0,599 9	0,599 9
0,40	—	—	—	0,604 5	0,603 2	0,602 5	0,602 0	0,601 1	0,600 7	0,600 4	0,600 4	0,600 4
0,42	—	—	—	0,605 5	0,604 0	0,603 3	0,602 7	0,601 7	0,601 2	0,600 9	0,600 9	0,600 9
0,44	—	—	—	0,606 5	0,604 9	0,604 1	0,603 5	0,602 3	0,601 7	0,601 4	0,601 4	0,601 4
0,46	—	—	—	0,607 7	0,605 8	0,604 9	0,604 2	0,602 9	0,602 3	0,602 0	0,601 9	0,601 9
0,48	—	—	—	0,608 8	0,606 8	0,605 8	0,605 0	0,603 5	0,602 9	0,602 5	0,602 4	0,602 4
0,50	—	—	—	—	0,607 8	0,606 7	0,605 8	0,604 2	0,603 4	0,603 0	0,602 9	0,602 9
0,51	—	—	—	—	0,608 3	0,607 1	0,606 2	0,604 5	0,603 7	0,603 3	0,603 2	0,603 2
0,52	—	—	—	—	0,608 8	0,607 6	0,606 6	0,604 8	0,604 0	0,603 5	0,603 4	0,603 4
0,53	—	—	—	—	0,609 3	0,608 0	0,607 0	0,605 1	0,604 3	0,603 8	0,603 7	0,603 7
0,54	—	—	—	—	0,609 8	0,608 5	0,607 4	0,605 4	0,604 5	0,604 0	0,603 9	0,603 9
0,55	—	—	—	—	0,610 3	0,608 9	0,607 8	0,605 7	0,604 8	0,604 2	0,604 1	0,604 1
0,56	—	—	—	—	0,610 8	0,609 3	0,608 2	0,606 0	0,605 0	0,604 5	0,604 4	0,604 3
0,57	—	—	—	—	0,611 3	0,609 8	0,608 5	0,606 3	0,605 3	0,604 7	0,604 6	0,604 5
0,58	—	—	—	—	0,611 8	0,610 2	0,608 9	0,606 6	0,605 5	0,604 9	0,604 8	0,604 7
0,59	—	—	—	—	0,612 2	0,610 6	0,609 3	0,606 8	0,605 7	0,605 0	0,604 9	0,604 9
0,60	—	—	—	—	0,612 7	0,611 0	0,609 6	0,607 0	0,605 8	0,605 2	0,605 1	0,605 0
0,61	—	—	—	—	0,613 1	0,611 3	0,609 9	0,607 2	0,606 0	0,605 3	0,605 2	0,605 2
0,62	—	—	—	—	0,613 5	0,611 7	0,610 2	0,607 4	0,606 1	0,605 4	0,605 3	0,605 2
0,63	—	—	—	—	0,613 9	0,612 0	0,610 4	0,607 5	0,606 2	0,605 5	0,605 3	0,605 3
0,64	—	—	—	—	—	0,612 3	0,610 7	0,607 7	0,606 3	0,605 5	0,605 3	0,605 3
0,65	—	—	—	—	—	0,612 5	0,610 8	0,607 7	0,606 3	0,605 5	0,605 3	0,605 3
0,66	—	—	—	—	—	0,612 7	0,611 0	0,607 7	0,606 2	0,605 4	0,605 2	0,605 2
0,67	—	—	—	—	—	0,612 9	0,611 1	0,607 7	0,606 1	0,605 3	0,605 1	0,605 1
0,68	—	—	—	—	—	0,613 0	0,611 1	0,607 6	0,606 0	0,605 1	0,604 9	0,604 9
0,69	—	—	—	—	—	0,613 1	0,611 1	0,607 5	0,605 8	0,604 9	0,604 7	0,604 6
0,70	—	—	—	—	—	0,613 1	0,611 0	0,607 3	0,605 5	0,604 5	0,604 4	0,604 3
0,71	—	—	—	—	—	0,613 0	0,610 9	0,607 0	0,605 2	0,604 2	0,604 0	0,603 9
0,72	—	—	—	—	—	0,612 8	0,610 6	0,606 6	0,604 7	0,603 7	0,603 5	0,603 5
0,73	—	—	—	—	—	0,612 6	0,610 3	0,606 2	0,604 2	0,603 1	0,603 0	0,602 9
0,74	—	—	—	—	—	0,612 3	0,609 9	0,605 6	0,603 6	0,602 5	0,602 3	0,602 3
0,75	—	—	—	—	—	—	0,609 4	0,605 0	0,602 9	0,601 8	0,601 5	0,601 5

NOTE — This table is given for convenience. The values given are not intended for precise interpolation. Extrapolation is not permitted.

Table A.6 — Orifice plate with flange tappings — Discharge coefficient, C, for D = 150 mm

