# INTERNATIONAL STANDARD

# ISO 5167-4

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# Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full —

## Part 4:
## Venturi tubes

*Mesure de débit des fluides au moyen d'appareils déprimogènes insérés dans des conduites en charge de section circulaire —*

*Partie 4: Tubes de Venturi*

Reference number
ISO 5167-4:2003(E)

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# Foreword

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

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

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

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

ISO 5167-4 was prepared by Technical Committee ISO/TC 30, *Measurement of fluid flow in closed conduits*, Subcommittee SC 2, *Pressure differential devices*.

This first edition of ISO 5167-4, together with the second edition of ISO 5167-1 and the first editions of ISO 5167-2 and ISO 5167-3, cancels and replaces the first edition of ISO 5167-1:1991, which has been technically revised, and ISO 5167-1:1991/Amd.1:1998.

ISO 5167 consists of the following parts, under the general title *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full*:

- *Part 1: General principles and requirements*
- *Part 2: Orifice plates*
- *Part 3: Nozzles and Venturi nozzles*
- *Part 4: Venturi tubes*

# Introduction

ISO 5167, divided into four parts, covers 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 flowrate of the fluid flowing in the conduit. It also gives necessary information for calculating the flowrate and its associated uncertainty.

ISO 5167 is applicable only to pressure differential devices in which the flow remains subsonic throughout the measuring section and where the fluid can be considered as single-phase, but is not applicable to the measurement of pulsating flow. Furthermore, each of these devices can only be used within specified limits of pipe size and Reynolds number.

ISO 5167 deals with devices for which direct calibration experiments have been made, sufficient in number, spread and quality to enable coherent systems of application to be based on their results and coefficients to be given with certain predictable limits of uncertainty.

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

ISO 5167 is divided into the following four parts.

a) Part 1 of ISO 5167 gives general terms and definitions, symbols, principles and requirements as well as methods of measurement and uncertainty that are to be used in conjunction with Parts 2 to 4 of ISO 5167.

b) Part 2 of ISO 5167 specifies orifice plates, which can be used with corner pressure tappings, $D$ and $D/2$ pressure tappings[2], and flange pressure tappings.

c) Part 3 of ISO 5167 specifies ISA 1932 nozzles[3], long radius nozzles and Venturi nozzles, which differ in shape and in the position of the pressure tappings.

d) This part of ISO 5167 specifies classical Venturi tubes[4].

Aspects of safety are not dealt with in Parts 1 to 4 of ISO 5167. It is the responsibility of the user to ensure that the system meets applicable safety regulations.

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

[2] Orifice plates with "vena contracta" pressure tappings are not considered in ISO 5167.

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

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

# Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full —

## Part 4:
## Venturi tubes

## 1 Scope

This part of ISO 5167 specifies the geometry and method of use (installation and operating conditions) of Venturi tubes when they are inserted in a conduit running full to determine the flowrate of the fluid flowing in the conduit.

This part of ISO 5167 also provides background information for calculating the flowrate and is applicable in conjunction with the requirements given in ISO 5167-1.

This part of ISO 5167 is applicable only to Venturi tubes in which the flow remains subsonic throughout the measuring section and where the fluid can be considered as single-phase. In addition, each of these devices can only be used within specified limits of pipe size, roughness, diameter ratio and Reynolds number. This part of ISO 5167 is not applicable to the measurement of pulsating flow. It does not cover the use of Venturi tubes in pipes sized less than 50 mm or more than 1 200 mm, or where the pipe Reynolds numbers are below $2 \times 10^5$.

This part of ISO 5167 deals with the three types of classical Venturi tubes:

a) cast;

b) machined;

c) rough welded sheet-iron.

A Venturi tube is a device which consists of a convergent inlet connected to a cylindrical throat which is in turn connected to a conical expanding section called the “divergent”. The differences between the values of the uncertainty of the discharge coefficient for the three types of classical Venturi tube show, on the one hand, the number of results available for each type of classical Venturi tube and, on the other hand, the more or less precise definition of the geometric profile. The values are based on data collected many years ago. Venturi nozzles (and other nozzles) are dealt with in ISO 5167-3.

NOTE 1 Research into the use of Venturi tubes in high-pressure gas [$\geqslant$ 1 MPa ($\geqslant$ 10 bar)] is being carried out at present (see References [1], [2], [3] in the Bibliography). In many cases for Venturi tubes with machined convergent sections discharge coefficients which lie outside the range predicted by this part of ISO 5167 by 2 % or more have been found. For optimum accuracy Venturi tubes for use in gas should be calibrated over the required flowrate range. In high-pressure gas the use of single tappings (or at most two tappings in each plane) is not uncommon.

NOTE 2 In the USA the classical Venturi tube is sometimes called the Herschel Venturi tube.

## 2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

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

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 4006 and ISO 5167-1 apply.

## 4 Principles of the method of measurement and computation

The principle of the method of measurement is based on the installation of a Venturi tube into a pipeline in which a fluid is running full. In a Venturi tube a static pressure difference exists between the upstream section and the throat section of the device. Whenever the device is geometrically similar to one on which direct calibration has been made, the conditions of use being the same, the flowrate can be determined from the measured value of this pressure difference and from a knowledge of the fluid conditions.

The mass flowrate can be determined by the following formula:

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

The uncertainty limits can be calculated using the procedure given in Clause 8 of ISO 5167-1:2003.

Similarly, the value of the volume flowrate can be calculated since

$$q_V = \frac{q_m}{\rho}$$

where $\rho$ is the fluid density at the temperature and pressure for which the volume is stated.

Computation of the flowrate, which is a purely arithmetic process, is performed by replacing the different items on the right-hand side of Equation (1) by their numerical values. Table A.1 gives Venturi tube expansibility factors ($\varepsilon$). They are not intended for precise interpolation. Extrapolation is not permitted.

The diameters $d$ and $D$ mentioned in Equation (1) are the values of the diameters at working conditions. Measurements taken at any other conditions should be corrected for any possible expansion or contraction of the primary device and the pipe due to the values of the temperature and pressure of the fluid during the measurement.

It is necessary to know the density and the viscosity of the fluid at working conditions. In the case of a compressible fluid, it is also necessary to know the isentropic exponent of the fluid at working conditions.

# 5 Classical Venturi tubes

## 5.1 Field of application

### 5.1.1 General

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

Three types of standard classical Venturi tube are defined according to the method of manufacture of the internal surface of the entrance cone and the profile at the intersection of the entrance cone and the throat. These three methods of manufacture are described in 5.1.2 to 5.1.4 and have somewhat different characteristics.

There are limits to the roughness and Reynolds number for each type which shall be addressed.

### 5.1.2 Classical Venturi tube with an “as cast” convergent section

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

These classical Venturi tubes can be used in pipes of diameter between 100 mm and 800 mm and with diameter ratios $\beta$ between 0,3 and 0,75 inclusive.

### 5.1.3 Classical Venturi tube with a machined convergent section

This is a classical Venturi tube cast or fabricated as in 5.1.2 but in which the convergent section is machined as are the throat and the entrance cylinder. The junctions between the cylinders and cones may or may not be rounded.

These classical Venturi tubes can be used in pipes of diameter between 50 mm and 250 mm and with diameter ratios $\beta$ between 0,4 and 0,75 inclusive.

