International Standard 5167

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION•МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ•ORGANISATION INTERNATIONALE DE NORMALISATION

Measurement of fluid flow by means of orifice plates, nozzles and venturi tubes inserted in circular cross-section conduits running full

Mesure de débit des fluides au moyen de diaphragmes, tuyères et tubes de Venturi insérés dans des conduites en charge de section circulaire

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FOREWORD

ISO (the International Organization for Standardization) is a worldwide federation of national standards institutes (ISO member bodies). The work of developing International Standards is carried out through ISO technical committees. Every member body interested in a subject for which a technical committee has been set up 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.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council.

International Standard ISO 5167 was developed by Technical Committee ISO/TC 30 has been set up in order to resolve the differences between the two documents.

It has been approved by the member bodies of the following countries :

Australia
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Finland
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Turkey
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The member body of the following country expressed disapproval of the document on technical grounds :

USA

This International Standard cancels and replaces ISO Recommendations R 541-1967 and R 781-1968, of which it constitutes a technical revision.

During the development of this International Standard, it was found that it was in conflict with a document on the same subject being prepared by ISO/TC 28/SC 5 *"Measurement of light hydrocarbon fluids"*. A liaison group ISO/TC 28/SC 5 – ISO/TC 30 has been set up in order to resolve the differences between the two documents.

The completion in the future of the work of this liaison group may therefore lead to the revision of this International Standard.

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INTERNATIONAL STANDARD **ISO 5167-1980 (E)**

Measurement of fluid flow by means of orifice plates, nozzles and venturi tubes inserted in circular cross-section conduits running full

1 SCOPE AND FIELD OF APPLICATION

This International Standard 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 rate of the fluid flowing in the conduit. It also gives necessary information for calculating the flow-rate and its associated uncertainty.

This International Standard 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 International Standard cannot be used 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 tappings. All other instruments or devices required for the measurement are known as "secondary devices". This International Standard covers the primary devices; secondary devices[1] will be mentioned only occasionally.

The different primary devices dealt with in this International Standard are as follows :

- orifice plates, which can be used with the various following arrangements of pressure tappings :
    - corner pressure tappings,
    - *D* and *D*/2 pressure tappings,[2]
    - flange pressure tappings,
- nozzles :
    - ISA 1932 nozzle[3],
    - long radius nozzle,

    which differ in shape and/or in the position of the pressure tappings,
- venturi tubes :
    - classical venturi tube[4],
    - venturi-nozzle,

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

2 SYMBOLS AND DEFINITIONS

The vocabulary and symbols used in this International Standard are defined in ISO 4006, *Measurement of fluid flow in closed conduits — Vocabulary and symbols.*

Table 1 reproduces the symbols which are used in this International Standard.

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.

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[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 tappings are not considered in this International 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.

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 pipediameter (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 7.3.2.1)	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 (see ISO/R 468)	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
$\Delta\bar{\omega}$	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.

2.2 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 International Standard.

2.2.3 differential pressure : Difference between the static pressure measured by wall tappings, 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 tappings has been taken into account.

The term "differential pressure" is used only if the pressure tappings are in the positions specified by this International 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 portion 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 part is a standardized ISA 1932 nozzle, the device is called a "venturi-nozzle". If the convergent part 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 tappings.

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 International 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 International 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 International 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 considered 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 :

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

ϵ 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 ϵ 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 ϵ given in this International Standard have been based on data determined experimentally.

2.4.8 roughness criterion

The roughness criterion R_a used in this standard is that given in ISO/R 468 and 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 introduction of a primary device (such as an orifice plate, a nozzle or a venturi tube) into a pipe-line through which a fluid is running full. The introduction of the primary device creates 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 flowing fluid as well as the circumstances under which the device is being used, assuming 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 International Standard.

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

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

or

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

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

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

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, when one has to determine the diameter of a primary element to be installed in a given pipe line in order to perform a flow measurement, 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.

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 is effected by replacing the different terms on the right-hand side of the basic formulae (1) or (2) by their numerical values.

The computation itself involves no difficulty other than of an arithmetical nature and merely calls for the following comments :

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) Attention is called to the fact that d and D mentioned in the formulae, are the values of the diameters at operating conditions and hence measurements taken at ambient conditions must 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) For the purpose of the measurement, 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 tappings (as described in 7.2.4).

3.4.1.1 This 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 tappings 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 5 D 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 the density, static pressure and the temperature of the fluid is acceptable if it enables reliable values of the pressure, the temperature, the viscosity and the mass density of the fluid at the upstream tapping plane to be obtained without disturbing the flow measurement 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 some indications to enable the selection of the type of primary device to be made to meet the required characteristics.

TABLE 2 – **Selection criteria of the type of primary device**

Characteristics to be considered	**Consideration for 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 International Standard.

When the manufacturing characteristics and conditions of use of the primary devices are outside the limits given in this International 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 International 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 International Standard.