Diameter ratio β	Discharge coefficient, C, for Re_D equal to											
	5×10^3	1×10^4	2×10^4	3×10^4	5×10^4	7×10^4	1×10^5	3×10^5	1×10^6	1×10^7	1×10^8	∞
0,20	—	0,598 6	0,597 9	0,597 7	0,597 4	0,597 3	0,597 2	0,597 1	0,597 0	0,596 9	0,596 9	0,596 9
0,22	—	0,599 3	0,598 4	0,598 1	0,597 8	0,597 7	0,597 5	0,597 3	0,597 2	0,597 2	0,597 2	0,597 2
0,24	—	—	0,599 0	0,598 6	0,598 2	0,598 0	0,597 9	0,597 6	0,597 5	0,597 4	0,597 4	0,597 4
0,26	—	—	0,599 6	0,599 1	0,598 7	0,598 4	0,598 3	0,598 0	0,597 8	0,597 7	0,597 7	0,597 7
0,28	—	—	0,600 3	0,599 7	0,599 2	0,598 9	0,598 7	0,598 3	0,598 1	0,598 0	0,598 0	0,598 0
0,30	—	—	0,601 0	0,600 3	0,599 7	0,599 4	0,599 2	0,598 7	0,598 5	0,598 4	0,598 4	0,598 3
0,32	—	—	0,601 9	0,601 0	0,600 3	0,599 9	0,599 6	0,599 1	0,598 9	0,598 7	0,598 7	0,598 7
0,34	—	—	—	0,601 8	0,600 9	0,600 5	0,600 2	0,599 6	0,599 3	0,599 1	0,599 1	0,599 1
0,36	—	—	—	0,602 6	0,601 6	0,601 2	0,600 8	0,600 0	0,599 7	0,599 5	0,599 5	0,599 5
0,38	—	—	—	0,603 5	0,602 4	0,601 8	0,601 4	0,600 6	0,600 2	0,600 0	0,599 9	0,599 9
0,40	—	—	—	0,604 4	0,603 1	0,602 5	0,602 0	0,601 1	0,600 7	0,600 4	0,600 4	0,600 4
0,42	—	—	—	—	0,604 0	0,603 3	0,602 7	0,601 7	0,601 2	0,600 9	0,600 8	0,600 8
0,44	—	—	—	—	0,604 8	0,604 0	0,603 4	0,602 2	0,601 7	0,601 4	0,601 3	0,601 3
0,46	—	—	—	—	0,605 7	0,604 9	0,604 1	0,602 8	0,602 2	0,601 9	0,601 8	0,601 8
0,48	—	—	—	—	0,606 7	0,605 7	0,604 9	0,603 4	0,602 7	0,602 4	0,602 3	0,602 3
0,50	—	—	—	—	0,607 6	0,606 5	0,605 6	0,604 0	0,603 3	0,602 9	0,602 8	0,602 8
0,51	—	—	—	—	0,608 1	0,607 0	0,606 0	0,604 3	0,603 5	0,603 1	0,603 0	0,603 0
0,52	—	—	—	—	—	0,607 4	0,606 4	0,604 6	0,603 8	0,603 3	0,603 2	0,603 2
0,53	—	—	—	—	—	0,607 8	0,606 8	0,604 9	0,604 0	0,603 5	0,603 5	0,603 4
0,54	—	—	—	—	—	0,608 2	0,607 1	0,605 2	0,604 3	0,603 8	0,603 7	0,603 6
0,55	—	—	—	—	—	0,608 6	0,607 5	0,605 4	0,604 5	0,604 0	0,603 9	0,603 8
0,56	—	—	—	—	—	0,609 0	0,607 8	0,605 7	0,604 7	0,604 1	0,604 0	0,604 0
0,57	—	—	—	—	—	0,609 4	0,608 2	0,605 9	0,604 9	0,604 3	0,604 2	0,604 2
0,58	—	—	—	—	—	0,609 8	0,608 5	0,606 1	0,605 1	0,604 4	0,604 3	0,604 3
0,59	—	—	—	—	—	0,610 1	0,608 8	0,606 3	0,605 2	0,604 6	0,604 5	0,604 4
0,60	—	—	—	—	—	0,610 5	0,609 1	0,606 5	0,605 3	0,604 7	0,604 5	0,604 5
0,61	—	—	—	—	—	—	0,609 3	0,606 7	0,605 4	0,604 7	0,604 6	0,604 6
0,62	—	—	—	—	—	—	0,609 5	0,606 8	0,605 5	0,604 8	0,604 6	0,604 6
0,63	—	—	—	—	—	—	0,609 7	0,606 8	0,605 5	0,604 7	0,604 6	0,604 6
0,64	—	—	—	—	—	—	0,609 9	0,606 9	0,605 5	0,604 7	0,604 5	0,604 5
0,65	—	—	—	—	—	—	0,610 0	0,606 8	0,605 4	0,604 6	0,604 4	0,604 4
0,66	—	—	—	—	—	—	0,610 0	0,606 8	0,605 3	0,604 4	0,604 3	0,604 2
0,67	—	—	—	—	—	—	0,610 0	0,606 6	0,605 1	0,604 2	0,604 0	0,604 0
0,68	—	—	—	—	—	—	0,609 9	0,606 4	0,604 8	0,603 9	0,603 8	0,603 7
0,69	—	—	—	—	—	—	0,609 8	0,606 2	0,604 5	0,603 6	0,603 4	0,603 4
0,70	—	—	—	—	—	—	0,609 6	0,605 8	0,604 1	0,603 1	0,602 9	0,602 9
0,71	—	—	—	—	—	—	0,609 3	0,605 4	0,603 6	0,602 6	0,602 4	0,602 4
0,72	—	—	—	—	—	—	0,608 9	0,604 9	0,603 0	0,602 0	0,601 8	0,601 7
0,73	—	—	—	—	—	—	—	0,604 3	0,602 3	0,601 2	0,601 0	0,601 0
0,74	—	—	—	—	—	—	—	0,603 5	0,601 5	0,600 4	0,600 2	0,600 1
0,75	—	—	—	—	—	—	—	0,602 7	0,600 6	0,599 4	0,599 2	0,599 2

NOTE — This table is given for convenience. The values given are not intended for precise interpolation. Extrapolation is not permitted.