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

This is a classical Venturi tube normally fabricated by welding. For larger sizes it may not be machined if the tolerance required in 5.2.4 can be achieved, but in the smaller sizes the throat is machined.

These classical Venturi tubes can be used in pipes of diameter between 200 mm and 1 200 mm and with diameter ratios $\beta$ between 0,4 and 0,7 inclusive.

## 5.2 General shape

**5.2.1** Figure 1 shows a section through the centreline of the throat of a classical Venturi tube. The letters used in the text refer to those shown on Figure 1.

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

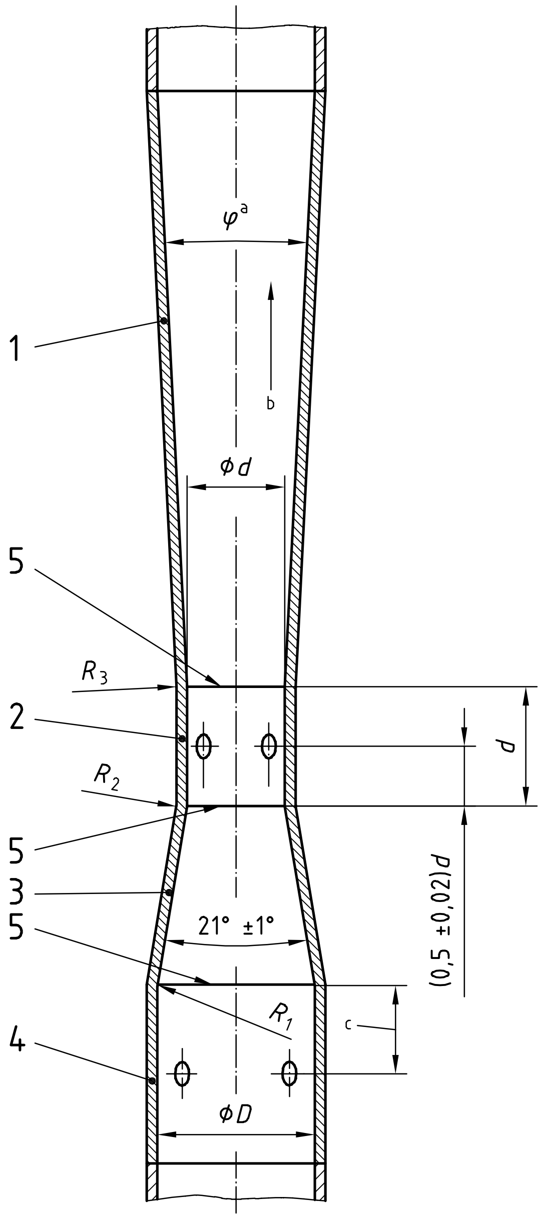
**5.2.2** The minimum cylinder length, measured from the plane containing the intersection of the cone frustum B with the cylinder A, may vary as a result of the manufacturing process (see 5.2.8 to 5.2.10). It is, however, recommended that it be chosen to be equal to $D$.

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

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

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

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



**Key**

1 conical convergent E

2 cylindrical throat, C

3 conical convergent B

4 entrance cylinder A

5 connecting planes

[a] $7^\circ \leqslant \varphi \leqslant 15^\circ$

[b] Flow direction

[c] See 5.4.7

Figure 1 — Geometric profile of the classical Venturi tube

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

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

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

The profile of the convergent section shall be checked by means of a template. The deviation between the template and the conical section of the convergent section shall not exceed, in any place, 0,004$D$.

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

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

**5.2.4** The throat C shall be cylindrical with a diameter $d$. It is limited upstream by the plane containing the intersection of the cone frustum B with the throat C (or their prolongations) and downstream by the plane containing the intersection of the throat C with the cone frustum E (or their prolongations). The length of the throat C, i.e the distance between those two planes, shall be equal to $d \pm 0{,}03d$ whatever the type of classical Venturi tube.

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

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

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

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

The throat of the classical Venturi tube shall be machined or be of equivalent smoothness over the whole of its length to the surface roughness specified in 5.2.7.

It shall be checked that the joining curvatures into the throat with radii $R_2$ and $R_3$ are surfaces of revolution as described in 5.2.3. This requirement is satisfied when two diameters, situated in the same plane perpendicular to the axis of revolution, do not differ from the value of the mean diameter by more than 0,1 %.

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

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

**5.2.5** The divergent section E shall be conical and may have an included angle, $\varphi$, of between 7° and 15°. It is, however, recommended that an angle between 7° and 8° be chosen. Its smallest diameter shall not be less than the throat diameter.

**5.2.6** A classical Venturi tube is called “truncated” when the outlet diameter of the divergent section is less than the diameter $D$ and “not truncated” when the outlet diameter is equal to diameter $D$. The divergent portion may be truncated by about 35 % of its length without significantly modifying the pressure loss of the device or its discharge coefficient.

**5.2.7** The roughness criterion $Ra$, of the throat and that of the adjacent curvature shall be as small as possible and shall always be less than $10^{-4}d$. The divergent section is rough cast. Its internal surface shall be clean and smooth. Other parts of the classical Venturi tube have specified roughness limits depending on the type considered.

**5.2.8** The profile of the classical Venturi tube with an “as cast” convergent section has the following characteristics.

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

The minimum length of the entrance cylinder A shall be equal to the smaller of the following two values:

— $D$, or

— $0{,}25D + 250$ mm (see 5.2.2).

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

The radius of curvature $R_1$ shall be equal to $1{,}375D \pm 0{,}275D$.

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

The length of the cylindrical part of the throat shall be no less than $d/3$. In addition, the length of the cylindrical part between the end of the joining curvature $R_2$ and the plane of the pressure tappings, as well as the length of the cylindrical part between the plane of the throat pressure tappings and the beginning of the joining curvature $R_3$, shall be no less than $d/6$ (see also 5.2.4 for the throat length).

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

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

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

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

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

The length of the throat cylindrical part between the end of the curvature $R_2$ and the plane of the throat pressure tappings shall be no less than $0{,}25d$.

The length of the throat cylindrical part between the plane of the throat pressure tappings and the beginning of the joining curvature $R_3$ shall be no less than $0{,}3d$.

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

The entrance cylinder and the convergent section shall have a surface finish equal to that of the throat (see 5.2.7).

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

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

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

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

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

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

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

## 5.3 Material and manufacture

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

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

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

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

## 5.4 Pressure tappings

**5.4.1** The upstream and throat pressure tappings shall be made in the form of separate pipe wall pressure tappings interconnected by annular chambers, piezometer rings or, if there are four tappings, a “triple-T” arrangement (see 5.4.3 of ISO 5167-1:2003).

**5.4.2** If $d$ is greater than or equal to 33,3 mm, the diameter of these tappings shall be between 4 mm and 10 mm and moreover shall never be greater than $0{,}1D$ for the upstream tappings and $0{,}13d$ for the throat pressure tappings.

If $d$ is less than 33,3 mm, the diameter of the throat pressure tappings shall be between $0{,}1d$ and $0{,}13d$ and the diameter of the upstream pressure tappings shall be between $0{,}1d$ and $0{,}1D$.

