भारतीय मानक

Indian Standard

IS 14615 (Part 4) : 2024
ISO 5167-4 : 2022

पूर्ण भरे बहाव वाली वृत्ताकार अनुप्रस्थ काट की वाहिकाओं में विभेदक दबाव उपकरणों के माध्यम से द्रव प्रवाह मापन

भाग 4 वेन्चुरी नलिकाएँ

(पहला पुनरीक्षण)

Measurement of Fluid Flow by Means of Pressure Differential Devices Inserted in Circular Cross Section Conduits Running Full

Part 4 Venturi Tubes

(First Revision)

ICS 17.120.10

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NATIONAL FOREWORD

This Indian Standard (Part 4) (First Revision) which is identical to ISO 5167-4 : 2022 ‘Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full — Part 4 : Venturi tubes' issued by the International Organization for Standardization (ISO) was adopted by the Bureau of Indian Standards on the recommendation of the Hydrometry Sectional Committee and approved of the Water Resources Division Council.

This standard was first published in 2018 based on ISO 5167-4 : 2003. This first revision has been undertaken to align it with the latest version of ISO 5167-4 : 2022.

This standard is being published in five parts. Other parts in the series are:

Part 1 General principles and requirements
Part 2 Orifice plates
Part 3 Nozzles and venturi nozzles
Part 5 Cone meters

The text of ISO standard has been approved as suitable for publication as an Indian Standard without deviations. Certain conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appear referring to this standard, they should be read as 'Indian Standard'; and

b) Comma (,) has been used as a decimal marker, while in Indian Standards, the current practice is to use a point (.) as the decimal marker.

In this adopted standard, reference to certain International Standards appears for which Indian Standards also exist. The corresponding Indian Standards, which are to be substituted in their place, are listed below along with their degree of equivalence for the edition indicated:

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
ISO 5167-1 : 2022 Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full — Part 1: General principles and requirements	NA	NA

The Committee responsible for the preparation of this standard has reviewed the provisions of the following ISO/IEC standard and has decided that they are acceptable for use in conjunction with this standard:

International Standard	*Title*
ISO 4006	Measurement of fluid flow in closed conduits — Vocabulary and symbols

For the purpose of deciding whether a particular requirement of this standard is complied with the final value, observed or calculated expressing the result of a test or analysis shall be rounded off in accordance with IS 2 : 2022 ‘Rules for rounding off numerical values (*second revision*)’. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

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Introduction

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

ISO 5167 (all parts) 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 uncalibrated within specified limits of pipe size and Reynolds number, or alternatively they can be used across their calibrated range.

ISO 5167 (all parts) 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. ISO 5167 (all parts) also provides methodology for bespoke calibration of differential pressure meters.

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 to facilitate the instrument readings are known as secondary devices, and the flow computer that receives these readings and performs the algorithms is known as a tertiary device. ISO 5167 (all parts) covers primary devices; secondary devices (see ISO 2186) and tertiary devices will be mentioned only occasionally.

Aspects of safety are not dealt with in ISO 5167-1 to ISO 5167-6. It is the responsibility of the user to ensure that the system meets applicable safety regulations.

Indian Standard

MEASUREMENT OF FLUID FLOW BY MEANS OF PRESSURE DIFFERENTIAL DEVICES INSERTED IN CIRCULAR CROSS SECTION CONDUITS RUNNING FULL

PART 4 VENTURI TUBES

(First Revision)

1 Scope

This document specifies the geometry and method of use (installation and operating conditions) of Venturi tubes[1] when they are inserted in a conduit running full to determine the flow rate of the fluid flowing in the conduit.

This document also provides background information for calculating the flow rate and is applicable in conjunction with the requirements given in ISO 5167-1.

This document 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, Venturi tubes can only be used uncalibrated in accordance with this standard within specified limits of pipe size, roughness, diameter ratio and Reynolds number, or alternatively they can be used across their calibrated range. This document is not applicable to the measurement of pulsating flow. It does not cover the use of uncalibrated Venturi tubes in pipes sized less than 50 mm or more than 1 200 mm, or where the pipe Reynolds numbers are below 2×10^5.