Table A.7 — Orifice plate with flange tappings — Discharge coefficient, C, for $D = 200$ mm

Diameter ratio β	Discharge coefficient, C, for Re_D equal to										
	5×10^3	1×10^4	2×10^4	3×10^4	5×10^4	7×10^4	1×10^5	3×10^5	1×10^6	1×10^7	1×10^8	∞
0,20	—	—	0,597 9	0,597 7	0,597 4	0,597 3	0,597 2	0,597 1	0,597 0	0,597 0	0,596 9	0,596 9
0,22	—	—	0,598 4	0,598 1	0,597 8	0,597 7	0,597 5	0,597 3	0,597 2	0,597 2	0,597 2	0,597 2
0,24	—	—	0,599 0	0,598 6	0,598 2	0,598 0	0,597 9	0,597 6	0,597 5	0,597 4	0,597 4	0,597 4
0,26	—	—	0,599 6	0,599 1	0,598 7	0,598 5	0,598 3	0,598 0	0,597 8	0,597 7	0,597 7	0,597 7
0,28	—	—	0,600 3	0,599 7	0,599 2	0,598 9	0,598 7	0,598 3	0,598 1	0,598 0	0,598 0	0,598 0
0,30	—	—	—	0,600 3	0,599 7	0,599 4	0,599 2	0,598 7	0,598 5	0,598 4	0,598 4	0,598 4
0,32	—	—	—	0,601 0	0,600 3	0,599 9	0,599 7	0,599 1	0,598 9	0,598 7	0,598 7	0,598 7
0,34	—	—	—	0,601 8	0,600 9	0,600 5	0,600 2	0,599 6	0,599 3	0,599 1	0,599 1	0,599 1
0,36	—	—	—	—	0,601 6	0,601 2	0,600 8	0,600 1	0,599 7	0,599 5	0,599 5	0,599 5
0,38	—	—	—	—	0,602 4	0,601 8	0,601 4	0,600 6	0,600 2	0,600 0	0,599 9	0,599 9
0,40	—	—	—	—	0,603 1	0,602 5	0,602 0	0,601 1	0,600 7	0,600 4	0,600 4	0,600 4
0,42	—	—	—	—	0,604 0	0,603 3	0,602 7	0,601 6	0,601 1	0,600 9	0,600 8	0,600 8
0,44	—	—	—	—	0,604 8	0,604 0	0,603 4	0,602 2	0,601 7	0,601 4	0,601 3	0,601 3
0,46	—	—	—	—	—	0,604 8	0,604 1	0,602 8	0,602 2	0,601 8	0,601 8	0,601 8
0,48	—	—	—	—	—	0,605 6	0,604 8	0,603 4	0,602 7	0,602 3	0,602 2	0,602 2
0,50	—	—	—	—	—	0,606 5	0,605 6	0,604 0	0,603 2	0,602 8	0,602 7	0,602 7
0,51	—	—	—	—	—	0,606 9	0,605 9	0,604 2	0,603 4	0,603 0	0,602 9	0,602 9
0,52	—	—	—	—	—	0,607 3	0,606 3	0,604 5	0,603 7	0,603 2	0,603 1	0,603 1
0,53	—	—	—	—	—	—	0,606 7	0,604 8	0,603 9	0,603 4	0,603 3	0,603 3
0,54	—	—	—	—	—	—	0,607 0	0,605 0	0,604 1	0,603 6	0,603 5	0,603 5
0,55	—	—	—	—	—	—	0,607 3	0,605 3	0,604 3	0,603 8	0,603 7	0,603 7
0,56	—	—	—	—	—	—	0,607 7	0,605 5	0,604 5	0,604 0	0,603 9	0,603 8
0,57	—	—	—	—	—	—	0,608 0	0,605 7	0,604 7	0,604 1	0,604 0	0,604 0
0,58	—	—	—	—	—	—	0,608 3	0,605 9	0,604 8	0,604 2	0,604 1	0,604 1
0,59	—	—	—	—	—	—	0,608 6	0,606 1	0,605 0	0,604 3	0,604 2	0,604 2
0,60	—	—	—	—	—	—	0,608 8	0,606 3	0,605 1	0,604 4	0,604 3	0,604 3
0,61	—	—	—	—	—	—	0,609 0	0,606 4	0,605 1	0,604 4	0,604 3	0,604 3
0,62	—	—	—	—	—	—	0,609 2	0,606 4	0,605 2	0,604 4	0,604 3	0,604 3
0,63	—	—	—	—	—	—	0,609 4	0,606 5	0,605 1	0,604 4	0,604 3	0,604 2
0,64	—	—	—	—	—	—	—	0,606 5	0,605 1	0,604 3	0,604 2	0,604 1
0,65	—	—	—	—	—	—	—	0,606 4	0,605 0	0,604 1	0,604 0	0,604 0
0,66	—	—	—	—	—	—	—	0,606 3	0,604 8	0,603 9	0,603 8	0,603 8
0,67	—	—	—	—	—	—	—	0,606 1	0,604 5	0,603 7	0,603 5	0,603 5
0,68	—	—	—	—	—	—	—	0,605 9	0,604 2	0,603 3	0,603 2	0,603 1
0,69	—	—	—	—	—	—	—	0,605 5	0,603 9	0,602 9	0,602 7	0,602 7
0,70	—	—	—	—	—	—	—	0,605 1	0,603 4	0,602 4	0,602 2	0,602 2
0,71	—	—	—	—	—	—	—	0,604 6	0,602 8	0,601 8	0,601 6	0,601 6
0,72	—	—	—	—	—	—	—	0,604 0	0,602 1	0,601 1	0,600 9	0,600 9
0,73	—	—	—	—	—	—	—	0,603 3	0,601 4	0,600 3	0,600 1	0,600 0
0,74	—	—	—	—	—	—	—	0,602 5	0,600 5	0,599 3	0,599 1	0,599 1
0,75	—	—	—	—	—	—	—	0,601 5	0,599 4	0,598 3	0,598 1	0,598 0

NOTE — This table is given for convenience. The values given are not intended for precise interpolation. Extrapolation is not permitted.

