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Measurement of fluid flow in closed conduits

Part 1. Pressure differential devices

Section 1.1 Specification for square-edged orifice plates, nozzles and venturi tubes inserted in circular cross-section conduits running full

Mesure de débit des fluides dans les conduites fermées

Partie 1. Appareils déprimogènes

Section 1.1 Diaphragmes à arêtes vives, tuyères et tubes de venturi insérés dans des conduites en charge de section circulaire — Spécifications

Durchflußmessung von Flüssigkeiten in geschlossenen Leitungen

Teil 1. Differenzdruckmeßgeräte

Abschnitt 1.1 Anforderungen an scharfkantige Blenden, Düsen und Venturi-Röhren bei voller Strömung in Leitungen mit rundem Querschnitt

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Foreword

This British Standard has been prepared under the direction of the Industrial-process Measurement and Control Standards Committee. It is technically equivalent to ISO 5167 — 1980 'Measurement of fluid flow by means of orifice plates, nozzles and venturi tubes inserted in circular cross-section conduits running full', published by the International Organization for Standardization (ISO).

For ease of reproduction the text of ISO 5167 has been used with certain editorial changes made in order to clarify the text. Some terminology and certain conventions are not identical with those used in British Standards; attention is especially drawn to the following.

The comma has been used throughout as a decimal marker. In British Standards it is current practice to use a full stop on the baseline as the decimal marker.

BS 1042 : Part 1 : 1964 is being revised in four Sections of which this is Section 1.1. Section 1.2 provides supplementary information to Section 1.1, consisting of the specification of the geometry and method of use (installation and operating conditions) of pressure difference devices not dealt with in Section 1.1. Those devices are:

- conical orifice plates;
- quarter circle orifice plates;
- eccentric orifice plates;
- Borda inlets for air measurements.

Information is also given on using square-edged orifice plate installations under conditions not covered in Section 1.1.

Those conditions include the following:

- drain holes through the orifice plate or nozzle;
- orifice plates installed in pipes with diameters in the range $25 \text{ mm} \leq D < 50 \text{ mm}$;
- orifice plates, nozzles or venturi nozzles installed where there is no upstream or downstream pipeline.

Section 1.3 (under consideration) will deal with critical flow measurement and the requirements for and the method of use of critical flow venturi nozzles inserted in a closed conduit to determine the rate of flow of the fluid flowing in the conduit. Section 1.3 will also cover the calculation of critical flowrates and their associated uncertainties.

Section 1.4 contains sample calculations, physical data and other additional information on using pressure differential devices specified in Sections 1.1 and 1.2.

An index is provided in Section 1.4 to facilitate the rapid cross-referencing of subject matter.

It should be noted that guidance on the effects of departure from the requirements given in this standard can be found in BS 1042 : Part 3 : 1965.

British Standard

Measurement of fluid flow in closed conduits

Part 1. Pressure differential devices

Section 1.1 Specification for square-edged orifice plates, nozzles and venturi tubes inserted in circular cross section conduits running full

1 SCOPE AND FIELD OF APPLICATION

This British Standard specifies the geometry and method of use (installation and operating conditions) of square-edged orifice plates, nozzles and venturi tubes when they are inserted in a conduit running full, to determine the 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 difference devices in which the flow remains subsonic throughout the measuring section, is steady or varies only slowly with time and the fluid is single-phased. In addition, each of these devices can only be used within limits which are specified, for example of pipe size and Reynolds number. Thus this British Standard does not apply for pipe sizes less than 50 mm or more than 1 200 mm or for pipe Reynolds numbers below 3150.

It deals with devices for which direct calibration experiments have been made, sufficient in number and quantity 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 tapplings. All other instruments or devices required for the measurement are known as "secondary devices". This British Standard covers the primary devices; but secondary devices¹⁾ are mentioned occasionally.

The different primary devices dealt with are as follows:

- orifice plates, which can be used with the various following arrangements of pressure tapplings :

- corner pressure tapplings,
- D and $D/2$ pressure tapplings,²⁾
- flange pressure tapplings,
- nozzles :
 - ISA 1932 nozzle³⁾,
 - long radius nozzle,

which differ in shape and/or in the position of the pressure tapplings,

- venturi tubes :
 - classical venturi tube⁴⁾,
 - venturi-nozzle,

which differ in shape and/or in the position of pressure tapplings.

NOTE. The titles of the standards publications referred to in this standard are listed on the inside back cover.

2 SYMBOLS AND DEFINITIONS

The vocabulary and symbols used in this British Standard are defined in BS 5875, but for convenience those symbols which are used in this British Standard are reproduced in table 1.

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

1) See ISO 2186, *Fluid flow in closed conduits — Connections for pressure signal transmission between primary and secondary devices*.

2) Orifice plates with *vena contracta* pressure tapplings are not considered in this British Standard.

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

4) In the U.S.A. the classical venturi tube is sometimes called Herschel venturi tube.

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2.1 Symbols

TABLE 1 — Symbols

Symbols	Represented quantity	Dimensions M : mass L : length T : time Θ : temperature	SI Unit
C	Coefficient of discharge, $C = \frac{\alpha}{E}$	dimensionless	
d	Diameter of orifice or throat of primary device at operating conditions	L	m
D	Upstream internal pipe diameter (or upstream diameter of a classical venturi tube) at operating conditions	L	m
e	Relative uncertainty	dimensionless	
E	Velocity of approach factor, $E = (1 - \beta^4)^{-1/2}$	dimensionless	
k	Uniform equivalent roughness (see 7.3.1)	L	m
l	Pressure tapping spacing	L	m
L	Relative pressure tapping spacing, $L = \frac{l}{D}$	dimensionless	
p	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 from the mean line of the profile ²⁾	L	m
Re	Reynolds number	dimensionless	
Re_D Re_d	Reynolds number referred to D or d	dimensionless	
t	Temperature of the fluid	Θ	°C
U	Mean axial velocity of the fluid in the pipe	LT^{-1}	m/s
X	Acoustic ratio, $X = \frac{\Delta p}{p_1 \kappa}$	dimensionless	
α	Flow coefficient	dimensionless	
β	Diameter ratio, $\beta = \frac{d}{D}$	dimensionless	
γ	Specific heat capacities ratio ¹⁾	dimensionless	
Δp	Differential pressure	$ML^{-1}T^{-2}$	Pa
$\Delta \bar{p}$	Pressure loss	$ML^{-1}T^{-2}$	Pa
ϵ	Expansibility (expansion) factor	dimensionless	
κ	Isentropic exponent ¹⁾	dimensionless	
μ	Dynamic viscosity of the fluid	$ML^{-1}T^{-1}$	Pa.s
ν	Kinematic viscosity of the fluid, $\nu = \frac{\mu}{\rho}$	L^2T^{-1}	m^2/s
ξ	Relative pressure loss	dimensionless	
ρ	Mass 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	dimensionless	radian

1) 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 values (see 2.4.3). These values depend on the nature of the gas.

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

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

2) See BS 1134

2.2 Pressure measurement : Definitions

2.2.1 wall pressure tapping : Hole drilled in the wall of a pipe, the inside edge of which is flush with the inside surface of the pipe.

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

2.2.2 static pressure of a fluid flowing through a straight pipe-line : Pressure which can be measured by connecting a pressure gauge to a wall pressure tapping. Only the value of the absolute static pressure is used in this British Standard.

2.2.3 differential pressure : Difference between the static pressure measured at the wall tapplings, one of which is on the upstream side and the other 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 tapplings has been taken into account.

The term "differential pressure" is used only if the pressure tapplings are in the positions specified by this British Standard for each standard primary device.