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

**5.4.3** At least four pressure tappings shall be provided for the upstream and throat pressure measurements. The centrelines of the pressure tappings shall meet the centreline of the classical Venturi tube, shall form equal angles with each other and shall be contained in planes perpendicular to the centreline of the classical Venturi tube.

**5.4.4** At the point of break-through, the hole of the pressure tapping shall be circular. The edges shall be flush with the pipe wall and free from burrs. If joining curvatures are required, the radius shall not exceed one-tenth of the diameter of the pressure tapping.

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

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

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

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

- $0{,}5D \pm 0{,}25D$ for $100\ \text{mm} < D < 150\ \text{mm}$, and
- $0{,}5D^{\ 0}_{-0{,}25D}$ for $150\ \text{mm} < D < 800\ \text{mm}$.

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

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

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

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

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

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

## 5.5 Discharge coefficient, $C$

### 5.5.1 Limits of use

Whatever the type of classical Venturi tube, a simultaneous use of extreme values for $D$, $\beta$ and $Re_D$ shall be avoided as otherwise the uncertainties given in 5.7 are likely to be increased.

For installations outside the limits defined in 5.5.2, 5.5.3 and 5.5.4 for $D$, $\beta$ and $Re_D$ it remains necessary to calibrate separately the primary element in its actual conditions of service.

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

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

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

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

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

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

Under these conditions the value of the discharge coefficient $C$ is

$$C = 0{,}984$$

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

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

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

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

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

Under these conditions the value of the discharge coefficient $C$ is

$$C = 0{,}995$$

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

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

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

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

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

Under these conditions the value of the discharge coefficient $C$ is

$$C = 0{,}985$$

## 5.6 Expansibility [expansion] factor, $\varepsilon$

The expansibility [expansion] factor, $\varepsilon$, is calculated by means of Equation (2):

$$\varepsilon = \sqrt{\left(\frac{\kappa \tau^{2/\kappa}}{\kappa - 1}\right)\left(\frac{1-\beta^4}{1-\beta^4 \tau^{2/\kappa}}\right)\left(\frac{1-\tau^{(\kappa-1)/\kappa}}{1-\tau}\right)} \qquad (2)$$

Equation (2) is applicable only for values of $\beta$, $D$ and $Re_D$ as specified in 5.5.2, 5.5.3 or 5.5.4 as appropriate. Test results for determination of $\varepsilon$ are only known for air, steam and natural gas. However, there is no known objection to using the same formula for other gases and vapours for which the isentropic exponent is known.

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

Values of the expansibility [expansion] factor for a range of isentropic exponents, pressure ratios and diameter ratios are given for convenience in Table A.1. These values are not intended for precise interpolation. Extrapolation is not permitted.

## 5.7 Uncertainty of the discharge coefficient $C$

### 5.7.1 Classical Venturi tube with an "as cast" convergent section

The relative uncertainty of the discharge coefficient as given in 5.5.2 is equal to 0,7 %.

### 5.7.2 Classical Venturi tube with a machined convergent section

The relative uncertainty of the discharge coefficient as given in 5.5.3 is equal to 1 %.

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

The relative uncertainty of the discharge coefficient as given in 5.5.4 is equal to 1,5 %.

## 5.8 Uncertainty of the expansibility [expansion] factor $\varepsilon$

The relative uncertainty of $\varepsilon$ is equal to

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

## 5.9 Pressure loss

### 5.9.1 Definition of the pressure loss (see Figure 2)

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

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

### 5.9.2 Relative pressure loss

The relative pressure loss, $\xi$, is the ratio of the pressure loss $\Delta p'' - \Delta p'$ to the differential pressure $\Delta p$:

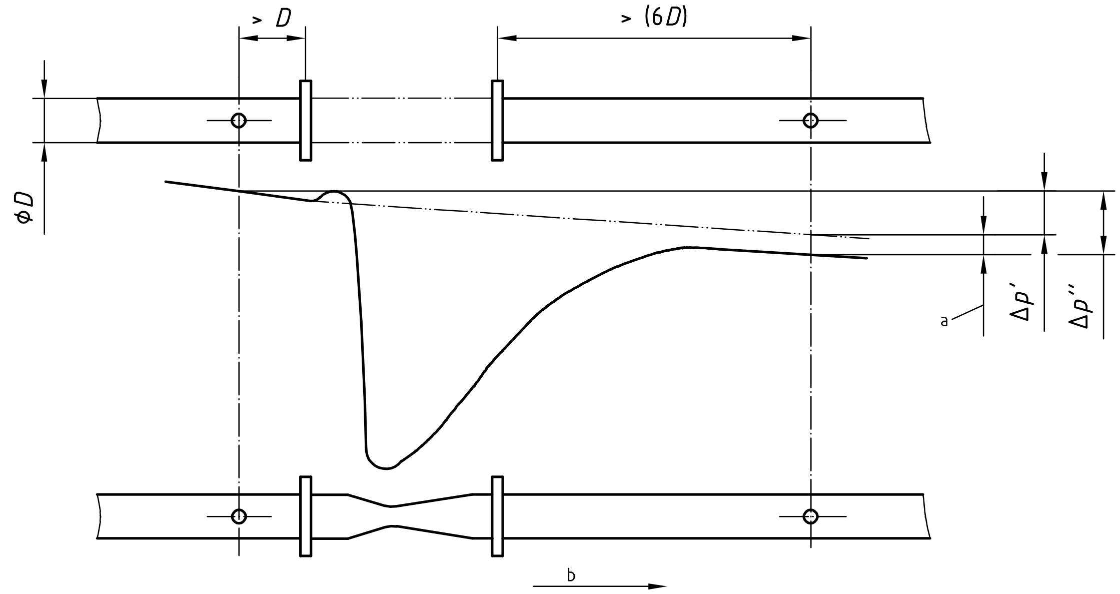
$$\xi = \frac{\Delta p'' - \Delta p'}{\Delta p}$$

It depends, in particular, on

- the diameter ratio ($\xi$ decreases when $\beta$ increases);
- the Reynolds number ($\xi$ decreases when $Re_D$ increases);
- the manufacturing characteristics of the Venturi tube: angle of the divergent, manufacturing of the convergent, surface finish of the different parts, etc ($\xi$ increases when $\varphi$ and $Ra/D$ increase);
- the installation conditions (good alignment, roughness of the upstream conduit, etc).

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

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



a Pressure loss

b Direction of flow

**Figure 2 — Pressure loss across a classical Venturi tube**

## 6 Installation requirements

### 6.1 General

General installation requirements for pressure differential devices are contained in Clause 7 of ISO 5167-1:2003 and should be followed in conjunction with the additional specific installation requirements for Venturi tubes given in this clause. The general requirements for flow conditions at the primary device are given in 7.3 of ISO 5167-1:2003. The requirements for use of a flow conditioner are given in 7.4 of ISO 5167-1:2003. For some commonly used fittings as specified in Table 1 the minimum straight lengths of pipe indicated may be used. Detailed requirements are given in 6.2. Many of the lengths given in 6.2 are based on data included in Reference [4] of the Bibliography.