Table A.8 — Orifice plate with flange tappings — Discharge coefficient, C, for $D = 250$ mm

Diameter ratio β	Discharge coefficient, C, for Re_D equal to											
	5×10^3	1×10^4	2×10^4	3×10^4	5×10^4	7×10^4	1×10^5	3×10^5	1×10^6	1×10^7	1×10^8	∞
0,20	—	—	0,597 9	0,597 7	0,597 4	0,597 3	0,597 2	0,597 1	0,597 0	0,597 0	0,597 0	0,596 9
0,22	—	—	0,598 4	0,598 1	0,597 8	0,597 7	0,597 6	0,597 3	0,597 2	0,597 2	0,597 2	0,597 2
0,24	—	—	0,599 0	0,598 6	0,598 2	0,598 0	0,597 9	0,597 6	0,597 5	0,597 5	0,597 4	0,597 4
0,26	—	—	—	0,599 1	0,598 7	0,598 5	0,598 3	0,598 0	0,597 8	0,597 7	0,597 7	0,597 7
0,28	—	—	—	0,599 7	0,599 2	0,598 9	0,598 7	0,598 3	0,598 1	0,598 0	0,598 0	0,598 0
0,30	—	—	—	0,600 3	0,599 7	0,599 4	0,599 2	0,598 7	0,598 5	0,598 4	0,598 4	0,598 4
0,32	—	—	—	—	0,600 3	0,599 9	0,599 7	0,599 1	0,598 9	0,598 7	0,598 7	0,598 7
0,34	—	—	—	—	0,600 9	0,600 5	0,600 2	0,599 6	0,599 3	0,599 1	0,599 1	0,599 1
0,36	—	—	—	—	0,601 6	0,601 2	0,600 8	0,600 1	0,599 7	0,599 5	0,599 5	0,599 5
0,38	—	—	—	—	0,602 4	0,601 8	0,601 4	0,600 6	0,600 2	0,600 0	0,599 9	0,599 9
0,40	—	—	—	—	—	0,602 5	0,602 0	0,601 1	0,600 6	0,600 4	0,600 4	0,600 4
0,42	—	—	—	—	—	0,603 2	0,602 7	0,601 6	0,601 1	0,600 9	0,600 8	0,600 8
0,44	—	—	—	—	—	0,604 0	0,603 4	0,602 2	0,601 6	0,601 3	0,601 3	0,601 3
0,46	—	—	—	—	—	0,604 8	0,604 1	0,602 8	0,602 2	0,601 8	0,601 7	0,601 7
0,48	—	—	—	—	—	—	0,604 8	0,603 3	0,602 7	0,602 3	0,602 2	0,602 2
0,50	—	—	—	—	—	—	0,605 5	0,603 9	0,603 2	0,602 7	0,602 7	0,602 6
0,51	—	—	—	—	—	—	0,605 9	0,604 2	0,603 4	0,602 9	0,602 9	0,602 9
0,52	—	—	—	—	—	—	0,606 2	0,604 5	0,603 6	0,603 2	0,603 1	0,603 1
0,53	—	—	—	—	—	—	0,606 6	0,604 7	0,603 8	0,603 4	0,603 3	0,603 3
0,54	—	—	—	—	—	—	0,606 9	0,605 0	0,604 1	0,603 5	0,603 5	0,603 4
0,55	—	—	—	—	—	—	0,607 3	0,605 2	0,604 3	0,603 7	0,603 6	0,603 6
0,56	—	—	—	—	—	—	0,607 6	0,605 4	0,604 4	0,603 9	0,603 8	0,603 7
0,57	—	—	—	—	—	—	—	0,605 6	0,604 6	0,604 0	0,603 9	0,603 9
0,58	—	—	—	—	—	—	—	0,605 8	0,604 7	0,604 1	0,604 0	0,604 0
0,59	—	—	—	—	—	—	—	0,606 0	0,604 8	0,604 2	0,604 1	0,604 1
0,60	—	—	—	—	—	—	—	0,606 1	0,604 9	0,604 2	0,604 1	0,604 1
0,61	—	—	—	—	—	—	—	0,606 2	0,605 0	0,604 3	0,604 1	0,604 1
0,62	—	—	—	—	—	—	—	0,606 3	0,605 0	0,604 2	0,604 1	0,604 1
0,63	—	—	—	—	—	—	—	0,606 3	0,604 9	0,604 2	0,604 0	0,604 0
0,64	—	—	—	—	—	—	—	0,606 2	0,604 8	0,604 1	0,603 9	0,603 9
0,65	—	—	—	—	—	—	—	0,606 1	0,604 7	0,603 9	0,603 7	0,603 7
0,66	—	—	—	—	—	—	—	0,606 0	0,604 5	0,603 7	0,603 5	0,603 5
0,67	—	—	—	—	—	—	—	0,605 8	0,604 2	0,603 4	0,603 2	0,603 2
0,68	—	—	—	—	—	—	—	0,605 5	0,603 9	0,603 0	0,602 8	0,602 8
0,69	—	—	—	—	—	—	—	0,605 1	0,603 5	0,602 5	0,602 4	0,602 3
0,70	—	—	—	—	—	—	—	0,604 7	0,602 9	0,602 0	0,601 8	0,601 8
0,71	—	—	—	—	—	—	—	0,604 1	0,602 3	0,601 3	0,601 1	0,601 1
0,72	—	—	—	—	—	—	—	0,603 5	0,601 6	0,600 6	0,600 4	0,600 3
0,73	—	—	—	—	—	—	—	0,602 7	0,600 8	0,599 7	0,599 5	0,599 5
0,74	—	—	—	—	—	—	—	0,601 8	0,599 8	0,598 7	0,598 5	0,598 5
0,75	—	—	—	—	—	—	—	0,600 8	0,598 7	0,597 6	0,597 4	0,597 3

NOTE — This table is given for convenience. The values given are not intended for precise interpolation. Extrapolation is not permitted.