2.2.4 pressure ratio : the absolute static pressure at the downstream pressure tapping, divided by that at the upstream pressure tapping.

2.3 Primary devices : Definitions

2.3.1 orifice or throat : Opening of minimum cross-sectional area in a primary device.

Standard primary device orifices are circular and coaxial with the pipe-line.

2.3.2 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.

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

2.3.4 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".

2.3.5 diameter ratio of a primary device in a given pipe : The diameter of the orifice (or throat) of the primary device divided by the internal diameter of the measuring pipe upstream of the primary device.

However, when the primary device has a cylindrical section upstream, equivalent in diameter to that of the pipe (as in the case of the classical venturi tube), the diameter ratio is the quotient of the throat diameter divided by the diameter of this cylindrical section at the plane of the upstream pressure tapplings.

2.4 Flow : Definitions

2.4.1 rate of flow of fluid passing through a primary device : 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, expressed in mass per time unit, or the volume rate of flow, expressed in volume per time unit, is being used.

2.4.2 Reynolds number

The Reynolds number used in this British Standard is referred to :

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

$$Re_D = \frac{U_1 D}{\nu_1}$$

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

$$Re_d = Re_D \times \beta^{-1}$$

2.4.3 isentropic exponent

The isentropic exponent κ appears in the different formulae for the expansibility (expansion) factor ϵ either directly or in the ratio X . The isentropic exponent 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 purpose of this British Standard, the ratio of the specific heat capacities of ideal gases may be used in place of the isentropic exponent for the computation of the rate of flow.

2.4.4 acoustic ratio : The differential pressure ratio divided by the isentropic exponent (compressible fluid).

2.4.5 velocity of approach factor

It is equal to :

$$E = (1 - \beta^4)^{-1/2} = \frac{D^2}{\sqrt{D^4 - d^4}}$$

2.4.6 flow and discharge coefficients

Calibration of standard primary devices by means of nominally incompressible fluids (liquids) shows that α , called the flow coefficient, a pure number defined by the following relation, is dependent only on the Reynolds number for a given primary device in a given installation.

$$\alpha = \frac{q_m}{\frac{\pi}{4} d^2 \sqrt{2 \Delta p \times \rho_1}}$$

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

The ratio $C = \frac{\alpha}{E}$ is called the "discharge coefficient".

The equations for the numerical values of α and of C given in this British Standard were based on data determined experimentally.

2.4.7 expansibility (expansion) factor

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

$$\frac{q_m}{\frac{\pi}{4} d^2 \sqrt{2 \Delta p \times \rho_1}}$$

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

The method adopted for representing these variations consists in multiplying the flow coefficient α of the primary device, as determined by direct calibration effected by means of liquids for the same value of Reynolds number, by the "expansibility", a so-called (expansion) factor defined by the relation :

$$e = \frac{q_m}{\alpha \frac{\pi}{4} d^2 \sqrt{2 \Delta p \times \rho_1}}$$

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

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

The numerical values of e given in this British Standard have been based on data determined experimentally.

2.4.8 roughness criterion

The roughness criterion $R_a^{1)}$ equals the 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 the rougher surfaces of pipes.

For pipes, the equivalent roughness is used. This height k can be determined experimentally (see 7.3.1) or taken from tables (see table 6).

3 PRINCIPLE OF THE METHOD OF MEASUREMENT AND COMPUTATION

3.1 Principle of the method of measurement

The principle of the method of measurement is based on the insertion of a primary device (such as an orifice plate, a nozzle or a venturi tube) into a pipe-line in which a fluid is running full. 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 a knowledge of the characteristics of flowing fluid as well as the circumstances under which the device is being used. It is assumed the device is geometrically similar to one on which calibration has been made and that the conditions of use are the same, i.e. that it is in accordance with this British Standard.

The rate of flow can be determined since the mass rate of flow is related to the pressure differential within the uncertainty stated in this British Standard, by the following formulae :

$$q_m = \alpha e \frac{\pi}{4} d^2 \sqrt{2 \Delta p \times \rho_1} \quad \dots (1)$$

or

$$q_m = CE e \frac{\pi}{4} d^2 \sqrt{2 \Delta p \times \rho_1} \quad \dots (2)$$

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

$$q_v = \frac{q_m}{\rho} \quad \dots (3)$$

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

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

In practice, in determining the diameter of a primary element to be installed in a given pipe line, α or CE used in the basic formulae (1) or (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.

1) The roughness criterion used in this standard is that given in BS 1134.

The related values of q_m and Δp shall then be inserted in the basic formulae rewritten in the form below :

$$\alpha \beta^2 = \frac{4 q_m}{\epsilon \pi D^2 \sqrt{2 \Delta p \times \rho_1}}$$

and the diameter ratio of the selected primary device can be determined by successive approximations.

3.3 Computation of rate of flow

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 formulae (1) or (2) by their numerical values taking into account the following :

- a) α may be dependent on Re , which is itself dependent on q_m . In such cases the final value of α , and hence of q_m , is to be obtained by iteration from an initial chosen value of α (or Re). Generally it may be convenient to adopt the value of α at a Reynolds number of 10^6 as the starting point.
- b) Δp represents the differential pressure, as defined under 2.2.3.
- c) d and D in the formulae, are the values of the diameters at operating conditions; measurements taken at ambient conditions shall be corrected for any possible expansion or contraction of the primary device and the pipe due to the values of fluid temperature and pressure during the measurement.
- d) It is necessary to know the mass density and the viscosity of the fluid under the conditions of the measurement.

3.4 Determination of mass density

The mass density of the fluid is required to be known at the plane of the upstream pressure tapping; it can either be measured directly or calculated from the knowledge of static pressure, temperature and characteristics of the fluid at this plane.

3.4.1 The static pressure of the fluid shall be measured in the plane of the upstream pressure tapping, by means

of an individual pipe-wall pressure tapping (as described in 7.2.1) or by means of a carrier ring tapping (as described in 7.2.4).

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

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

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

3.4.2 Although the temperature of the fluid from which the density and viscosity are calculated is that measured in the upstream pressure tapping plane, the temperature of the fluid shall preferably be measured downstream of the primary device, and 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 $5D$ if the pocket is located downstream, and in accordance with the last two lines of table 3 if the pocket is located upstream.

If the measured fluid is a gas, its upstream temperature may be calculated from the temperature measured on the downstream side when assuming an isentropic expansion through the primary device.

3.4.3 Any method of determining reliable values of mass density, static pressure, temperature and viscosity is acceptable if it does not interfere with the distribution of flow in any way.

3.4.4 The temperature of the primary device and that of the fluid upstream of the primary device are assumed to be the same (see 6.1.9).

4 SELECTION OF THE PRIMARY DEVICE

Table 2 gives criteria for the selection of the primary device to meet the required characteristics.

TABLE 2 — Selection criteria of the type of primary device

Characteristics to be considered	Factors to be considered in selection
Pipe diameter Diameter ratio Reynolds number	For each primary device, there exist limiting values of the internal pipe diameter, the diameter ratio β and the flow Reynolds number. If the chosen value of the differential pressure and flow-rate are such that the value of β for an orifice plate exceeds the permissible limit, it may be possible to use a nozzle since it results in a lower β value for the same conditions.
Pressure loss	For the same pressure difference, pressure losses are 4 to 6 times lower for classical venturi tubes and venturi nozzles than for orifice plates and nozzles.
Straight lengths to be provided upstream and downstream	Classical venturi tubes require smaller pipe straight lengths than orifice plates, nozzles and venturi nozzles.
Overall dimensions	The required distance between flanges to mount the device into the pipe is significant for classical venturi tubes and venturi nozzles.
Type of fluid	With abrasive or corrosive fluids, the coefficients of orifice plates may change steadily with time as the square edge becomes rounded; surface deposits on nozzles and venturi tubes have an immediate effect on the flow coefficient but thereafter there is a probability that the change with time will be less.
Accuracy	The uncertainties on the flow-rate coefficient are defined for each primary device.
Cost and manufacture	Orifice plates are cheaper and simpler to manufacture than any other primary device.