### 6.2 Minimum upstream and downstream straight lengths for installation between various fittings and the Venturi tube

**6.2.1** The minimum straight lengths of pipe to be installed upstream of the classical Venturi tube and following the various fittings in the installation without flow conditioners are given in Table 1.

For devices with the same $\beta$, the lengths specified in Table 1 for classical Venturi tubes are shorter than those specified in ISO 5167-2 and ISO 5167-3 for orifice plates, nozzles and Venturi nozzles.

This is due to the attenuation of flow non-uniformities taking place within the contraction section of the classical Venturi tube. However in considering the overall installation length for the classical Venturi tube the additional pipe length required to accommodate the primary device itself shall be taken into account.

**6.2.2** When a flow conditioner is not used, the lengths specified in Table 1 shall be regarded as the minimum values. For research and calibration work in particular, it is recommended that the upstream values specified in Table 1 be increased by at least a factor of 2 to minimize the measurement uncertainty.

**6.2.3** When the upstream straight length used is equal to or longer than the value specified in columns A of Table 1 for “zero additional uncertainty” and the downstream straight length is equal to or longer than the value specified in Table 1, it is not necessary to increase the uncertainty in discharge coefficient to take account of the effect of the particular installation.

**Table 1 — Required straight lengths for classical Venturi tubes**

Values expressed as multiples of internal diameter $D$

| **Diameter ratio** $\beta$ | **Single 90° bend** [a] | | **Two or more 90° bends in the same plane or different planes** [a] | | **Reducer** 1,33$D$ **to** $D$ **over a length of** 2,3$D$ | | **Expander** 0,67$D$ **to** $D$ **over a length of** 2,5$D$ | | **Reducer** 3$D$ **to** $D$ **over a length of** 3,5 $D$ | | **Expander** 0,75$D$ **to** $D$ **over a length of** $D$ | | **Full bore ball or gate valve fully open** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | | 8 | |
| | A[b] | B[c] | A[b] | B[c] | A[b] | B[c] | A[b] | B[c] | A[b] | B[c] | A[b] | B[c] | A[b] | B[c] |
| 0,30 | 8 | 3 | 8 | 3 | 4 | [d] | 4 | [d] | 2,5 | [d] | 2,5 | [d] | 2,5 | [d] |
| 0,40 | 8 | 3 | 8 | 3 | 4 | [d] | 4 | [d] | 2,5 | [d] | 2,5 | [d] | 2,5 | [d] |
| 0,50 | 9 | 3 | 10 | 3 | 4 | [d] | 5 | 4 | 5,5 | 2,5 | 2,5 | [d] | 3,5 | 2,5 |
| 0,60 | 10 | 3 | 10 | 3 | 4 | [d] | 6 | 4 | 8,5 | 2,5 | 3,5 | 2,5 | 4,5 | 2,5 |
| 0,70 | 14 | 3 | 18 | 3 | 4 | [d] | 7 | 5 | 10,5 | 2,5 | 5,5 | 3,5 | 5,5 | 3,5 |
| 0,75 | 16 | 8 | 22 | 8 | 4 | [d] | 7 | 6 | 11,5 | 3,5 | 6,5 | 4,5 | 5,5 | 3,5 |

The minimum straight lengths required are the lengths between various fittings located upstream of the classical Venturi tube and the classical Venturi tube itself. Straight lengths shall be measured from the downstream end of the curved portion of the nearest (or only) bend or the downstream end of the curved or conical portion of the reducer or expander to the upstream pressure tapping plane of the classical Venturi tube.

If temperature pockets or wells are installed upstream of the classical Venturi tube, they shall not exceed 0,13$D$ in diameter and shall be located at least 4$D$ upstream of the upstream tapping plane of the Venturi tube.

For downstream straight lengths, fittings or other disturbances (as indicated in this Table) or densitometer pockets situated at least four throat diameters downstream of the throat pressure tapping plane do not affect the accuracy of the measurement (see 6.2.3 and 6.2.5).

[a] The radius of curvature of the bend shall be greater than or equal to the pipe diameter.

[b] Column A for each fitting gives lengths corresponding to “zero additional uncertainty” values (see 6.2.3).

[c] Column B for each fitting gives lengths corresponding to “0,5 % additional uncertainty” values (see 6.2.4).

[d] The straight length in Column A gives zero additional uncertainty; data are not available for shorter straight lengths which could be used to give the required straight lengths for Column B.

**6.2.4** When the upstream straight length is shorter than the value corresponding to “zero additional uncertainty” shown in columns A and either equal to or greater than the “0,5 % additional uncertainty” value shown in columns B of Table 1 for a given fitting, an additional uncertainty of 0,5 % shall be added arithmetically to the uncertainty in the discharge coefficient.

**6.2.5** This part of ISO 5167 cannot be used to predict the value of any additional uncertainty when the upstream straight length is shorter than the “0,5 % additional uncertainty” values specified in columns B of Table 1 or when the downstream straight length is shorter than the value specified in the text in Table 1.

**6.2.6** The valves included in Table 1 shall be set fully open during the flow measurement process. It is recommended that control of the flowrate be achieved by valves located downstream of the Venturi tube. Isolating valves located upstream of the Venturi tube shall be set fully open, and these valves shall be full bore. The valve should be fitted with stops for alignment of the ball or gate in the open position. The valve is of the same nominal diameter as the upstream pipework but of a different bore diameter from the adjacent pipework.

**6.2.7** In the metering system, upstream valves which are match bored to the adjacent pipework and are designed in such a manner that in the fully opened condition there are no steps, can be regarded as part of the metering pipework length and do not need to have added lengths as in Table 1.

**6.2.8** The values given in Table 1 were determined experimentally with a very long straight length mounted upstream of the fitting in question so that the flow immediately upstream of the fitting was considered as fully developed and swirl-free. Since in practice such conditions are difficult to achieve, the following information may be used as a guide for normal installation practice.

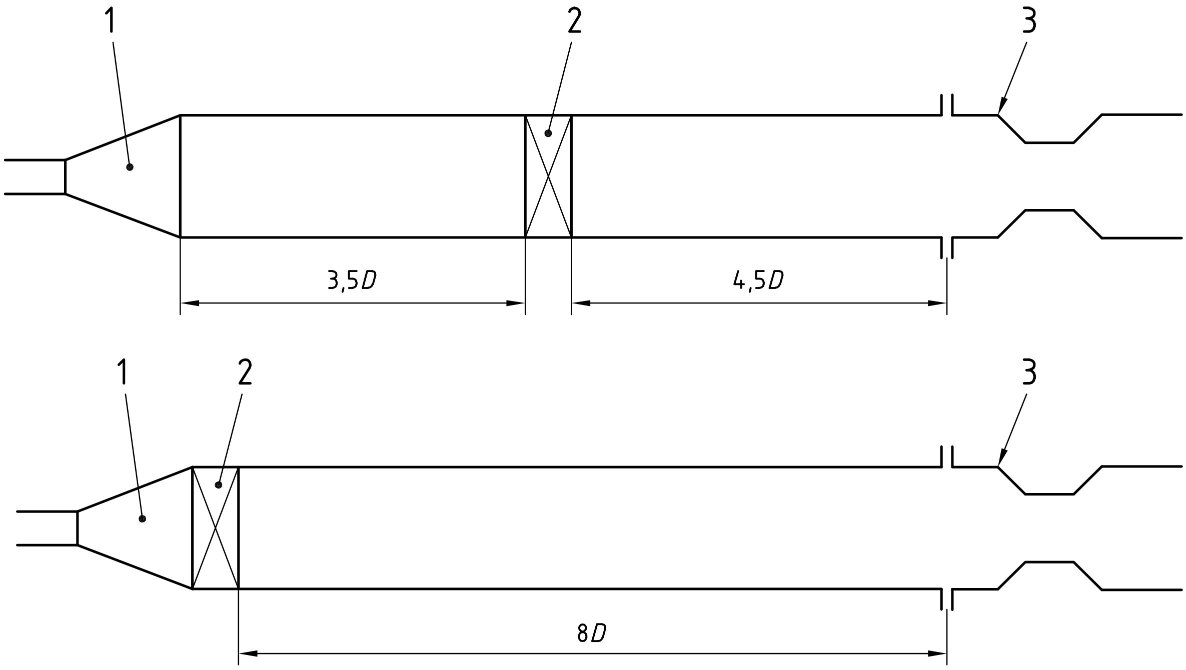
a) If several fittings of the type covered by Table 1, other than the combinations of 90° bends already covered by these Tables, are placed in series upstream of the Venturi tube the following shall be applied.