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

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 (see 3.3 d).

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 International 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 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 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 measuring process 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 sufficiently 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 conforms to requirements given in clause 6.

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 International Standard.

The pipe is considered straight when it appears so by mere 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 indicated in tables 3 and 4.

6.1.5 The value for the pipe diameter D to be used in the computation of the diameter ratio shall be the mean of the internal diameter 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 then 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 not encrusted 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 over at least the whole length of the required straight runs. 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 selected by the user as being sufficient for the accuracy of flow measurement which he requires.

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 comply with the requirements of tables 3 and 4 and when they are longer than or equal to the values given 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.

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[1] This is the subject of 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.

6.2.4 When the upstream OR downstream straight lengths are shorter than the "zero additional uncertainty" values[1] and equal to or greater than the "± 0,5 % additional uncertainty" values[2], as given in tables 3 and 4, an additional deviation of ± 0,5 % shall be added arithmetically to the uncertainty on the flow coefficient.

6.2.5 If the straight lengths are shorter than "the ± 0,5 % additional uncertainty" values[2] given in tables 3 and 4, this International 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" values[1].

6.2.6 The valves mentioned in tables 3 and 4 shall be fully open. It is recommended that control 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 the tappings (if pairs of single tappings) be installed in such a way 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 "± 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	**On upstream (inlet) side of the primary device**							**On downstream (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
⩽ 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)

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

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1) Unbracketed values in tables 3 and 4.

2) Bracketed values in tables 3 and 4.

TABLE 4 — **Required 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 ± 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 $k/D \leqslant 10^{-3}$).

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 close enough to a fully developed and swirl-free flow. Usually, such conditions are not available and the following remarks 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° bends[5] 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 ± 0,5 % additional uncertainty shall be added to the flow coefficient uncertainty.

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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.