5 GENERAL REQUIREMENTS FOR THE MEASUREMENTS

It is necessary to ensure that all the following requirements, some of which are explained in detail in the following sections, are completely fulfilled during the period of measurement.

5.1 Primary device

5.1.1 The primary device shall be manufactured, installed and used in accordance with this British Standard.

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

5.1.2 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 the conformity with this British Standard is maintained.

Attention is drawn to the fact that even apparently neutral fluids may form deposits or encrustations on primary

devices. Variations or changes in the discharge coefficient which may occur over a period of time may lead to values outside the uncertainties given in this British Standard.

5.1.3 The primary device shall be manufactured from material the coefficient of expansion of which is known.

5.2 Type of fluid

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

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

5.2.3 To carry out the measurement, it is necessary to know the density and viscosity of the fluid under the conditions of measurement.

5.3 Flow conditions

5.3.1 The rate of flow shall be constant or, in practice, vary only slightly and slowly with time. This British Standard does not provide for the measurement of pulsating flow.¹⁾

5.3.2 The flow of fluid through the primary device shall not cause any change of phase. To determine whether or not there is a change of phase, the computation of flow shall be carried out on the assumption that the expansion is isentropic if the fluid is a gas, or isothermal if the fluid is a liquid.

5.3.3 If the fluid is a gas, the pressure ratio as defined in 2.2.4 shall be equal to or greater than 0,75.

6 INSTALLATION REQUIREMENTS

6.1 General

6.1.1 The method of measurement applies only to fluids flowing through a pipe-line of circular cross-section.

6.1.2 The pipe shall run full at the measuring section.

6.1.3 The primary device shall be installed in the pipe-line at a position such that the flow conditions immediately upstream approach those of a fully developed profile and are free from swirl (see 6.4). Such conditions may be expected to exist if the installation complies with the requirements given in this clause.

6.1.4 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 British Standard.

The pipe is considered 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 3 and 4.

6.1.5 The values for the pipe diameter D to be used in the computation of the diameter ratio shall be the mean of the internal diameters over a length of $0,5 D$ upstream of the upstream pressure tapping. This internal mean diameter shall be the arithmetic mean of measurements at four

diameters at least, distributed in each of at least three cross sections themselves distributed over a length of $0,5 D$, two of these sections being at distances $0 D$ and $0,5 D$ from the upstream tapping. If there is a carrier ring (figure 4 a) this value of $0,5 D$ is to be taken from the upstream edge of the carrier ring

6.1.6 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 mere visual inspection. The circularity of the outside of the pipe may 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 6.5.1 and 6.6.1).

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

6.1.8 The inside surface of the measuring pipe shall be clean, free from pitting and deposit and encrustations for at least a length of $10 D$ upstream and $4 D$ downstream of the primary device.

6.1.9 The measuring section 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 straight length of the downstream pipe, does not exceed any limiting value for the accuracy of flow measurement required.

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

6.2.1 The minimum straight lengths are given in tables 3 and 4.

6.2.2 The straight lengths given in tables 3 and 4 are minimum values, and straight lengths longer than those indicated are always recommended. For research work especially at least double the upstream values given in tables 3 and 4 are recommended for "zero additional uncertainty".

6.2.3 When the straight lengths are longer than or equal to the values given in tables 3 and 4 for "zero additional uncertainty"²⁾, there is no need to add any additional deviation to the flow coefficient uncertainty to take account of the effect of such installation conditions.

1) This is the subject of ISO Technical Report 3313 "Measurement of pulsating fluid flow by means of orifice plates, nozzles or venturi tubes, in particular in the case of sinusoidal or square wave intermittent periodic type fluctuation".

2) Unbracketed values in tables 3 and 4.

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6.2.4 When the upstream OR downstream straight lengths are shorter than the "zero additional uncertainty" values¹⁾ and equal to or greater than the " $\pm 0,5\%$ additional uncertainty" values²⁾, as given in tables 3 and 4, an additional deviation of $\pm 0,5\%$ shall be added arithmetically to the uncertainty on the flow coefficient.

6.2.5 If the straight lengths are shorter than "the $\pm 0,5\%$ additional uncertainty" values²⁾ given in tables 3 and 4, this British Standard gives no information by which to predict the value of any further uncertainty to be taken into account; this is also the case when the upstream AND

downstream straight lengths are simultaneously shorter than the "zero additional uncertainty" values¹⁾.

6.2.6 The valves mentioned in tables 3 and 4 shall be fully open. It is recommended that control of flow be effected by valves located downstream of the primary device. Isolating valves located upstream shall be preferably of the "gate" type and shall be fully open.

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

TABLE 3 — Required straight lengths for orifice plates, nozzles and venturi nozzles

Minimum straight lengths required between various fittings located upstream or downstream of the primary device and the primary device itself.

The unbracketed values are "zero additional uncertainty" values (see 6.2.3).

The bracketed values are " $\pm 0,5\%$ additional uncertainty" values (see 6.2.4).

All straight lengths are expressed as multiples of the diameter D . They shall be measured from the upstream face of the primary device.

β	Upstream (inlet) side of the primary device							Down-stream (outlet) side
	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 (2 D to D over a length of 1,5 D to 3 D)	Expander (0,5 D to D over a length of 1 D to 2 D)	Globe valve fully open	Gate valve fully open	All fittings included in this table
$\leq 0,20$	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)	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)

For all β values	Fittings	Minimum upstream (inlet) straight length required
	Abrupt symmetrical reduction having a diameter ratio $\geq 0,5$	30 (15)
	Thermometer pocket or well of diameter $\leq 0,03 D$ Thermometer pocket or well of diameter between $0,03 D$ and $0,13 D$	5 (3) 20 (10)

1) Unbracketed values in tables 3 and 4.

2) Bracketed values in tables 3 and 4.

TABLE 4 — Required upstream straight lengths for classical venturi tubes

Minimum straight lengths required between various fittings located upstream of the classical venturi tube and the classical venturi tube itself.

The values without brackets are values for a "zero additional uncertainty" (see 6.2.3).

The values between brackets are values for an "additional uncertainty of $\pm 0,5\%$ " (see 6.2.4).

All straight lengths are expressed as multiples of diameter D . They shall be measured from the pressure tapping plane upstream of the classical venturi tube. The pipe roughness, at least over the length indicated in table 4 shall not exceed that of a smooth, commercially available pipe-line (approximately $k/D \leq 10^{-3}$).

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

Diameter ratio	Single 90° short radius bend ¹⁾	Two or more 90° bends in the same plane ¹⁾	Two or more 90° bends in different planes ^{1) 2)}	Reducer 3 D to D over a length of 3,5 D	Expander 0,75 D to D over a length of D	Gate valve fully open
0,30	0,5 ³⁾	1,5 (0,5)	(0,5)	0,5 ³⁾	1,5 (0,5)	1,5 (0,5)
0,35	0,5 ³⁾	1,5 (0,5)	(0,5)	1,5 (0,5)	1,5 (0,5)	2,5 (0,5)
0,40	0,5 ³⁾	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 (1,0)	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)

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

2) As the effect of these fittings may still be present after 40 D , no unbracketed values can be given in the table.