   1) Between the fitting immediately upstream of the Venturi tube, fitting 1, and the Venturi tube itself the minimum length criterion given in Table 1 shall be adopted.

   2) In addition, between fitting 1 and the next fitting further from the Venturi tube (fitting 2), a straight length at least equal to half the product of the diameter of the pipe between fitting 1 and fitting 2 and the number of diameters given in Table 1 for a Venturi tube of diameter ratio 0,7 used in conjunction with fitting 2 shall be included between fittings 1 and 2 irrespective of the actual $\beta$ for the Venturi tube used. If either of the minimum straight lengths is selected from column B (i.e. prior to taking the half value from fitting 1 to 2) of Table 1, a 0,5 % additional uncertainty shall be added arithmetically to the discharge coefficient uncertainty. For the case of two or more 90° bends, these shall be treated as a single fitting in accordance with Table 1 column 1 if the length between the consecutive bends is less than $15D$.

   3) If the upstream metering section has a full bore valve preceded by another fitting, e.g. an expander, then the valve can be installed at the outlet of the second fitting from the primary device. The required length between the valve and the second fitting according to 2) should be added to the length between the primary device and the first fitting specified in Table 1 (Figure 3). It should be noted that 6.2.8 b) shall also be satisfied (as it is in Figure 3).

b) In addition to the rule in a) any fitting, treating any two consecutive 90° bends as a single fitting, shall be located at a distance from the Venturi tube at least as great as the distance given by the product of the pipe diameter at the Venturi tube and the number of diameters required between that fitting and a Venturi tube of the same diameter ratio in Table 1, regardless of the number of fittings between that fitting and the Venturi tube. The distance between the Venturi tube and the fitting shall be measured along the pipe axis. If for any upstream fitting the distance meets this requirement using the number of diameters in column B but not that in column A then a 0,5 % additional uncertainty shall be added arithmetically to the discharge coefficient uncertainty, but this additional uncertainty shall not be added more than once under the provisions of a) and b).



**Key**

1 expander, 0,67$D$ to $D$ over a length of 2,5$D$

2 full bore ball valve or gate valve fully open

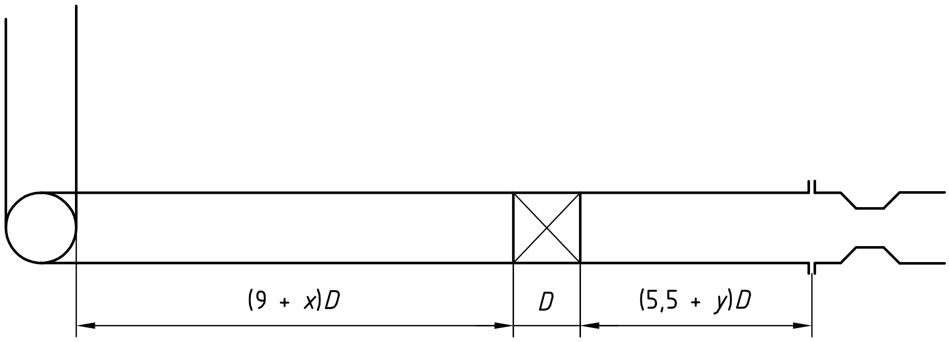
3 venturi tube

**Figure 3 — Layout including a full bore valve for** $\beta = 0{,}6$

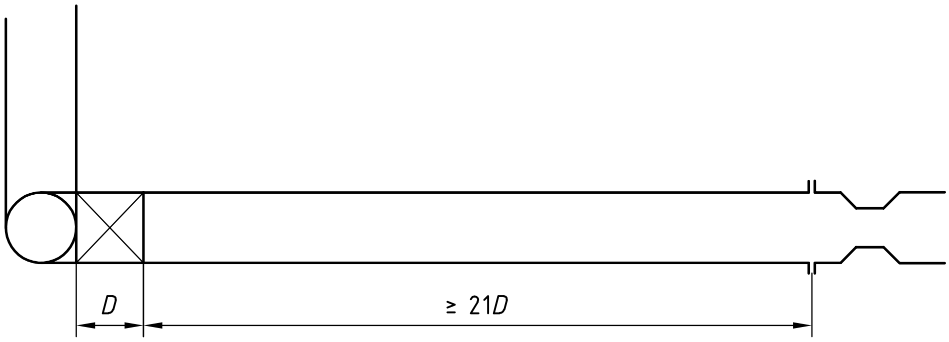
**6.2.9** By way of example, two cases of the application of 6.2.8 a) and b) are considered. In each case the second fitting from the Venturi tube is two bends in perpendicular planes and the Venturi tube has a diameter ratio 0,75.

If the first fitting is a full bore ball valve fully open [see Figure 4 a)], the distance between the valve and the Venturi tube shall be at least 5,5$D$ (from Table 1) and that between the two bends in perpendicular planes and the valve shall be at least 9$D$ [from 6.2.8 a)]; the distance between the two bends in perpendicular planes and the Venturi tube shall be at least 22$D$ [from 6.2.8 b)]. If the valve has length 1$D$ an additional total length of 6,5$D$ is required which may be either upstream or downstream of the valve or partly upstream and partly downstream of it. 6.2.8 a) 3) could also be used to move the valve to be adjacent to the two bends in perpendicular planes provided that there is at least 22$D$ from the two bends in perpendicular planes to the Venturi tube [see Figure 4 b)].