This document deals with the three types of classical Venturi tubes:

a) “as cast”;

b) machined;

c) fabricated (also known as “rough-welded sheet-iron”).

A Venturi tube consists of a convergent inlet connected to a cylindrical throat which is in turn connected to a conical expanding section called the divergent section (or alternatively the diffuser). Venturi nozzles (and other nozzles) are dealt with in ISO 5167-3.

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

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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, *Measurement of fluid flow in closed conduits — Vocabulary and symbols*

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

ISO 5168, *Measurement of fluid flow — Procedures for the evaluation of uncertainties*

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

ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

3 Terms and definitions

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at https://www.electropedia.org/

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. A static pressure difference exists between the upstream section and the throat section of the device. Venturi tube geometries and designs have been extensively tested across a wide range of flow conditions and shown to have a reproducible value of the discharge coefficient, C, within a given uncertainty. Uncalibrated Venturi tubes of one of these geometries and designs, within that same range of flow conditions, can be used to determine the flow rate from the measured value of this pressure difference and from a knowledge of the fluid conditions.

The mass flow rate can be determined by Formula (1):

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

The uncertainty limits can be calculated using the procedure given in ISO 5167-1:2022, Clause 8.

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

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

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

Computation of the flow rate, which is an arithmetic process, is performed by replacing the different items on the right-hand side of Formula (1) by their numerical values. Table A.1 gives Venturi tube expansibility factors (ε). They are not intended for precise interpolation. Extrapolation is not permitted.

The diameters d and D mentioned in Formula (1) (since D is required to calculate β) 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 document depends on the way in which they are manufactured.

Three types of standard classical Venturi tube are specified 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 (and hence roughness) are described in 5.1.2 to 5.1.4, and the resulting Venturi tubes have somewhat different characteristics.

There are limits given for the roughness of the internal surfaces and the Reynolds number for each type.

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 the convergent and divergent sections are rounded.

These classical Venturi tubes can be used in pipes of diameter between 100 mm and 800 mm and with diameter ratios β 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 the convergent and divergent sections may or may not be rounded.

These classical Venturi tubes can be used in pipes of diameter between 50 mm and 350 mm and with diameter ratios β between 0,4 and 0,75 inclusive.

5.1.4 Classical Venturi tube with a fabricated convergent section

This is a classical Venturi tube normally fabricated by rolling sheet iron (or an alternative sheet material) to form the sections of the Venturi tube, welding to complete the cylindrical, convergent and divergent sections, and then welding these together. 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 β between 0,4 and 0,7 inclusive.

5.2 General shape

5.2.1 General

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.

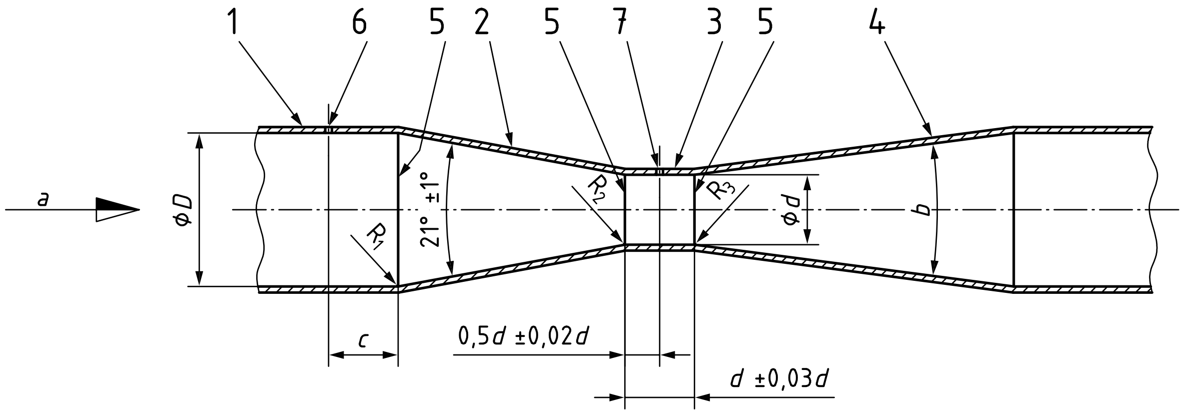
5.2.2 Entrance cylinder

The minimum cylinder length, measured from the plane containing the intersection of the convergent section 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 tapping(s). The number of measurements shall be at least four, of which one shall be measured near each pressure tapping. 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 tapping(s).