3) Since no fitting can be placed closer than 0,5 D to the upstream pressure tapping in the venturi tube, the "zero additional uncertainty" value is the only one applicable in this distance.

NOTE — The reasons for which the minimum straight lengths required for classical venturi tubes are less than those defined in table 3 for orifice plates, nozzles and venturi nozzles, include the following :

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.

6.2.8 The values given in tables 3 and 4 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 the disturbance was virtually fully developed and swirl-free. As in practice such conditions are not realizable, 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 30 D ⁴⁾. If any fitting is installed, then the straight lengths given in tables 3 and 4 shall also apply between this fitting and the primary device.

b) If several fittings other than 90° bends⁵⁾ are placed

in series upstream from the primary device, the following rule shall be applied : between the closest fitting (1) 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 the actual values of β in tables 3 and 4. 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 given in the tables 3 and 4 for fitting (2) applicable to 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, which case is covered by paragraph a) above.

If one of the minimum straight lengths so adopted is a bracketed one, a $\pm 0,5\%$ additional uncertainty shall be added to the flow coefficient uncertainty.

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

5) In the case of several 90° bends, refer to tables 3 and 4 which can be applied whatever the length between two consecutive bends.

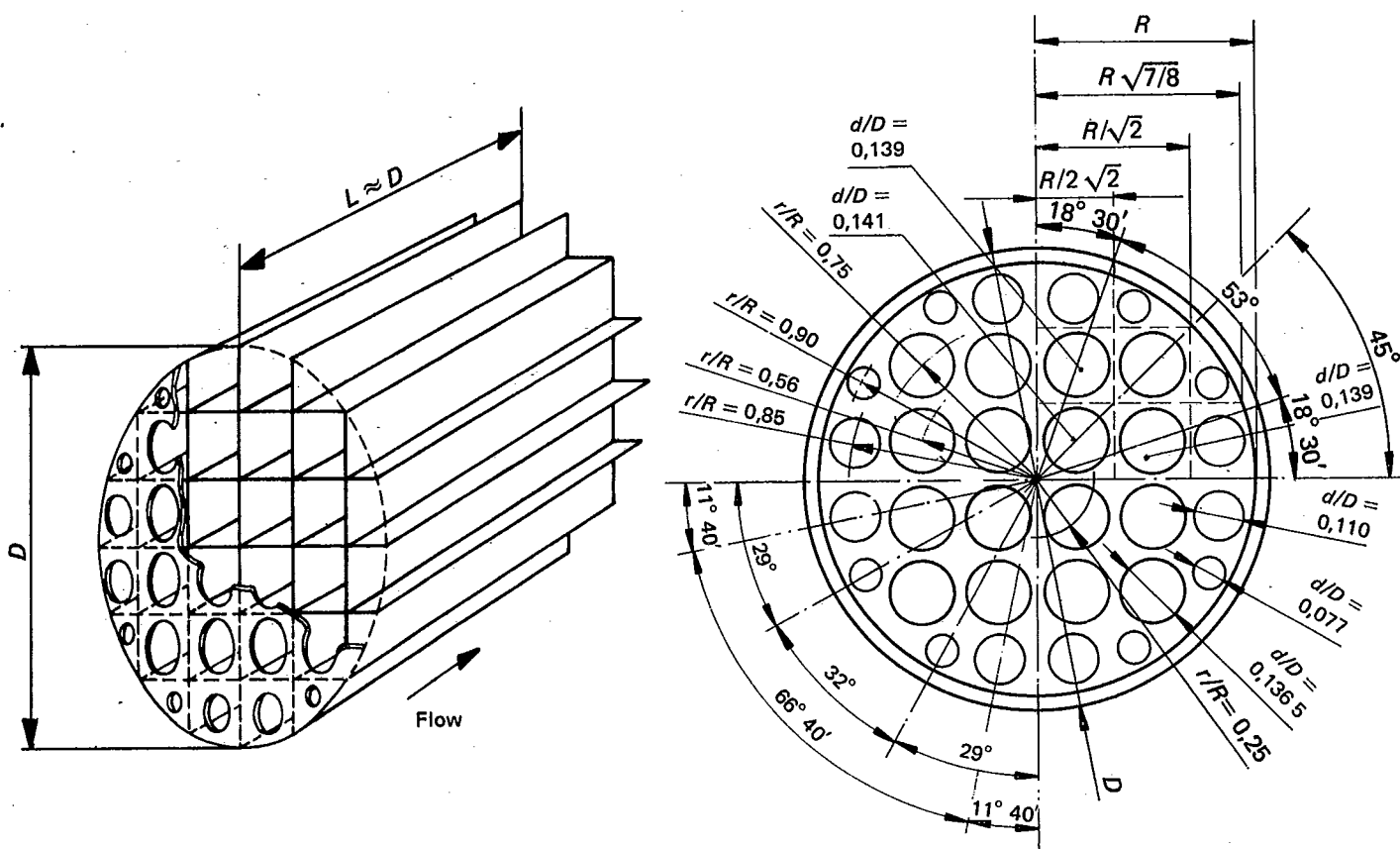
6.3 Straightening devices

The use of flow straightening devices of the types described in 6.3.2 and figure 1 is recommended to permit the installation of primary devices downstream of fittings not included in table 3 or table 4. When a large area 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 3.

When installed as described in 6.3.1, the use of a flow straightener does not introduce any additional uncertainty to the flow coefficient uncertainty.

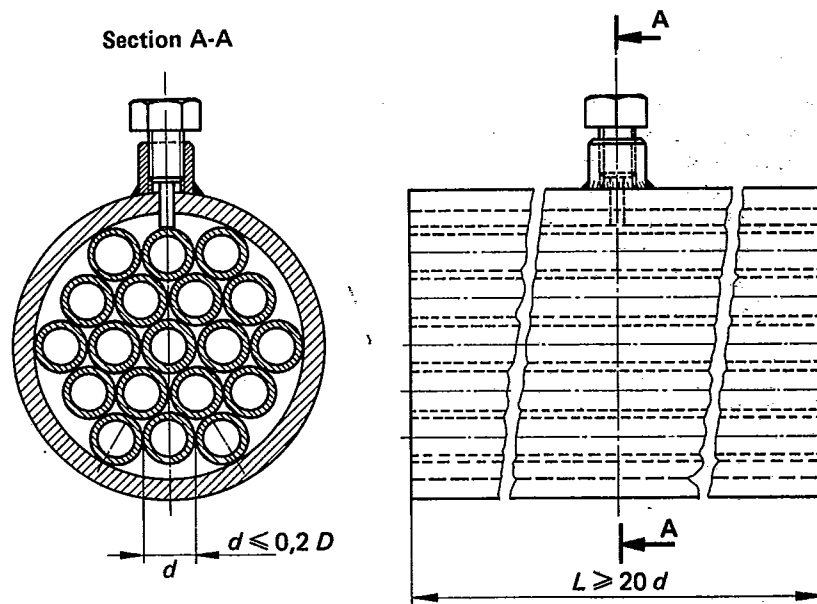
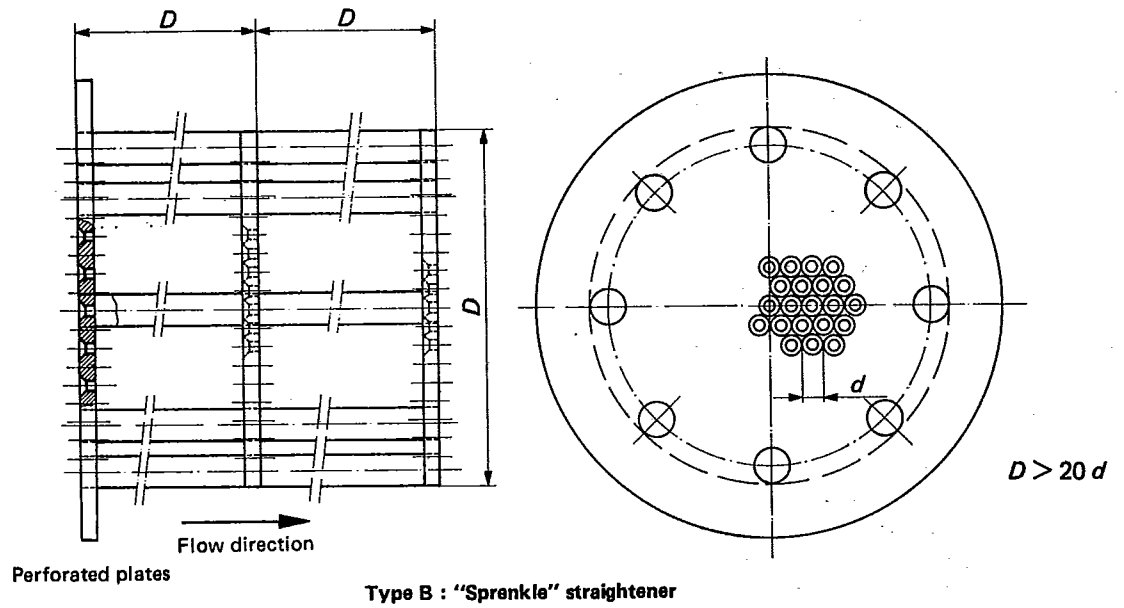
6.3.1 Installation