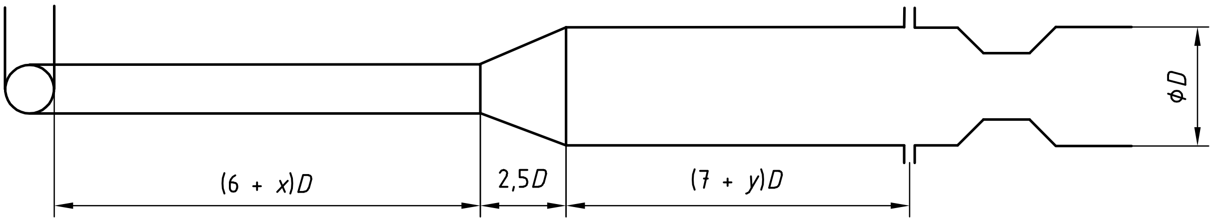
If the first fitting is an expander from 0,67$D$ to $D$ over a length of 2,5$D$ [see Figure 4 c)], the distance between the expander and the Venturi tube shall be at least 7$D$ (from Table 1) and that between the two bends in perpendicular planes and the expander shall be at least 9 × 0,67$D$ [from 6.2.8 a)]; the distance between the two bends in perpendicular planes and the Venturi tube shall be at least 22$D$ [from 6.2.8 b)]. So an additional total length of 6,5$D$ is required which may be either upstream or downstream of the expander or partly upstream and partly downstream of it.



**a)** $x \geqslant 0, y \geqslant 0, x + y \geqslant 6{,}5$



**b)**



**c)** $x \geqslant 0, y \geqslant 0, x + y \geqslant 6{,}5$

**Figure 4 — Examples of acceptable installations** (see 6.2.9)

## 6.3 Flow conditioners

A flow conditioner can be used to reduce upstream straight lengths either through meeting the compliance test given in 7.4.1 of ISO 5167-1:2003, in which case it can be used downstream of any upstream fitting, or through meeting the requirements of 7.4.2 of ISO 5167-1:2003, which gives additional possibilities outside the compliance test. In either case, the test work shall be carried out using a classical Venturi tube.

## 6.4 Additional specific installation requirements for classical Venturi tubes

### 6.4.1 Circularity and cylindricality of the pipe

**6.4.1.1** Over an upstream length of at least $2D$ measured from the upstream end of the entrance cylinder of the Venturi tube, the pipe shall be cylindrical. This pipe is said to be cylindrical when no diameter in any plane differs by more than 2 % from the mean of the measured diameters of the pipe.

**6.4.1.2** The mean diameter of the pipe where it joins the classical Venturi tube shall be within 1 % of the classical Venturi tube entrance cylinder diameter $D$, as defined in 5.2.2.

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

### 6.4.2 Roughness of the upstream pipe

The upstream pipe shall have a relative roughness of $Ra/D \leqslant 3{,}2 \times 10^{-4}$ on a length at least equal to $2D$ measured from the upstream end of the entrance cylinder of the Venturi tube.

### 6.4.3 Alignment of the classical Venturi tube

The offset or distance between the centrelines of the upstream pipe and of the Venturi tube, as measured in the connecting plane of the upstream pipe and entrance cylinder A (see 5.2), shall be less than $0{,}005D$. The angular alignment uncertainty of the Venturi tube centreline with respect to the upstream pipe centreline shall be less than 1°. Finally the sum of the offset and half the diameter deviation (see 6.4.1.2) shall be less than $0{,}007\,5D$. Therefore mating flanges would require the bores to be matched and the flanges aligned on installation. Dowels or self-centring gaskets could be used.

# Annex A
(informative)

# Table of expansibility [expansion] factor

**Table A.1 — Venturi tubes — Expansibility [expansion] factor, $\varepsilon$**

| Diameter ratio | | Expansibility [expansion] factor, $\varepsilon$, for $p_2/p_1$ equal to | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $\beta$ | $\beta^4$ | 1,00 | 0,98 | 0,96 | 0,94 | 0,92 | 0,90 | 0,85 | 0,80 | 0,75 |
| for $\kappa$ = 1,2 | | | | | | | | | | |
| 0,300 0 | 0,008 1 | 1,000 0 | 0,987 3 | 0,974 5 | 0,961 6 | 0,948 6 | 0,935 4 | 0,902 1 | 0,867 8 | 0,832 7 |
| 0,562 3 | 0,100 0 | 1,000 0 | 0,985 6 | 0,971 2 | 0,956 8 | 0,942 3 | 0,927 8 | 0,891 3 | 0,854 3 | 0,816 9 |
| 0,668 7 | 0,200 0 | 1,000 0 | 0,983 4 | 0,966 9 | 0,950 4 | 0,934 1 | 0,917 8 | 0,877 3 | 0,837 1 | 0,797 0 |
| 0,740 1 | 0,300 0 | 1,000 0 | 0,980 5 | 0,961 3 | 0,942 4 | 0,923 8 | 0,905 3 | 0,860 2 | 0,816 3 | 0,773 3 |
| 0,750 0 | 0,316 4 | 1,000 0 | 0,980 0 | 0,960 3 | 0,940 9 | 0,921 8 | 0,903 0 | 0,857 1 | 0,812 5 | 0,769 0 |
| for $\kappa$ = 1,3 | | | | | | | | | | |
| 0,300 0 | 0,008 1 | 1,000 0 | 0,988 3 | 0,976 4 | 0,964 5 | 0,952 4 | 0,940 2 | 0,909 2 | 0,877 3 | 0,844 5 |
| 0,562 3 | 0,100 0 | 1,000 0 | 0,986 7 | 0,973 4 | 0,960 0 | 0,946 6 | 0,933 1 | 0,899 0 | 0,864 5 | 0,829 4 |
| 0,668 7 | 0,200 0 | 1,000 0 | 0,984 6 | 0,969 3 | 0,954 1 | 0,938 9 | 0,923 7 | 0,885 9 | 0,848 1 | 0,810 2 |
| 0,740 1 | 0,300 0 | 1,000 0 | 0,982 0 | 0,964 2 | 0,946 6 | 0,929 2 | 0,912 0 | 0,869 7 | 0,828 3 | 0,787 5 |
| 0,750 0 | 0,316 4 | 1,000 0 | 0,981 5 | 0,963 2 | 0,945 2 | 0,927 4 | 0,909 8 | 0,866 7 | 0,824 6 | 0,783 3 |
| for $\kappa$ = 1,4 | | | | | | | | | | |
| 0,300 0 | 0,008 1 | 1,000 0 | 0,989 1 | 0,978 1 | 0,967 0 | 0,955 7 | 0,944 4 | 0,915 4 | 0,885 5 | 0,854 6 |
| 0,562 3 | 0,100 0 | 1,000 0 | 0,987 7 | 0,975 3 | 0,962 8 | 0,950 3 | 0,937 7 | 0,905 8 | 0,873 3 | 0,840 2 |
| 0,668 7 | 0,200 0 | 1,000 0 | 0,985 7 | 0,971 5 | 0,957 3 | 0,943 0 | 0,928 8 | 0,893 3 | 0,857 7 | 0,821 9 |
| 0,740 1 | 0,300 0 | 1,000 0 | 0,983 2 | 0,966 7 | 0,950 3 | 0,934 0 | 0,917 8 | 0,878 0 | 0,838 8 | 0,800 0 |
| 0,750 0 | 0,316 4 | 1,000 0 | 0,982 8 | 0,965 8 | 0,948 9 | 0,932 3 | 0,915 8 | 0,875 2 | 0,835 3 | 0,796 0 |
| for $\kappa$ = 1,66 | | | | | | | | | | |
| 0,300 0 | 0,008 1 | 1,000 0 | 0,990 8 | 0,981 5 | 0,972 1 | 0,962 5 | 0,952 9 | 0,928 1 | 0,902 4 | 0,875 8 |
| 0,562 3 | 0,100 0 | 1,000 0 | 0,989 6 | 0,979 1 | 0,968 5 | 0,957 8 | 0,947 1 | 0,919 7 | 0,891 7 | 0,862 9 |
| 0,668 7 | 0,200 0 | 1,000 0 | 0,987 9 | 0,975 9 | 0,963 7 | 0,951 6 | 0,939 4 | 0,908 8 | 0,877 8 | 0,846 4 |
| 0,740 1 | 0,300 0 | 1,000 0 | 0,985 8 | 0,971 8 | 0,957 7 | 0,943 8 | 0,929 9 | 0,895 3 | 0,860 9 | 0,826 5 |
| 0,750 0 | 0,316 4 | 1,000 0 | 0,985 4 | 0,971 0 | 0,956 6 | 0,942 3 | 0,928 1 | 0,892 8 | 0,857 7 | 0,822 8 |
| NOTE This Table is given for convenience. The values given are not intended for precise interpolation. Extrapolation is not permitted. | | | | | | | | | | |