Table A.9 — Orifice plate with flange tappings — Discharge coefficient, C, for $D = 375$ mm

Diameter ratio β	Discharge coefficient, C, for Re_D equal to											
	5×10^3	1×10^4	2×10^4	3×10^4	5×10^4	7×10^4	1×10^5	3×10^5	1×10^6	1×10^7	1×10^8	∞
0,20	—	—	0,597 9	0,597 7	0,597 4	0,597 3	0,597 2	0,597 1	0,597 0	0,597 0	0,597 0	0,597 0
0,22	—	—	—	0,598 1	0,597 8	0,597 7	0,597 6	0,597 3	0,597 3	0,597 2	0,597 2	0,597 2
0,24	—	—	—	0,598 6	0,598 2	0,598 0	0,597 9	0,597 6	0,597 5	0,597 5	0,597 4	0,597 4
0,26	—	—	—	—	0,598 7	0,598 5	0,598 3	0,598 0	0,597 8	0,597 7	0,597 7	0,597 7
0,28	—	—	—	—	0,599 2	0,598 9	0,598 7	0,598 3	0,598 2	0,598 1	0,598 0	0,598 0
0,30	—	—	—	—	0,599 7	0,599 4	0,599 2	0,598 7	0,598 5	0,598 4	0,598 4	0,598 4
0,32	—	—	—	—	0,600 3	0,600 0	0,599 7	0,599 1	0,598 9	0,598 8	0,598 7	0,598 7
0,34	—	—	—	—	—	0,600 5	0,600 2	0,599 6	0,599 3	0,599 1	0,599 1	0,599 1
0,36	—	—	—	—	—	0,601 2	0,600 8	0,600 1	0,599 7	0,599 5	0,599 5	0,599 5
0,38	—	—	—	—	—	0,601 8	0,601 4	0,600 6	0,600 2	0,600 0	0,599 9	0,599 9
0,40	—	—	—	—	—	—	0,602 0	0,601 1	0,600 6	0,600 4	0,600 4	0,600 3
0,42	—	—	—	—	—	—	0,602 7	0,601 6	0,601 1	0,600 9	0,600 8	0,600 8
0,44	—	—	—	—	—	—	0,603 3	0,602 2	0,601 6	0,601 3	0,601 3	0,601 2
0,46	—	—	—	—	—	—	0,604 0	0,602 7	0,602 1	0,601 8	0,601 7	0,601 7
0,48	—	—	—	—	—	—	—	0,603 3	0,602 6	0,602 2	0,602 2	0,602 2
0,50	—	—	—	—	—	—	—	0,603 8	0,603 1	0,602 7	0,602 6	0,602 6
0,51	—	—	—	—	—	—	—	0,604 1	0,603 3	0,602 9	0,602 8	0,602 8
0,52	—	—	—	—	—	—	—	0,604 4	0,603 5	0,603 1	0,603 0	0,603 0
0,53	—	—	—	—	—	—	—	0,604 6	0,603 8	0,603 3	0,603 2	0,603 2
0,54	—	—	—	—	—	—	—	0,604 9	0,604 0	0,603 4	0,603 4	0,603 3
0,55	—	—	—	—	—	—	—	0,605 1	0,604 1	0,603 6	0,603 5	0,603 5
0,56	—	—	—	—	—	—	—	0,605 3	0,604 3	0,603 7	0,603 6	0,603 6
0,57	—	—	—	—	—	—	—	0,605 5	0,604 4	0,603 9	0,603 8	0,603 7
0,58	—	—	—	—	—	—	—	0,605 6	0,604 6	0,603 9	0,603 8	0,603 8
0,59	—	—	—	—	—	—	—	0,605 8	0,604 6	0,604 0	0,603 9	0,603 9
0,60	—	—	—	—	—	—	—	0,605 9	0,604 7	0,604 0	0,603 9	0,603 9
0,61	—	—	—	—	—	—	—	0,606 0	0,604 7	0,604 0	0,603 9	0,603 9
0,62	—	—	—	—	—	—	—	0,606 0	0,604 7	0,604 0	0,603 9	0,603 8
0,63	—	—	—	—	—	—	—	0,606 0	0,604 6	0,603 9	0,603 8	0,603 7
0,64	—	—	—	—	—	—	—	0,605 9	0,604 5	0,603 7	0,603 6	0,603 6
0,65	—	—	—	—	—	—	—	0,605 8	0,604 3	0,603 5	0,603 4	0,603 4
0,66	—	—	—	—	—	—	—	0,605 6	0,604 1	0,603 3	0,603 1	0,603 1
0,67	—	—	—	—	—	—	—	0,605 4	0,603 8	0,602 9	0,602 8	0,602 7
0,68	—	—	—	—	—	—	—	0,605 0	0,603 4	0,602 5	0,602 3	0,602 3
0,69	—	—	—	—	—	—	—	0,604 6	0,602 9	0,602 0	0,601 8	0,601 8
0,70	—	—	—	—	—	—	—	0,604 1	0,602 4	0,601 4	0,601 2	0,601 2
0,71	—	—	—	—	—	—	—	0,603 5	0,601 7	0,600 7	0,600 5	0,600 5
0,72	—	—	—	—	—	—	—	0,602 8	0,600 9	0,599 9	0,599 7	0,599 7
0,73	—	—	—	—	—	—	—	0,602 0	0,600 0	0,598 9	0,598 7	0,598 7
0,74	—	—	—	—	—	—	—	0,601 0	0,599 0	0,597 9	0,597 7	0,597 6
0,75	—	—	—	—	—	—	—	0,599 9	0,597 8	0,596 6	0,596 4	0,596 4

NOTE — This table is given for convenience. The values given are not intended for precise interpolation. Extrapolation is not permitted.