Any flow straightener used shall be installed in the straight length between the primary device and the upstream disturbance or fitting closest to the primary device. Unless the conditions stated in the first paragraph of 6.4 have been met, the straight length between this fitting and the straightener itself shall be equal to at least $20 D$, and the straight length between the straightener and the primary device shall be equal to at least $22 D$. Straighteners are only fully effective if their installation is such that the minimum of gaps are left around the resistive elements of the device, therefore permitting no by-pass flows which would prevent their proper functioning.



Type A : "Zanker" straightener

FIGURE 1 — Straighteners



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

FIGURE 1 — Straighteners (end)

6.3.2 Types of straightening devices

The three standardized types of straighteners, A, B and C are shown in figure 1. It should be noted that these devices create a pressure loss which

in the case of type A is approximately $5 \left(\frac{\rho U^2}{2} \right)$,

in the case of type B is approximately $15 \left(\frac{\rho U^2}{2} \right)$,

and in the case of type C is approximately $5 \left(\frac{\rho U^2}{2} \right)$.

6.3.2.1 TYPE A : ZANKER STRAIGHTENER

This straightener 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. The important dimensions are given in figure 1.

The various plates should be chosen of minimum thickness yet provide adequate strength.

6.3.2.2 TYPE B : SPRENKLE STRAIGHTENER

This straightener consists of three perforated plates in series with a length equal to one pipe diameter between successive plates. The perforations should preferably be chamfered on the upstream side, and the total area of the holes in each plate should be greater than 40 % of the cross sectional area of the pipe. The ratio of plate thickness to hole diameter shall be at least 1,0 and the diameter of the holes shall be less than 1/20 of the pipe diameter.

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, consistent with providing the required strength.

6.3.2.3 TYPE C : TUBE BUNDLE STRAIGHTENER

This type of straightener consist of a number of parallel tubes fixed together and held rigidly in the pipe. It is important in this case 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 straightener itself might introduce disturbances into the flow.

There shall be at least 19 tubes. Their length shall be more or equal to $20 d$. The tubes shall be joined together and the bundle tangent to the pipe.

6.4 General requirement for flow conditions at the primary device

If the prescribed installation conditions given in tables 3 and 4 or in 6.3 cannot be met this British Standard still remains valid if the flow conditions immediately upstream of the primary device comply with the requirements of 6.1.3.

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 $\pm 5\%$ with that which would be obtainable in swirl-free flow at the same radial position at a cross-section located at the end of a very long straight length (over $100 D$) of similar pipe.

6.5 Additional specific installation requirements for orifice plates, nozzles and venturi nozzles

6.5.1 Circularity of the pipe

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

6.5.1.1 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 $2 D$ and cylindrical. The pipe is said to be cylindrical when no diameter in any plane differs by more than 0,3 % from the value of D obtained as a mean value of all measurements in 6.1.5.

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

No additional uncertainty in the discharge coefficient is involved provided that the step between any two sections does not exceed the requirement for cylindricity of 0,3 % as defined in 6.5.1.1.

6.5.1.3 An additional uncertainty of $\pm 0,2\%$ shall be added arithmetically to the uncertainty for the flow coefficient, if the step h between any two sections exceeds the limits given in 6.5.1.2, but complies with the following relationships :

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

and

$$\frac{h}{D} \leq 0,05$$

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

6.5.1.4 If the step is greater than any one of the limits given in the equation above, the installation is not in accordance with this British Standard.

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

6.5.2 Drain holes and vent holes

The pipe can be provided with vent holes and drain holes for the removal of solid deposits and fluids, other than the measured fluid. However, there shall be no flow through these drain holes and vent holes whilst flow measurement is in progress.

The drain holes and vent holes should not be located near to the primary device, unless it is unavoidable to do so. In such a case, the diameter of these drain holes shall be smaller than $0,08 D$ and their location 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 $0,5 D$. Furthermore, the centre-line of the drain hole or vent hole shall be situated in an axial sector of the pipe which does not include any pressure tapping.

6.5.3 Location of primary device and rings

6.5.3.1 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 (see the arrow "flow direction" on the figures).

6.5.3.2 The primary device shall be perpendicular to the centre-line of the pipe to within $\pm 1^\circ$.

6.5.3.3 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 :

$$\frac{0,0005 D}{0,1 + 2,3 \beta^4}$$

If $\frac{0,0005 D}{0,1 + 2,3 \beta^4} < e_x \leq \frac{0,005 D}{0,1 + 2,3 \beta^4}$, an additional error of $\pm 0,3\%$ shall be added arithmetically to the uncertainty on the flow coefficient α .

6.5.3.4 When carrier rings are used, they shall be so centred that at no point do they protrude into the pipe.

6.5.4 Fixing and gaskets

6.5.4.1 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.

6.5.4.2 Gaskets, if used, shall be made and inserted in such a way that they do not protrude at any point inside the pipe or across the pressure hole or slot when corner tappings are used. The gaskets shall be not thicker than $0,03 D$.

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

6.6 Additional specific installation requirements for classical venturi tubes**6.6.1 Circularity of the pipe**

In the immediate vicinity of the classical venturi tube the following requirements shall apply :

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

6.6.1.2 The mean diameter of the pipe, D , where it joins the classical venturi tube shall be within $\pm 1\%$ of the classical venturi tube entrance cylinder diameter. Moreover, no single diameter of this inlet pipe section shall differ from the mean of the measured diameters by more than $\pm 2\%$ for a distance of two pipe diameters preceding the classical venturi tube.

6.6.1.3 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. This means that, in most cases, pipes having the same nominal bore as that of the venturi tube may be used.

6.6.2 Roughness of the upstream pipe

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

6.6.3 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 piece of pipe A, (see 9.1.2), shall be less than $0,005 D$. 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 6.1.5) shall be less than $0,0075 D$.

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6.6.4 Drain holes and vent holes

The pipe can be provided with vent holes and drain holes for the removal of solid deposits and fluids, other than the measured fluid. However, there shall be no flow through these drain holes and vent holes whilst flow measurement is in progress.