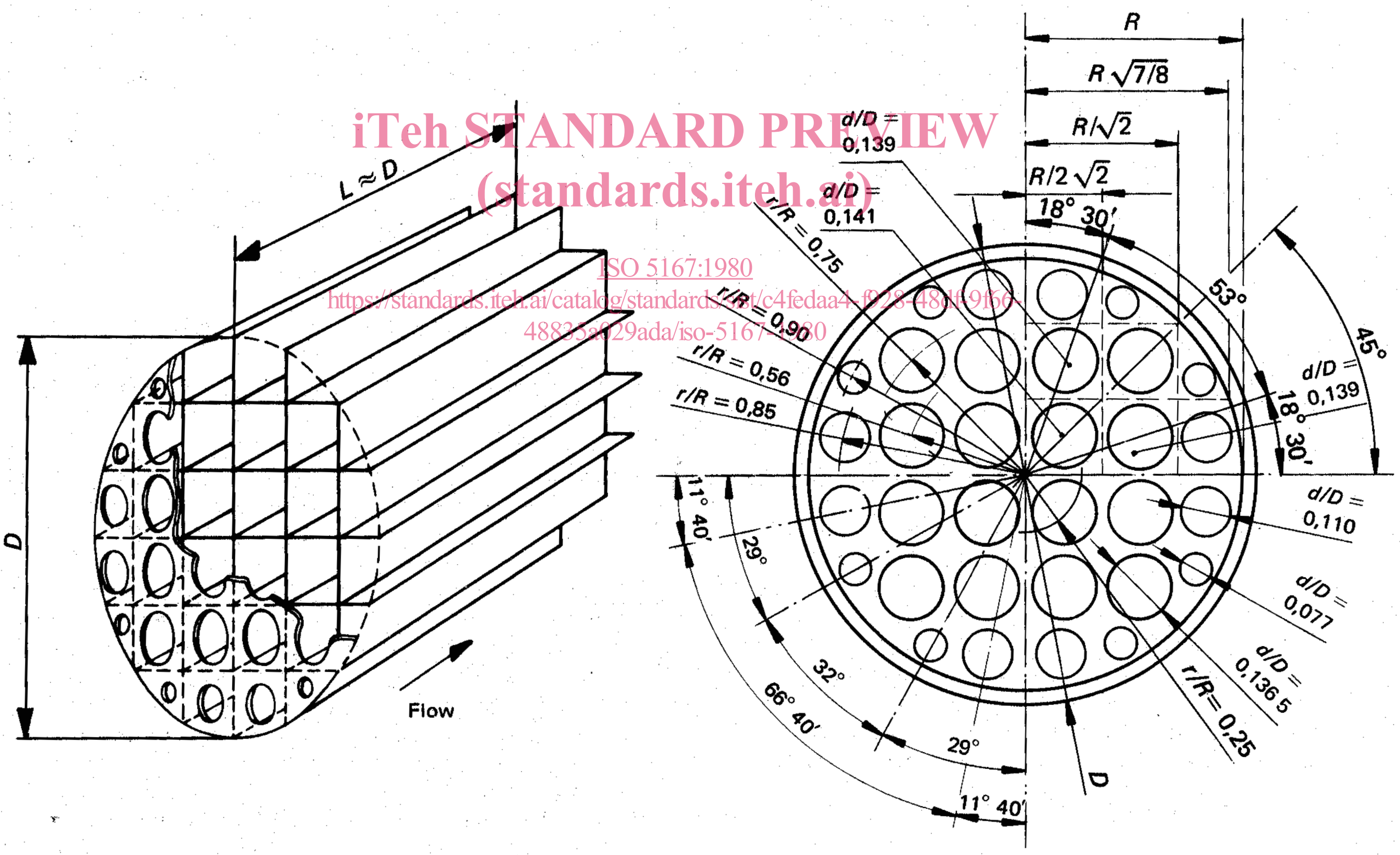
6.3 Straightening devices

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.

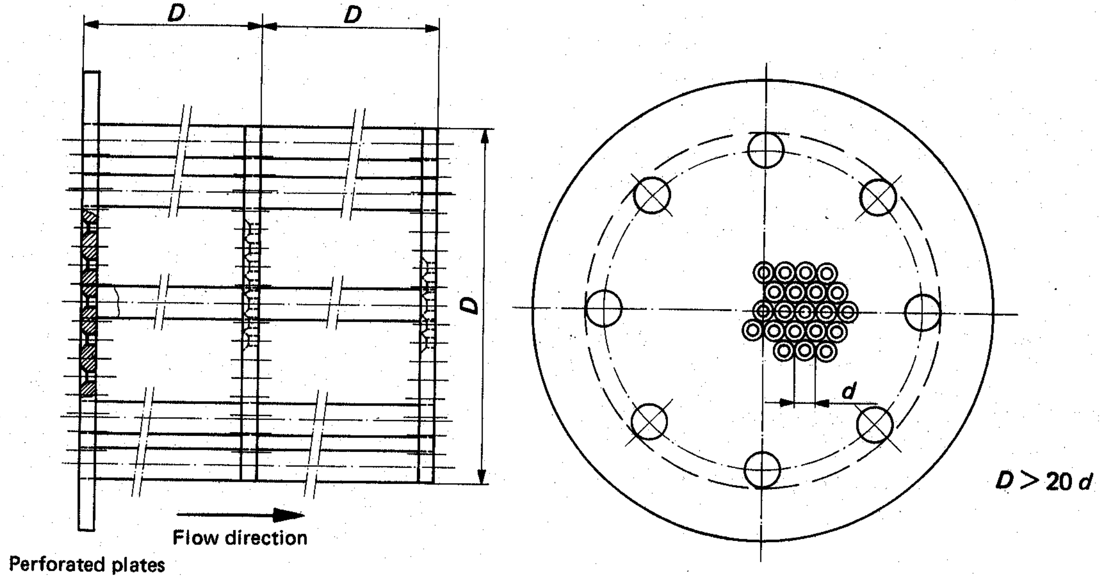
6.3.1 *Installation*

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.

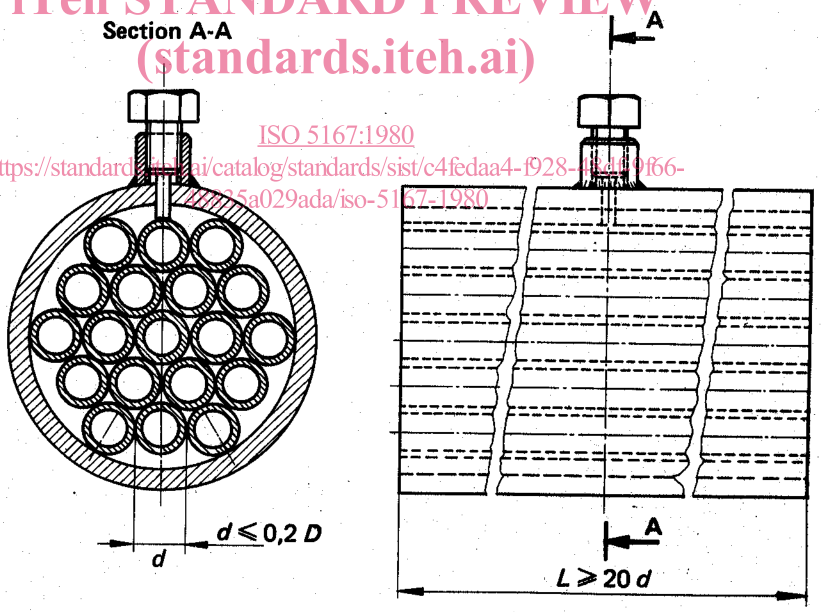


Type A : "Zanker" straightener

FIGURE 1 — **Straighteners**



Type B : "Sprenkle" straightener



Type C : Tube bundle straightener

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

FIGURE 1 — **Straighteners** *(end)*