Table A.10 — Orifice plate with flange tappings — Discharge coefficient, C, for D = 760 mm

Diameter ratio β	Discharge coefficient, C, for Re_D equal to											
	5×10^3	1×10^4	2×10^4	3×10^4	5×10^4	7×10^4	1×10^5	3×10^5	1×10^6	1×10^7	1×10^8	∞
0,20	—	—	—	—	0,597 4	0,597 3	0,597 2	0,597 1	0,597 0	0,597 0	0,597 0	0,597 0
0,22	—	—	—	—	0,597 8	0,597 7	0,597 6	0,597 4	0,597 3	0,597 2	0,597 2	0,597 2
0,24	—	—	—	—	—	0,598 1	0,597 9	0,597 7	0,597 5	0,597 5	0,597 5	0,597 5
0,26	—	—	—	—	—	0,598 5	0,598 3	0,598 0	0,597 8	0,597 8	0,597 7	0,597 7
0,28	—	—	—	—	—	—	0,598 7	0,598 3	0,598 2	0,598 1	0,598 0	0,598 0
0,30	—	—	—	—	—	—	0,599 2	0,598 7	0,598 5	0,598 4	0,598 4	0,598 4
0,32	—	—	—	—	—	—	0,599 7	0,599 1	0,598 9	0,598 8	0,598 7	0,598 7
0,34	—	—	—	—	—	—	—	0,599 6	0,599 3	0,599 1	0,599 1	0,599 1
0,36	—	—	—	—	—	—	—	0,600 1	0,599 7	0,599 5	0,599 5	0,599 5
0,38	—	—	—	—	—	—	—	0,600 5	0,600 2	0,600 0	0,599 9	0,599 9
0,40	—	—	—	—	—	—	—	0,601 1	0,600 6	0,600 4	0,600 4	0,600 3
0,42	—	—	—	—	—	—	—	0,601 6	0,601 1	0,600 8	0,600 8	0,600 8
0,44	—	—	—	—	—	—	—	0,602 1	0,601 6	0,601 3	0,601 2	0,601 2
0,46	—	—	—	—	—	—	—	0,602 7	0,602 1	0,601 7	0,601 7	0,601 7
0,48	—	—	—	—	—	—	—	0,603 2	0,602 6	0,602 2	0,602 1	0,602 1
0,50	—	—	—	—	—	—	—	0,603 8	0,603 0	0,602 6	0,602 5	0,602 5
0,51	—	—	—	—	—	—	—	0,604 0	0,603 3	0,602 8	0,602 7	0,602 7
0,52	—	—	—	—	—	—	—	0,604 3	0,603 5	0,603 0	0,602 9	0,602 9
0,53	—	—	—	—	—	—	—	0,604 5	0,603 7	0,603 2	0,603 1	0,603 1
0,54	—	—	—	—	—	—	—	0,604 8	0,603 8	0,603 3	0,603 2	0,603 2
0,55	—	—	—	—	—	—	—	0,605 0	0,604 0	0,603 5	0,603 4	0,603 4
0,56	—	—	—	—	—	—	—	—	0,604 2	0,603 6	0,603 5	0,603 5
0,57	—	—	—	—	—	—	—	—	0,604 3	0,603 7	0,603 6	0,603 6
0,58	—	—	—	—	—	—	—	—	0,604 4	0,603 8	0,603 7	0,603 6
0,59	—	—	—	—	—	—	—	—	0,604 5	0,603 8	0,603 7	0,603 7
0,60	—	—	—	—	—	—	—	—	0,604 5	0,603 8	0,603 7	0,603 7
0,61	—	—	—	—	—	—	—	—	0,604 5	0,603 8	0,603 7	0,603 6
0,62	—	—	—	—	—	—	—	—	0,604 4	0,603 7	0,603 6	0,603 6
0,63	—	—	—	—	—	—	—	—	0,604 4	0,603 6	0,603 5	0,603 4
0,64	—	—	—	—	—	—	—	—	0,604 2	0,603 4	0,603 3	0,603 3
0,65	—	—	—	—	—	—	—	—	0,604 0	0,603 2	0,603 0	0,603 0
0,66	—	—	—	—	—	—	—	—	0,603 7	0,602 9	0,602 7	0,602 7
0,67	—	—	—	—	—	—	—	—	0,603 4	0,602 5	0,602 3	0,602 3
0,68	—	—	—	—	—	—	—	—	0,602 9	0,602 0	0,601 9	0,601 8
0,69	—	—	—	—	—	—	—	—	0,602 4	0,601 5	0,601 3	0,601 3
0,70	—	—	—	—	—	—	—	—	0,601 8	0,600 8	0,600 6	0,600 6
0,71	—	—	—	—	—	—	—	—	0,601 1	0,600 1	0,599 9	0,599 8
0,72	—	—	—	—	—	—	—	—	0,600 2	0,599 2	0,599 0	0,598 9
0,73	—	—	—	—	—	—	—	—	0,599 2	0,598 2	0,598 0	0,597 9
0,74	—	—	—	—	—	—	—	—	0,598 1	0,597 0	0,596 8	0,596 8
0,75	—	—	—	—	—	—	—	—	0,596 9	0,595 7	0,595 5	0,595 4

NOTE — This table is given for convenience. The values given are not intended for precise interpolation. Extrapolation is not permitted.