7 ORIFICE PLATES

The various types of standard orifice plates are similar and therefore need only the one description. Each type of standard orifice plate is characterized by the arrangement of pressure tapings.

The description given in 7.1 shall apply to orifice plates under operating conditions.

7.1 Description

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

The letters shown in figure 2 are for reference purposes in the following text.

7.1.1 General shape

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

7.1.1.2 Unless otherwise stated, the remainder of 7.1 applies only to that part of the plate located within the pipe.

7.1.1.3 Care shall be taken in the design of the orifice plate to ensure that the plastic buckling and elastic deformation of the plate, due to the magnitude of the differential pressure or of any other stress does not cause the flatness limit given below to be exceeded.

7.1.2 Upstream face A

7.1.2.1 The upstream face of the plate A shall be flat. It is considered as such when the slope of a straight line connecting any two points of its surface in relation to a plane perpendicular to the centre-line is less than 1 %, ignoring the inevitable local defects of the surface which are invisible to the naked eye.

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

7.1.2.3 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.

7.1.3 Downstream face B

7.1.3.1 The downstream face shall be flat and parallel with the upstream face.

7.1.3.2 It is unnecessary to provide the same quality of surface finish for the downstream face as for the upstream face.

7.1.3.3 The flatness and surface condition of the downstream face can be judged by mere visual inspection.

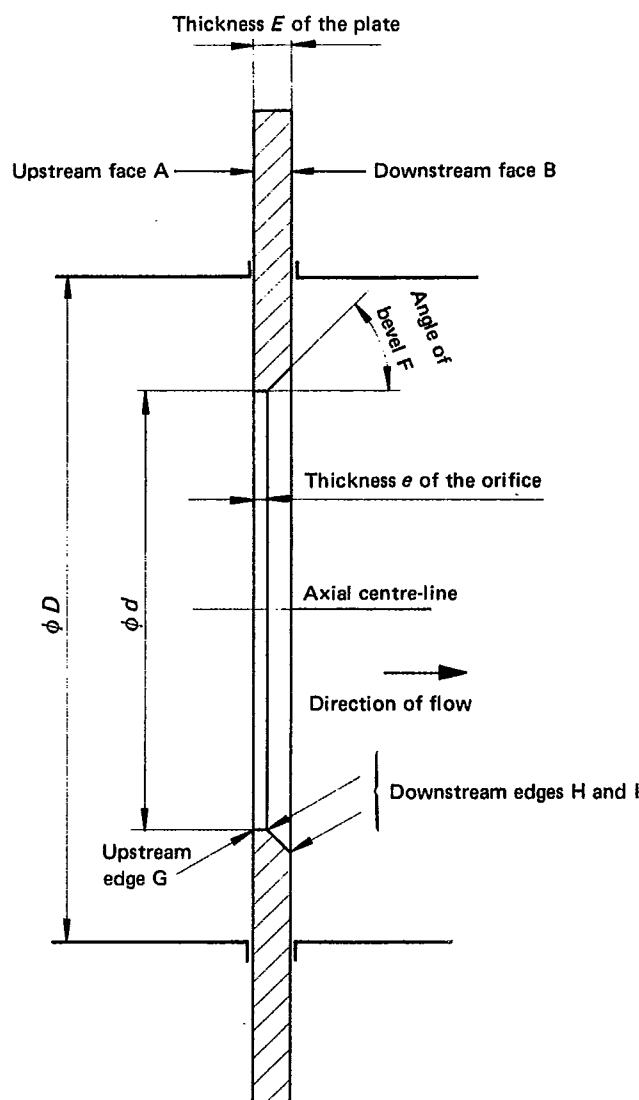


FIGURE 2 – Standard orifice plate

7.1.4 Thickness E and e

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

7.1.4.2 The values of e measured at any point on the orifice shall not differ among themselves by more than $0,001 D$.

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

7.1.4.4 The values of E measured at any point of the plate shall not differ among themselves by more than $0,001 D$.

7.1.5 Angle of bevel F

7.1.5.1 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 7.1.2.2).

7.1.5.2 The angle of bevel F shall be between 30 and 45° .

7.1.6 Edges G , H and I

7.1.6.1 The upstream edge G and the downstream edges H and I shall have neither wire-edges, nor burrs, nor, in general, any peculiarities visible to the naked eye.

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

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

If $d < 125$ mm visual inspection is not sufficient but this requirement can generally be considered as satisfied when the upstream face of the orifice plate is finished by a very fine radial cut from the centre outwards (see 7.1.9.2).

However if there is any doubt as to whether this requirement is satisfied, the edge radius shall be measured.

7.1.7 Diameter of orifice d

7.1.7.1 The diameter d shall be equal to or greater than $12,5$ mm. The ratio $\beta = d/D$ is always equal to or greater than $0,20$ or $0,23$ and less than or equal to $0,75$ or $0,80$ according to the type of orifice plate used.

Within these limits, the value of β is chosen by the user to define an orifice plate of a given type.

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

7.1.7.3 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 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.

Attention is called to the fact that it is possible to check circularity of an orifice bore within the accuracy required without it being necessary to measure the mean diameter of the orifice bore itself.

7.1.8 Symmetrical plates

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

- the plate shall not be bevelled;
- the two faces shall be as specified for the upstream face in 7.1.2;
- the thickness E of the plate shall be equal to the thickness e of the orifice as described in 7.1.4;
- the two edges of the orifice shall be as specified for the upstream edge in 7.1.6.

7.1.8.2 Furthermore (see 7.2), for orifice plates with D and $D/2$ tappings, two sets of upstream and downstream pressure taps should be arranged and used alternatively.

7.1.9 Material and manufacture

7.1.9.1 The plate can be manufactured of any material and in any way, provided 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.

7.1.9.2 The machining required to obtain a plate conforming to the description of this British Standard calls for the use of machine tools of good quality and in good condition.

7.2 Pressure tappings

At least one upstream pressure tapping and one downstream pressure tapping shall be provided for each primary device, installed in one or other of the recommended standard positions.

A single plate can be used with several sets of pressure tappings suitable for different types of standard orifice

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plates, but to avoid mutual interference, several tapplings on the one side of the orifice plate shall not be in the same axial plane.

7.2.1 *Shape and diameters of pressure tapplings, other than corner tapplings (for corner tapplings see 7.2.4)*

7.2.1.1 The centre-line of the tapping shall meet the pipe centre-line and be at right angles to it.

7.2.1.2 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 shall be permitted but shall be kept as small as possible and where it can be measured its radius shall be less than 1/10th 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.

7.2.1.3 Conformity of the pressure tapplings with the two foregoing Subclauses can be judged by mere visual inspection.

7.2.1.4 The diameters of pressure tapplings shall be less than $0,08 D$ and preferably less than 12 mm. No restriction is placed on the minimum diameter which is determined in practice by the likelihood of accidental blockage and satisfactory dynamic performance. The upstream and downstream pressure tapplings shall have the same diameter.

7.2.1.5 The pressure tapplings shall be cylindrical over a length at least 2,5 times the diameter of the tapping, measured from the inner wall of the pipe-line.

7.2.2 *Angular position of pressure tapplings, other than corner tapplings*

7.2.2.1 The centre-lines of the pressure tapplings may be located in any axial plane of the pipe-line subject to the comment made in 6.2.7.

7.2.2.2 The axis of the upstream tapping and that of the downstream tapping may be located in different axial planes (see also 6.2.7).

7.2.2.3 However, attention is drawn to the fact that, in all cases, the readings of differential pressure obtained by these pressure tapplings shall be in accordance with the definition of 2.2.3.