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	entrance cylinder A	a	Direction of flow.
2	conical convergent section B	b	$7° \leq \varphi \leq 15°$.
3	cylindrical throat C	c	See 5.4.7.
4	conical divergent section E		
5	connecting planes		
6	upstream pressure tapping(s)		
7	throat pressure tapping(s)		

Figure 1 — Geometric profile of the classical Venturi tube

5.2.3 Convergent section

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 section 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. The maximum deviation of the convergent section shall not exceed, in any place, $0{,}004D$.

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 Throat

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 tapping(s). The number of measurements shall be at least four, of which one shall be measured near each pressure tapping. 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 tapping(s).

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. The deviation shall evolve in a regular way for each curvature so that the maximum deviation that is measured occurs approximately midway along the profile. The value of this maximum deviation shall not exceed $0{,}02d$.

5.2.5 Divergent section

The divergent section E shall be conical and may have an included angle, φ, of between 7° and 15°. For low pressure-loss applications, it is recommended that an angle between 7° and 8° be chosen. Its smallest diameter shall not be less than the throat diameter.

5.2.6 Truncated Venturi tube

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 Roughness

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 internal surface of the divergent section shall be clean and smooth. Other parts of the classical Venturi tube have specified roughness limits depending on the type considered.

5.2.8 Classical Venturi tube with an “as cast” convergent section

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 Classical Venturi tube with a machined convergent section

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 Classical Venturi tube with a fabricated convergent section

The profile of the classical Venturi tube with a fabricated 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 other than that resulting from welding.

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 physical inspection 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.

One or more pressure tappings in each plane are permissible. Multiple tappings at the same plane may be interconnected by annular chambers, piezometer rings or, if there are four tappings, a “triple-T” arrangement (see ISO 5167-1:2022, 5.4.3).

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 pressure tapping(s) and $0{,}13d$ for the throat pressure tapping(s).

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

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

5.4.3 The centrelines of the pressure tappings shall meet the centreline of the classical Venturi tube, and shall be contained in planes perpendicular to the centreline of the classical Venturi tube.

Where interconnected multiple tappings are used, they shall be equally distributed around the cross section of the pipe.

5.4.4 At the point of break-through, the hole of the pressure tapping shall be circular. As small burrs or a wire edge can cause significant shifts in differential pressure, it is critical that the pressure tapping edges be flush with the pipe wall and free from any 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 physical 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 specified 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 mm < D < 150 mm;

— $0{,}5D^{\,0}_{-0{,}25D}$ for 150 mm < D < 800 mm.

For classical Venturi tubes with a machined or fabricated convergent section, 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 internal cross-sectional area 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 asymmetrical 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, β and Re_D shall be avoided as otherwise the uncertainties given in 5.7 are likely to be increased.

For installations outside the limits specified in 5.5.2, 5.5.3 and 5.5.4 for D, β and Re_D it remains necessary to calibrate separately the primary element over its in-service Reynolds number range.

The effects of Re_D, Ra/D and β on C are not yet sufficiently known for it to be possible to give reliable values of C outside the limits specified 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 document when,

$100 \text{ mm} \leq D \leq 800 \text{ mm}$,

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

$2 \times 10^5 \leq Re_D \leq 2 \times 10^6$.

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 document when,

$50\ \text{mm} \leq D \leq 350\ \text{mm}$,

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

$2 \times 10^5 \leq Re_D$.

Under these conditions the value of the discharge coefficient C is

$C = 0{,}995$ for $2 \times 10^5 \leq Re_D \leq 10^6$,

$C = 1{,}000$ for $10^6 < Re_D$.

5.5.4 Discharge coefficient of the classical Venturi tube with a fabricated convergent section

Classical Venturi tubes with a fabricated convergent section can only be used in accordance with this document when,

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

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

$2 \times 10^5 \leq Re_D \leq 2 \times 10^6$.