Table A.11 — Orifice plate with flange tappings — Discharge coefficient, C, for D = 1 000 mm

Diameter ratio β	Discharge coefficient, C, for Re_D equal to											
	5 × 10^3	1 × 10^4	2 × 10^4	3 × 10^4	5 × 10^4	7 × 10^4	1 × 10^5	3 × 10^5	1 × 10^6	1 × 10^7	1 × 10^8	∞
0,20	—	—	—	—	—	0,597 3	0,597 3	0,597 1	0,597 0	0,597 0	0,597 0	0,597 0
0,22	—	—	—	—	—	0,597 7	0,597 6	0,597 4	0,597 3	0,597 2	0,597 2	0,597 2
0,24	—	—	—	—	—	—	0,597 9	0,597 7	0,597 5	0,597 5	0,597 5	0,597 5
0,26	—	—	—	—	—	—	0,598 3	0,598 0	0,597 8	0,597 8	0,597 7	0,597 7
0,28	—	—	—	—	—	—	0,598 7	0,598 3	0,598 2	0,598 1	0,598 0	0,598 0
0,30	—	—	—	—	—	—	—	0,598 7	0,598 5	0,598 4	0,598 4	0,598 4
0,32	—	—	—	—	—	—	—	0,599 1	0,598 9	0,598 8	0,598 7	0,598 7
0,34	—	—	—	—	—	—	—	0,599 6	0,599 3	0,599 1	0,599 1	0,599 1
0,36	—	—	—	—	—	—	—	0,600 1	0,599 7	0,599 5	0,599 5	0,599 5
0,38	—	—	—	—	—	—	—	0,600 5	0,600 2	0,600 0	0,599 9	0,599 9
0,40	—	—	—	—	—	—	—	0,601 1	0,600 6	0,600 4	0,600 3	0,600 3
0,42	—	—	—	—	—	—	—	0,601 6	0,601 1	0,600 8	0,600 8	0,600 8
0,44	—	—	—	—	—	—	—	0,602 1	0,601 6	0,601 3	0,601 2	0,601 2
0,46	—	—	—	—	—	—	—	0,602 7	0,602 1	0,601 7	0,601 7	0,601 7
0,48	—	—	—	—	—	—	—	0,603 2	0,602 6	0,602 2	0,602 1	0,602 1
0,50	—	—	—	—	—	—	—	0,603 8	0,603 0	0,602 6	0,602 5	0,602 5
0,51	—	—	—	—	—	—	—	—	0,603 2	0,602 8	0,602 7	0,602 7
0,52	—	—	—	—	—	—	—	—	0,603 4	0,603 0	0,602 9	0,602 9
0,53	—	—	—	—	—	—	—	—	0,603 6	0,603 2	0,603 1	0,603 0
0,54	—	—	—	—	—	—	—	—	0,603 8	0,603 3	0,603 2	0,603 2
0,55	—	—	—	—	—	—	—	—	0,604 0	0,603 5	0,603 4	0,603 3
0,56	—	—	—	—	—	—	—	—	0,604 1	0,603 6	0,603 5	0,603 5
0,57	—	—	—	—	—	—	—	—	0,604 3	0,603 7	0,603 6	0,603 5
0,58	—	—	—	—	—	—	—	—	0,604 4	0,603 7	0,603 6	0,603 6
0,59	—	—	—	—	—	—	—	—	0,604 4	0,603 8	0,603 7	0,603 6
0,60	—	—	—	—	—	—	—	—	0,604 4	0,603 8	0,603 7	0,603 6
0,61	—	—	—	—	—	—	—	—	0,604 4	0,603 7	0,603 6	0,603 6
0,62	—	—	—	—	—	—	—	—	0,604 4	0,603 7	0,603 5	0,603 5
0,63	—	—	—	—	—	—	—	—	0,604 3	0,603 5	0,603 4	0,603 4
0,64	—	—	—	—	—	—	—	—	0,604 1	0,603 3	0,603 2	0,603 2
0,65	—	—	—	—	—	—	—	—	0,603 9	0,603 1	0,603 0	0,602 9
0,66	—	—	—	—	—	—	—	—	0,603 6	0,602 8	0,602 6	0,602 6
0,67	—	—	—	—	—	—	—	—	0,603 3	0,602 4	0,602 2	0,602 2
0,68	—	—	—	—	—	—	—	—	0,602 8	0,601 9	0,601 8	0,601 7
0,69	—	—	—	—	—	—	—	—	0,602 3	0,601 4	0,601 2	0,601 1
0,70	—	—	—	—	—	—	—	—	0,601 7	0,600 7	0,600 5	0,600 5
0,71	—	—	—	—	—	—	—	—	0,600 9	0,599 9	0,599 7	0,599 7
0,72	—	—	—	—	—	—	—	—	0,600 1	0,599 0	0,598 8	0,598 8
0,73	—	—	—	—	—	—	—	—	0,599 1	0,598 0	0,597 8	0,597 7
0,74	—	—	—	—	—	—	—	—	0,597 9	0,596 8	0,596 6	0,596 6
0,75	—	—	—	—	—	—	—	—	0,596 6	0,595 5	0,595 3	0,595 2

NOTE — This table is given for convenience. The values given are not intended for precise interpolation. Extrapolation is not permitted.