7.2.3 *Spacing of pressure tapplings*

7.2.3.1 The spacing l of a pressure tapping is the distance between the centre-line of the pressure tapping and the plane of one specified face of the orifice plate. When installing the pressure tapplings, due account has to be taken of the thickness of the gaskets and/or sealing material, which may be used.

7.2.3.2 The position of the pressure tapplings characterizes the type of standard orifice plate.

7.2.3.3 The position of corner tapplings is described under 7.2.4.

7.2.3.4 ORIFICE PLATE WITH D AND $D/2$ TAPPINGS (see figure 3)

The spacing l_1 of the upstream pressure tapping is nominally equal to D , but may be between $0,9 D$ and $1,1 D$ without modification of the flow coefficient.

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

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

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

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

7.2.3.5 ORIFICE PLATE WITH FLANGE TAPPINGS (see figure 3)

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 between the following values without modification of the flow coefficient :

$25,4 \pm 0,5$ mm when, simultaneously, $\beta > 0,6$ and $58 \text{ mm} < D < 150 \text{ mm}$

$25,4 \pm 1$ mm when $\beta \leq 0,6$

or $\beta > 0,6$ but $50 \text{ mm} \leq D \leq 58 \text{ mm}$

or $\beta > 0,6$ but $150 \text{ mm} \leq D \leq 760 \text{ mm}$

7.2.4 *Orifice plate with corner tapplings (see figure 4)*

7.2.4.1 The spacing between the centre-lines of the tapplings and the respective faces of the plate is equal to half the diameter or to half the width of the tapplings themselves, so that the tapping holes break through the wall flush with the faces of the plate (see also 7.2.4.5).

7.2.4.2 The pressure tapplings may be either single tapplings or annular slots. Both types of tapplings can be located either in the pipe or its flanges or in carrier rings as shown in the figures.

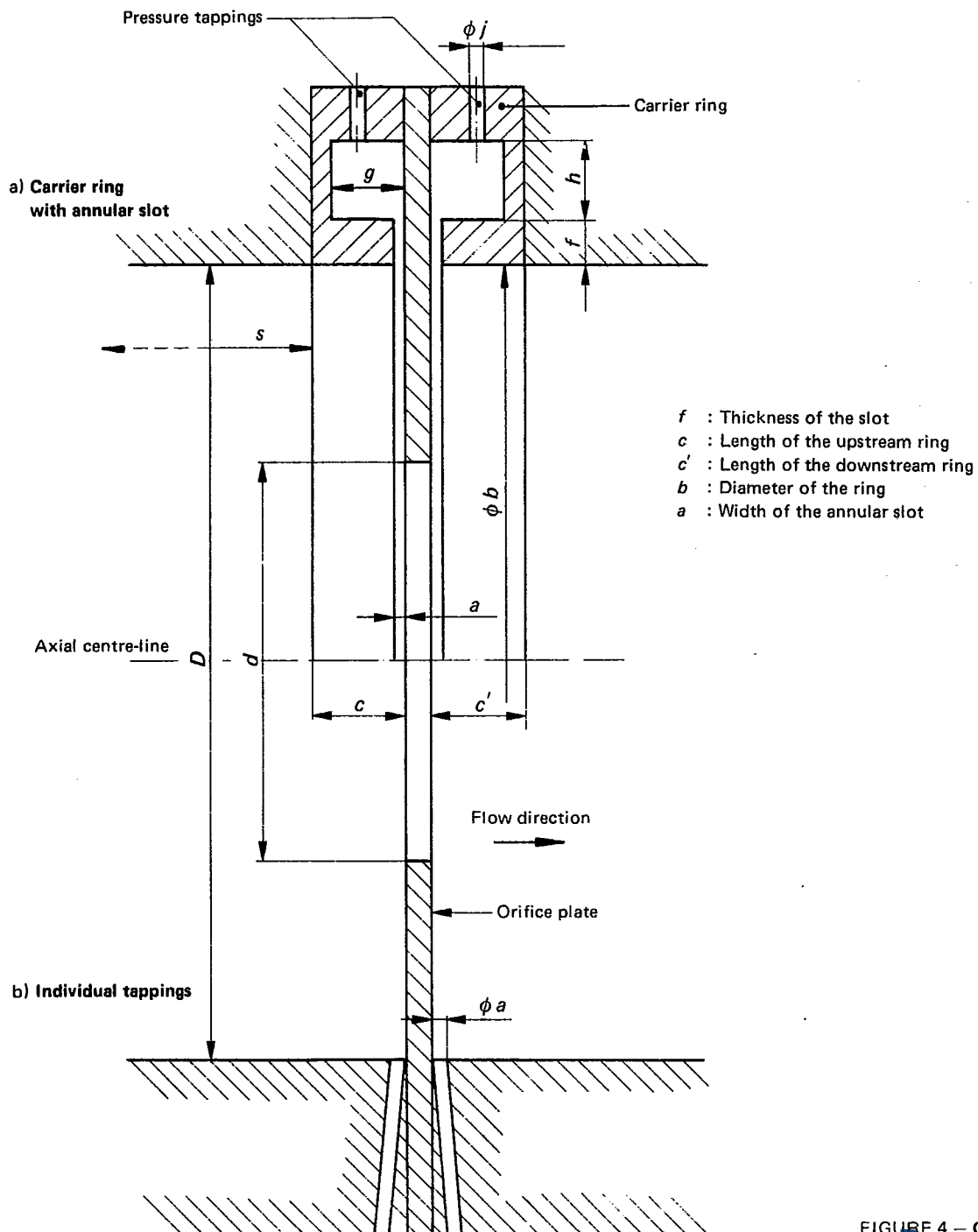
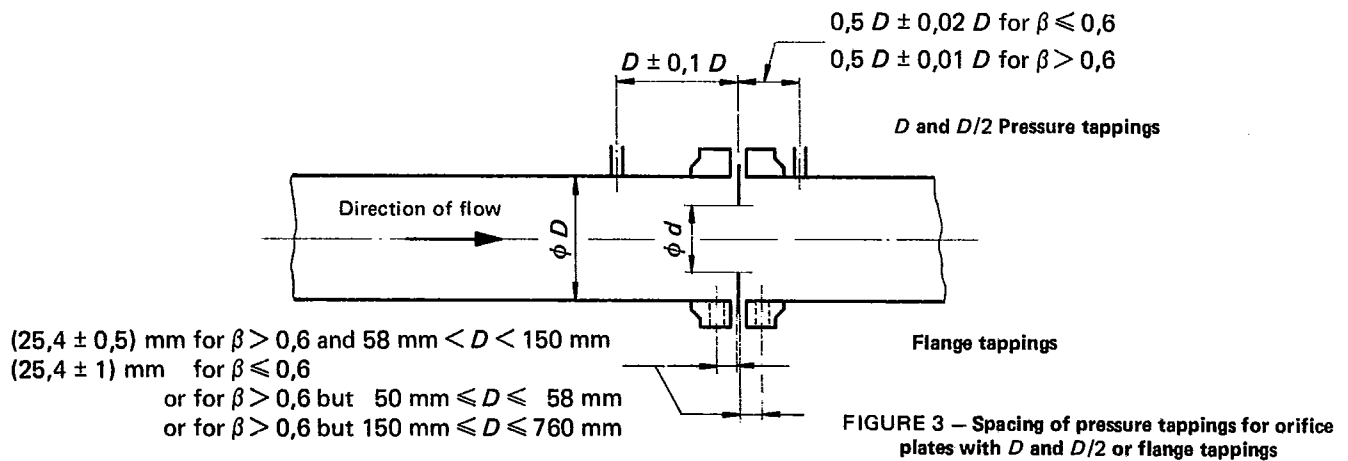


FIGURE 4 — Corner tapings

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7.2.4.3 The diameter a of single tapplings or the width a of annular slots are given below. The minimum diameter is determined in practice by the likelihood of accidental blockage and satisfactory performance.