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

$C = 0{,}985$

5.6 Expansibility [expansion] factor, ε

The expansibility [expansion] factor, ε, is calculated by means of Formula (2):

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

Formula (2) is applicable only if $p_2 / p_1 \geq 0{,}75$, and only for values of β, D and Re_D as specified in 5.5.2, 5.5.3 or 5.5.4 as appropriate.

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

U_C', the relative expanded uncertainty at $k = 2$ (approximately 95 % confidence level) 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

U_C', the relative expanded uncertainty at $k = 2$ (approximately 95 % confidence level) of the discharge coefficient as given in 5.5.3, is equal to

1 % for $2 \times 10^5 \leq Re_D \leq 10^6$

1,8 %[5] for $10^6 < Re_D$

5.7.3 Classical Venturi tube with a fabricated convergent section

U_c', the relative expanded uncertainty at $k = 2$ (approximately 95 % confidence level) of the discharge coefficient as given in 5.5.4, is equal to 1,5 %.

5.8 Uncertainty of the expansibility [expansion] factor, ε

U_ε', the relative expanded uncertainty of the value of ε at $k = 2$ (approximately 95 % confidence level), 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

The pressure loss caused by a classical Venturi tube (see Figure 2) has been 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 condition.

The upstream tapping was installed at least $1D$ upstream of the inlet flange of the Venturi tube. The downstream tapping was installed at least $6D$ downstream of the outlet flange of the Venturi tube.

$\Delta p'$ is the difference in pressure between these tappings, measured prior to the installation of the Venturi tube.

$\Delta p''$ is the difference in pressure between these same pressure tappings, measured after installation of the Venturi tube between these flanges.

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, ξ, is the ratio of the pressure loss $\Delta p'' - \Delta p'$ to the differential pressure Δp, given by Formula (3)

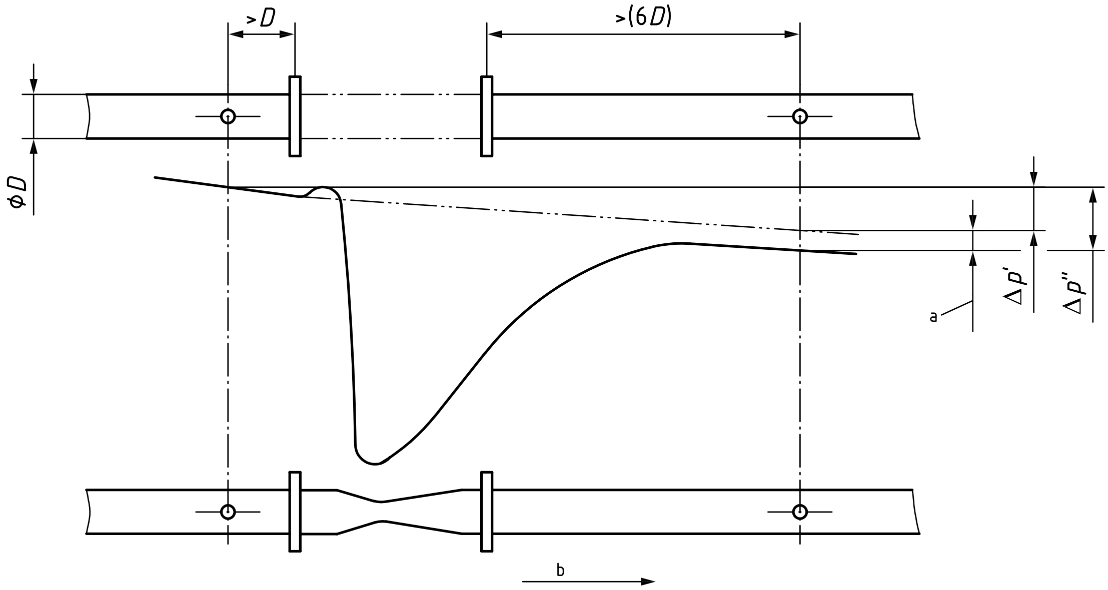
$$\xi = \frac{\Delta p'' - \Delta p'}{\Delta p} \tag{3}$$

It depends, in particular, on:

- the diameter ratio (ξ tends to decrease when β increases);
- the Reynolds number (ξ tends to decrease when Re_D increases);
- the manufacturing characteristics of the Venturi tube: angle of the divergent, manufacturing of the convergent, surface finish of the different parts, etc. (ξ tends to increase when φ 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 %. Metering systems using Venturi tubes have particularly small permanent pressure losses when compared with most other flow metering systems (see also ISO 5167-1:2022, Annex F).