# Annex B
(informative)

# Classical Venturi tubes used outside the scope of ISO 5167-4

## B.1 General

As indicated in 5.5.1 the effects of $Re_D$, $Ra/D$ and $\beta$ on $C$ are not yet known well enough to allow standardization outside the limits specified in ISO 5167-4.

The aim of this Annex is to summarize the data that can be used from all the results available; the values or the direction of variation of discharge coefficients and the uncertainties are given in terms of the various parameters [$\beta$, $Re_D$ and $Ra/D$] in order to allow an assessment of the flowrate. These various effects are dealt with separately although some results show that they are not independent.

In particular, the number of tests available on this subject is small and these tests were mostly carried out on Venturi tubes whose geometry was not strictly in accordance with ISO 5167-4. As a result the reliability not only of the discharge coefficients but also of the uncertainties is relatively low.

## B.2 Effect of the diameter ratio $\beta$

From an examination of the results available for Venturi tubes with diameter ratios of approximately $\beta \geqslant 0{,}75$ 5), it has been noted that the spread of measured discharge coefficients is wider than for smaller diameter ratios. Hence an increase in the uncertainty on the discharge coefficient should be assumed.

In order to allow an assessment of the uncertainty on the flowrate, it is recommended to double the uncertainty on $C$ when $\beta$ is greater than the maximum permissible value.

## B.3 Influence of the Reynolds number $Re_D$

### B.3.1 General

The influence of the Reynolds number $Re_D$ varies according to the type of classical Venturi tube. It is shown by a variation in the discharge coefficient and by an increase in the uncertainty.

### B.3.2 Classical Venturi tube with an “as cast” convergent section

When $Re_D$ decreases below $2 \times 10^5$, the discharge coefficient $C$ decreases and the uncertainty increases.

When $Re_D$ increases above $2 \times 10^6$, the discharge coefficient does not appear to change with Reynolds number nor does the uncertainty.

For an approximate estimation of the flowrate, the values of the discharge coefficient $C$ and the uncertainty given as guidance in Table B.1 may be used.

---

5) Values given below are based on tests carried out on Venturi tubes of diameter ratio $\beta$ up to 0,8.

**Table B.1 — Values of the discharge coefficient $C$ and the uncertainty as a function of $Re_D$**

| $Re_D$ | $C$ | Uncertainty<br>% |
|---|---|---|
| $4 \times 10^4$ | 0,957 | 2,5 |
| $6 \times 10^4$ | 0,966 | 2 |
| $1 \times 10^5$ | 0,976 | 1,5 |
| $1{,}5 \times 10^5$ | 0,982 | 1 |

### B.3.3 Classical Venturi tube with a machined convergent section

When $Re_D$ decreases below $2 \times 10^5$, it is often found that there is a small increase in the discharge coefficient $C$ before there is a steady decrease with decreasing $Re_D$. The uncertainty on $C$ increases slowly at first then rapidly increases.

In terms of throat Reynolds number $Re_d$, the position of the local maximum of the values of $C$ corresponds to values of $Re_d$ lying between $2 \times 10^5$ and $4 \times 10^5$.

When $Re_D$ increases above $10^6$, the pattern of $C$ as a function of Reynolds number is not very predictable. Sometimes there is a slight increase in $C$ with Reynolds number; sometimes there is a substantial but gradual increase; sometimes there is a substantial and sudden increase.

It is believed that there is sufficient evidence available to justify the statement that the discharge coefficient of this type of Venturi tube is a function of $Re_d$ (the Reynolds number based on the throat diameter) and not a function of $Re_D$. The results available show that better correlation is achieved in terms of $Re_d$ than in terms of $Re_D$.

In order to allow an assessment of the flowrate the values of the discharge coefficient and the uncertainty, given as guidance in Table B.2, may be used.

**Table B.2 — Values of the discharge coefficient $C$ and the uncertainty as a function of $Re_d$**

| $Re_d$ | $C$ | Uncertainty[a]<br>% |
|---|---|---|
| $5 \times 10^4$ | 0,970 | 3 |
| $1 \times 10^5$ | 0,977 | 2,5 |
| $2 \times 10^5$ | 0,992 | 2,5 |
| $3 \times 10^5$[b] | 0,998 | 1,5 |
| $5 \times 10^5$ to $10^6$ | 0,995 | 1 |
| $10^6$ to $2 \times 10^6$ | 1,000 | 2 |
| $2 \times 10^6$ to $10^8$ | 1,010 | 3 |

[a] For low Reynolds numbers, the spread of the experimental results is not a Gaussian distribution, the mean deviation of results smaller than the mean value of $C$ being greater than that of greater values.

[b] If $\beta \geqslant 0{,}67$, there is a difference between the values of discharge coefficient and uncertainty for $Re_d = 3 \times 10^5$ recommended in this table and those in 5.5.3 and 5.7.2.

### B.3.4 Classical Venturi tube with a rough-welded sheet-iron convergent section

The influence of the Reynolds number is as described below.

When $Re_D$ decreases below $2 \times 10^5$ the discharge coefficient $C$ decreases slightly while the uncertainty on $C$ increases.

Although there is relatively less information on this type of Venturi tube, the values of the discharge coefficient and the uncertainty, given as guidance in Table B.3, may be used to obtain an estimate of the flowrate.

The discharge coefficient does not appear to change when $Re_D$ is greater than $2 \times 10^6$.

Above $Re_D = 2 \times 10^6$, it is advisable to take the uncertainty as equal to 2 %.

**Table B.3 — Values of the discharge coefficient $C$ and the uncertainty as a function of $Re_D$**

| $Re_D$ | $C$ | Uncertainty % |
|---|---|---|
| $4 \times 10^4$ | 0,96 | 3 |
| $6 \times 10^4$ | 0,97 | 2,5 |
| $1 \times 10^5$ | 0,98 | 2,5 |

### B.3.5 Classical Venturi tube with a profile as defined for an "as cast" convergent section but with the entrance cylinder and convergent section machined

This Venturi tube has the same profile as defined in 5.2.8 with the exception that the entrance cylinder A and the convergent section B are machined so that they have a relative roughness $Ra$ less than both $5 \times 10^{-5}D$ and 15 µm. The pipe upstream of the entrance cylinder has the same roughness as the entrance cylinder over a length of at least $2D$ upstream of the entrance cylinder.