Clean fluids and steam

$$\text{For } \beta \leq 0,65 : 0,005 D \leq a \leq 0,03 D$$

$$\text{For } \beta > 0,65 : 0,01 D \leq a \leq 0,02 D$$

For any values of β

$$\text{For clean fluids : } 1 \text{ mm} \leq a \leq 10 \text{ mm}$$

$$\text{For steam with annular chambers : } 1 \text{ mm} \leq a \leq 10 \text{ mm}$$

$$\text{For steam and for liquefied gases with single tapplings : } 4 \text{ mm} \leq a \leq 10 \text{ mm}$$

7.2.4.4 The annular slots usually break through the pipe over the entire perimeter, with no break in continuity. If not, each 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 each is at least 12 mm².

7.2.4.5 If individual pressure tapplings, as shown in figure 4 b), are used, the centre-line of the tapplings shall cross the centre-line of the pipe at as near an angle of 90° as possible.

If there are several individual pressure tapplings for the same upstream or downstream axial plane, their centre-lines shall form equal angles with each other. The diameters of individual pressure tapplings are given in 7.2.4.3.

The pressure tapplings shall be cylindrical over a length at least 2,5 times the diameter of the tapplings, measured from the inner wall of the pipe-line.

7.2.4.6 The inner diameter b of the carrier rings shall be equal to or greater than the diameter D of the pipe to ensure that they do not protrude into the pipe. The following relation shall be fulfilled :

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

The lengths c and c' of the upstream and downstream rings (figure 4) shall not be greater than 0,5 D .

Moreover, the value of b shall be within the following limits :

$$D \leq b \leq 1,04 D$$

The length f 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 $g \times h$ shall be greater than or equal to half the total area of the opening connecting this chamber to the inside of the pipe.

7.2.4.7 All surfaces of the ring which can be in contact with the measured fluid shall be clean and have a good machined finish.

7.2.4.8 The pressure tapplings connecting the annular chambers to the secondary devices are pipe-wall tapplings, circular at the point of breakthrough and with diameters j between 4 and 10 mm. (See 7.2.1.2.)

7.2.4.9 The upstream and downstream carrier rings are not necessarily symmetrical in relation to each other, but they shall both comply with the foregoing requirements.

7.2.4.10 The diameter of the pipe to be used for the calculation of the diameter ratio, and hence the flow-rate, is to be measured as defined in 6.1.5, the carrier ring being regarded as part of the primary device. This also applies to the length requirement given in 6.5.1.3 so that the length s is to be taken from the upstream edge of the recess formed by the carrier ring.

7.3 Coefficients and corresponding uncertainties of orifice plates

7.3.1 Limits of use

The types of orifice plates specified shall only be used in accordance with this British Standard when :

	Corner taps	Flange taps	D and $D/2$ taps
d (mm)	$\geq 12,5$	$\geq 12,5$	$\geq 12,5$
D (mm)	$50 \leq D \leq 1\,000$	$50 \leq D \leq 760$	$50 \leq D \leq 760$
β	$0,23 \leq \beta \leq 0,80$	$0,2 \leq \beta \leq 0,75$	$0,2 \leq \beta \leq 0,75$
Re_D	$5\,000 \leq Re_D \leq 10^8$ for $0,23 \leq \beta \leq 0,45$ $10\,000 \leq Re_D \leq 10^8$ for $0,45 < \beta \leq 0,77$ $20\,000 \leq Re_D \leq 10^8$ for $0,77 < \beta \leq 0,80$	$\geq 1\,260 \beta^2 D^{1/4}$ $\leq 10^8$	$\geq 1\,260 \beta^2 D^{1/4}$ $\leq 10^8$

1) Where D is expressed in millimetres.

In addition, roughness shall conform to the values in table 5.

TABLE 5 — Upper limits of relative roughness of the upstream pipe-line for orifice plates

β	$\leq 0,3$	0,32	0,34	0,36	0,38	0,4	0,45	0,5	0,6	0,7	0,8
Corner taps $10^4 k/D$	25	18,1	12,9	10,0	8,3	7,1	5,6	4,9	4,2	4,0	3,9
Flange taps and D and $D/2$ taps $10^4 k/D$	25	18,1	12,9	10	10	10	10	10	10	10	10

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

However, approximate values of k for different materials can be obtained from the various tables given in reference literature, and table 6 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 the present British Standard are based, were carried out in pipes with a relative roughness $k/D \leq 3,8 \times 10^{-4}$ as regards corner tapplings, or $k/D \leq 10 \times 10^{-4}$ as regards D and $D/2$ or flange tapplings.

Pipes with higher relative roughness may be used if the roughness for at least $10 D$ upstream of the orifice plate is within the limits given in table 5.

7.3.2 Coefficients

7.3.2.1 DISCHARGE COEFFICIENT

The discharge coefficient C is given by the Stolz equation :

$$C = 0,5959 + 0,0312 \beta^{2,1} - 0,1840 \beta^8 + \\ + 0,0029 \beta^{2,5} \left[\frac{10^6}{Re_D} \right]^{0,75} + \\ + 0,0900 L_1 \beta^4 (1 - \beta^4)^{-1} - 0,0337 L'_2 \beta^3$$

NOTE — When $L_1 \geq \frac{0,0390}{0,0900}$ ($= 0,4333$), use 0,0390 for coefficient of $\beta^4 (1 - \beta^4)^{-1}$.

In this equation :

C is the discharge coefficient;

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

Re_D is the pipe Reynolds number;

$L_1 = l_1/D$ is the quotient of the distance of upstream tapping from the UPSTREAM face of the plate, divided by the pipe diameter;

$L'_2 = l'_2/D$ is the quotient of the distance of downstream tapping from the DOWNSTREAM face of the plate, divided by the pipe diameter. (The notation L'_2 denotes the reference of the downstream spacing from the DOWNSTREAM face, while L_2 would denote a reference of the downstream spacing from the UPSTREAM face.)

The values of L_1 and L'_2 to be entered in the equation, when the spacings are in accordance with the conditions of clauses 7.2.4 or 7.2.3.4 or 7.2.3.5 are as follows :

— for corner tapplings :

$$L_1 = L'_2 = 0$$

— for D and $D/2$ tapplings :

$$L_1 = 1$$

$$L'_2 = 0,47$$

(since L_1 is always $> 0,4333$. . . a value of 0,0390 will always be used for coefficient of $\beta^4 (1 - \beta^4)^{-1}$)

— for flange tapplings

$$L_1 = L'_2 = 25,4/D \text{ (D in millimetres)}$$

TABLE 6 — Examples of values of the pipe wall roughness k

Material	Condition	k , mm
brass, copper, aluminium, plastics, glass	smooth, without sediments	$< 0,03$
steel	new, seamless cold drawn	$< 0,03$
	new, seamless hot drawn	$< 0,03$
	new, seamless rolled	0,05 to 0,10
	new, welded longitudinally	0,10
	new, welded spirally	0,10 to 0,20
	slightly rusted	0,20 to 0,30
	rusty	0,50 to 2
	encrusted	> 2
	with heavy incrustations	0,03 to 0,05
	bituminized, new	0,10 to 0,20
cast iron	new	0,25
	rusty	1,0 to 1,5
	encrusted	$> 1,5$
	bituminized, new	0,03 to 0,05
asbestos cement	insulated and not insulated, new	$< 0,03$
	not insulated, normal	0,05