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



a Pressure loss.

b Direction of flow.

Figure 2 — Pressure loss across a classical Venturi tube

Modern Venturi tubes generally give data around the line marking the lower end of the shaded area in Figure C.1 a); so, taking account of $\Delta p'/\Delta p$, in most cases for $Re_D > 10^6$ and $0,4 \leq \beta \leq 0,75$

$$0,05 \leq \frac{\Delta p''}{\Delta p} \leq 0,15$$

The pressure loss coefficient, K, for a Venturi tube is approximately given by Formula (4):

$$K = \frac{\left(1-\beta^4\right)}{\beta^4} \frac{\Delta p''}{\Delta p} \tag{4}$$

where K is defined by Formula (5):

$$K = \frac{\Delta p''}{\frac{1}{2}\rho V^2} \tag{5}$$

where

ρ is the density of the fluid in the pipe;

V is the mean axial velocity of the fluid in the pipe.

6 Installation requirements

6.1 General

General installation requirements for pressure differential devices are contained in ISO 5167-1:2022, Clause 7 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 ISO 5167-1:2022, 7.3. The requirements for use of a flow conditioner are given in

ISO 5167-1:2022, 7.4. 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 [3].

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 β, 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 β	Single 90° bend[a]		Two or more 90° bends in the same plane or different planes[a]		Reducer 1,33D to D over a length of 2,3D		Expander 0,67D to D over a length of 2,5D		Reducer 3D to D over a length of 3,5 D		Expander 0,75D 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 0,13D in diameter and shall be located at least 4D 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.

[e] The majority of data for this table were collected with Venturi tubes with interconnected multiple tappings.

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 relative uncertainty of 0,5 % shall be added arithmetically to the relative expanded uncertainty in the discharge coefficient.

6.2.5 This document 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.

In such cases bespoke calibration with the meter installed at a calibration facility with the same pipework as the application is recommended (see 7.3).

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 flow rate 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 this table, are placed in series upstream of the Venturi tube the following shall be applied:

    1) Between the Venturi tube and fitting 1 (the fitting immediately upstream of the Venturi tube), there shall be a straight length greater than or equal to the minimum length given in Table 1 appropriate for the specific Venturi tube diameter ratio used with fitting 1.

    2) Between fitting 1 and fitting 2 (the next fitting upstream of the Venturi tube), there shall be a straight length greater than or equal to half the minimum length given in Table 1 for a Venturi tube of diameter ratio 0,7 used with fitting 2 (irrespective of the actual diameter ratio of the Venturi tube). If the pipe diameter changes at fitting 1, the pipe diameter between fitting 1 and fitting 2 is used to calculate this minimum length.

       If either of the minimum straight lengths is selected from Column B (i.e. prior to taking the half value from fitting 1 to fitting 2 of Table 1), a 0,5 % additional relative uncertainty shall be added arithmetically to the relative expanded uncertainty of the discharge coefficient.

       For the case of two or more 90° bends, these shall be treated as a single fitting in accordance with Table 1 column 3 if the length between the consecutive bends is less than 15D.