When $Re_D$ increases above $3{,}2 \times 10^6$, the discharge coefficient does not appear to change with Reynolds number nor does the uncertainty.

In order to allow an assessment of the flowrate the values of the discharge coefficient and the uncertainty, given as guidance in Table B.4, may be used.

**Table B.4 — Values of the discharge coefficient $C$ and the uncertainty as a function of $Re_D$**

| $Re_D$ | $C$ | Uncertainty % |
|---|---|---|
| $10^4$ | 0,963 | 2,5 |
| $6 \times 10^4$ | 0,978 | 2 |
| $10^5$ | 0,980 | 1,5 |
| $1{,}5 \times 10^5$ | 0,987 | 1 |
| $2 \times 10^5$ to $5 \times 10^5$ | 0,992 | 1 |
| $5 \times 10^5$ to $3{,}2 \times 10^6$ | 0,995 | 1 |

## B.4 Effects of the relative roughness $Ra/D$

### B.4.1 Roughness of the classical Venturi tube

It can be said that an increase in the convergent section roughness reduces the discharge coefficient $C$.

Classical Venturi tubes with a machined convergent section seem to be more sensitive to this effect than classical Venturi tubes with an “as cast” or rough-welded sheet-iron convergent section.

The pressure loss of the Venturi tube is also increased by an increase in the roughness.

### B.4.2 Roughness of the upstream pipe

An increase in the roughness of the upstream pipe produces an increase in the discharge coefficient $C$ of the classical Venturi tube. It appears that this effect becomes all the more marked as $\beta$ increases.

# Annex C
(informative)

# Pressure loss in a classical Venturi tube

## C.1 General

All values mentioned in this annex are given for guidance only (see 5.9.2).

## C.2 Mean value of the pressure loss and influence of the relative roughness

For a classical Venturi tube with a total angle of the divergent section equal to 7° and a pipe Reynolds number $Re_D$ greater than $10^6$, the relative pressure loss $\xi = (\Delta p'' - \Delta p')/\Delta p$ generally lies in the hatched area shown on Figure C.1 a). The values of $\xi$ close to the upper threshold of this area are for the upper values of the relative roughness $Ra/D$ and, therefore, for a given manufacturing design, are for the classical Venturi tube whose diameters are smallest.

## C.3 Influence of the Reynolds number

For a given Venturi tube, the value of $\xi$ decreases when $Re_D$ increases and it seems to reach a limiting value above about $Re_D = 10^6$. Figure C.1 b) gives an approximation of how the ratio of $\xi$ to its limiting values varies.

## C.4 Influence of the angle of the divergent section

The relative pressure loss increases with the angle of the divergent section. Figure C.1 c) shows, everything else being equal, the ratio of the values of $\xi$ for two Venturi tubes having angles of the divergent section $\varphi$ equal to 15° and 7°.

## C.5 Influence of the truncation

No precise indication is at present available on the pressure loss of a truncated Venturi tube. It is considered, however, that the length of the divergent section can be reduced by about 35 % without a significant increase in the pressure loss.

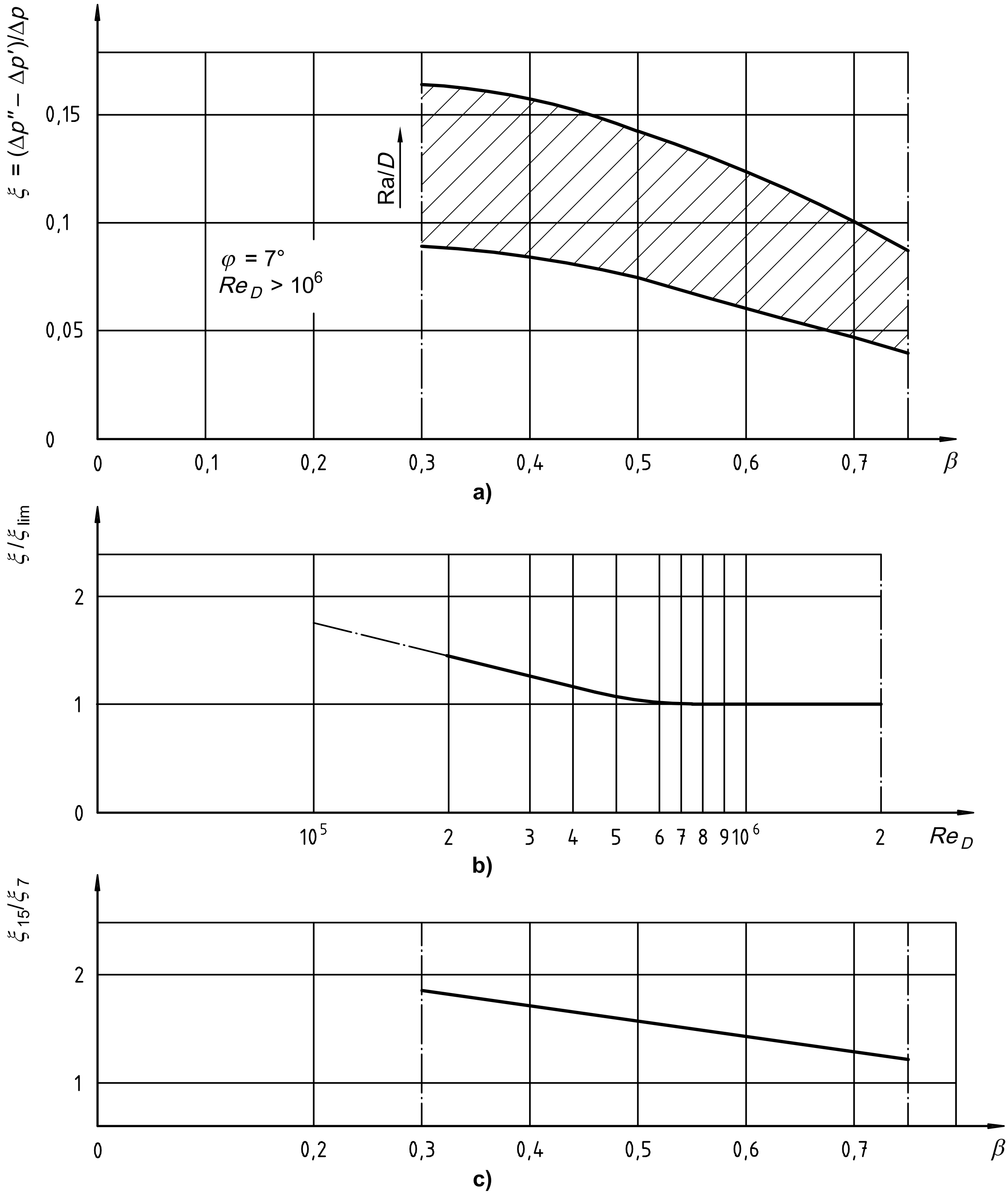


**Figure C.1 — Values of the pressure loss across a classical Venturi tube**

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