Table A.12 — ISA 1932 nozzle — Discharge coefficient, C

Diameter ratio β	Discharge coefficient, C, for Re_D equal to								
	2×10^4	3×10^4	5×10^4	7×10^4	1×10^5	3×10^5	1×10^6	2×10^6	1×10^7
0,30	—	—	—	0,985 5	0,986 5	0,987 8	0,988 2	0,988 3	0,988 4
0,32	—	—	—	0,984 7	0,985 8	0,987 3	0,987 7	0,987 8	0,987 9
0,34	—	—	—	0,983 8	0,985 0	0,986 6	0,987 1	0,987 2	0,987 3
0,36	—	—	—	0,982 8	0,984 0	0,985 9	0,986 4	0,986 5	0,986 6
0,38	—	—	—	0,981 6	0,983 0	0,984 9	0,985 5	0,985 6	0,985 7
0,40	—	—	—	0,980 3	0,981 8	0,983 9	0,984 5	0,984 6	0,984 7
0,42	—	—	—	0,978 9	0,980 5	0,982 7	0,983 3	0,983 4	0,983 5
0,44	0,961 6	0,969 2	0,975 0	0,977 3	0,978 9	0,981 3	0,982 0	0,982 1	0,982 2
0,45	0,960 4	0,968 2	0,974 1	0,976 4	0,978 1	0,980 5	0,981 2	0,981 3	0,981 4
0,46	0,959 2	0,967 2	0,973 1	0,975 5	0,977 3	0,979 7	0,980 4	0,980 5	0,980 6
0,47	0,957 9	0,966 1	0,972 2	0,974 6	0,976 3	0,978 8	0,979 5	0,979 7	0,979 7
0,48	0,956 7	0,965 0	0,971 1	0,973 6	0,975 4	0,977 9	0,978 6	0,978 7	0,978 8
0,49	0,955 4	0,963 8	0,970 0	0,972 6	0,974 3	0,976 9	0,977 6	0,977 7	0,977 8
0,50	0,954 2	0,962 6	0,968 9	0,971 5	0,973 3	0,975 8	0,976 6	0,976 7	0,976 8
0,51	0,952 9	0,961 4	0,967 8	0,970 3	0,972 1	0,974 7	0,975 4	0,975 6	0,975 7
0,52	0,951 6	0,960 2	0,966 5	0,969 1	0,970 9	0,973 5	0,974 3	0,974 4	0,974 5
0,53	0,950 3	0,958 9	0,965 3	0,967 8	0,969 6	0,972 2	0,973 0	0,973 1	0,973 2
0,54	0,949 0	0,957 6	0,963 9	0,966 5	0,968 3	0,970 9	0,971 7	0,971 8	0,971 9
0,55	0,947 7	0,956 2	0,962 6	0,965 1	0,966 9	0,969 5	0,970 2	0,970 4	0,970 5
0,56	0,946 4	0,954 8	0,961 1	0,963 7	0,965 5	0,968 0	0,968 8	0,968 9	0,969 0
0,57	0,945 1	0,953 4	0,959 6	0,962 1	0,963 9	0,966 4	0,967 2	0,967 3	0,967 4
0,58	0,943 8	0,952 0	0,958 1	0,960 6	0,962 3	0,964 8	0,965 5	0,965 6	0,965 7
0,59	0,942 4	0,950 5	0,956 5	0,958 9	0,960 6	0,963 0	0,963 8	0,963 9	0,964 0
0,60	0,941 1	0,949 0	0,954 8	0,957 2	0,958 8	0,961 2	0,961 9	0,962 0	0,962 1
0,61	0,939 8	0,947 4	0,953 1	0,955 4	0,957 0	0,959 3	0,960 0	0,960 1	0,960 2
0,62	0,938 5	0,945 8	0,951 3	0,953 5	0,955 0	0,957 3	0,957 9	0,958 0	0,958 1
0,63	0,937 1	0,944 2	0,949 4	0,951 5	0,953 0	0,955 1	0,955 8	0,955 9	0,956 0
0,64	0,935 8	0,942 5	0,947 5	0,949 5	0,950 9	0,952 9	0,953 5	0,953 6	0,953 7
0,65	0,934 5	0,940 8	0,945 5	0,947 3	0,948 7	0,950 6	0,951 1	0,951 2	0,951 3
0,66	0,933 2	0,939 0	0,943 4	0,945 1	0,946 4	0,948 1	0,948 7	0,948 7	0,948 8
0,67	0,931 9	0,937 2	0,941 2	0,942 8	0,944 0	0,945 6	0,946 0	0,946 1	0,946 2
0,68	0,930 6	0,935 4	0,939 0	0,940 4	0,941 4	0,942 9	0,943 3	0,943 4	0,943 5
0,69	0,929 3	0,933 5	0,936 7	0,937 9	0,938 8	0,940 1	0,940 5	0,940 5	0,940 6
0,70	0,928 0	0,931 6	0,934 3	0,935 3	0,936 1	0,937 2	0,937 5	0,937 5	0,937 6
0,71	0,926 8	0,929 6	0,931 8	0,932 6	0,933 2	0,934 1	0,934 4	0,934 4	0,934 4
0,72	0,925 5	0,927 6	0,929 2	0,929 8	0,930 3	0,930 9	0,931 1	0,931 1	0,931 2
0,73	0,924 3	0,925 6	0,926 5	0,926 9	0,927 2	0,927 6	0,927 7	0,927 7	0,927 8
0,74	0,923 1	0,923 5	0,923 8	0,923 9	0,924 0	0,924 1	0,924 2	0,924 2	0,924 2
0,75	0,921 9	0,921 3	0,920 9	0,920 8	0,920 7	0,920 5	0,920 5	0,920 5	0,920 5
0,76	0,920 7	0,919 2	0,918 0	0,917 6	0,917 2	0,916 8	0,916 6	0,916 6	0,916 6
0,77	0,919 5	0,916 9	0,915 0	0,914 2	0,913 6	0,912 8	0,912 6	0,912 6	0,912 5
0,78	0,918 4	0,914 7	0,911 8	0,910 7	0,909 9	0,908 8	0,908 4	0,908 4	0,908 3
0,79	0,917 3	0,912 3	0,908 6	0,907 1	0,906 0	0,904 5	0,904 1	0,904 0	0,904 0
0,80	0,916 2	0,910 0	0,905 3	0,903 4	0,902 0	0,900 1	0,899 6	0,899 5	0,899 4

NOTE — This table is given for convenience. The values given are not intended for precise interpolation. Extrapolation is not permitted.