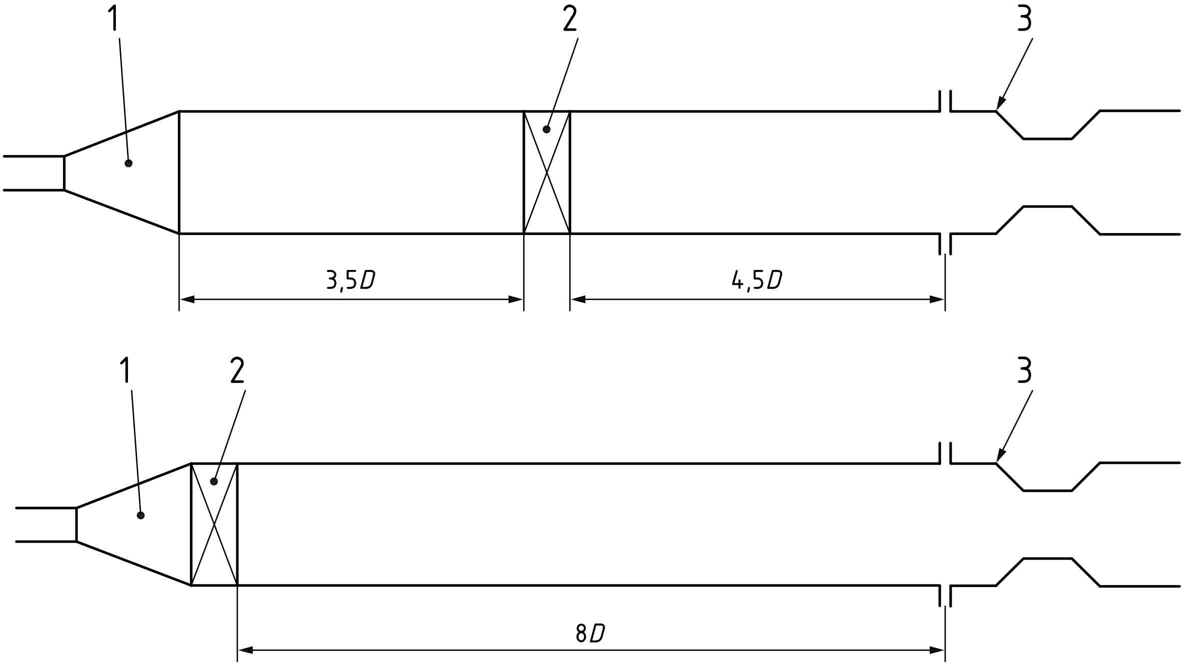
    3) If fitting 1 is a full-bore valve (as in Table 1), then the valve can be installed at the outlet of fitting 2.

       The required length between the valve and fitting 2 (as calculated from 2) above) should be added to the length between the Venturi tube and fitting 1 specified in Table 1; see Figure 3. It should be noted that 6.2.8 b) shall also be satisfied (as it is in Figure 3).

b) Between the Venturi tube and any upstream fitting (treating any two consecutive 90° bends as a single fitting), the straight length shall be greater than or equal to the minimum length given in Table 1 appropriate for the specific Venturi tube diameter ratio used with that fitting. The pipe diameter upstream of the Venturi tube is used to calculate this minimum length.

   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 relative uncertainty shall be added arithmetically to the relative expanded uncertainty of the discharge coefficient. However, this additional uncertainty shall not be added more than once under the provisions of a) and b).



Key

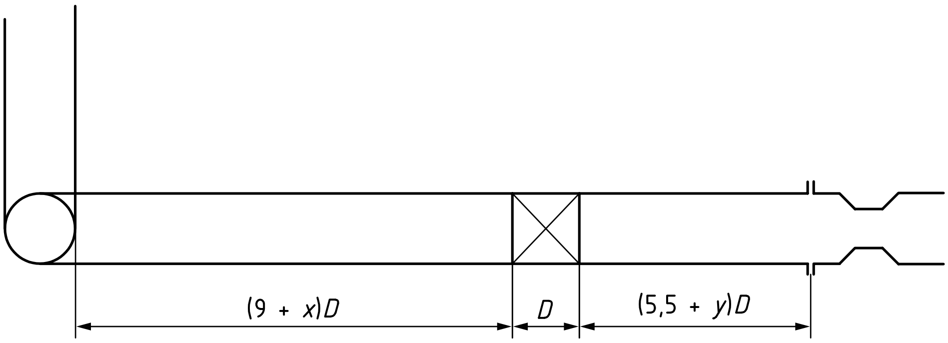
1	expander, 0,67*D* to *D* over a length of 2,5*D*
2	full bore ball valve or gate valve fully open
3	Venturi tube

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

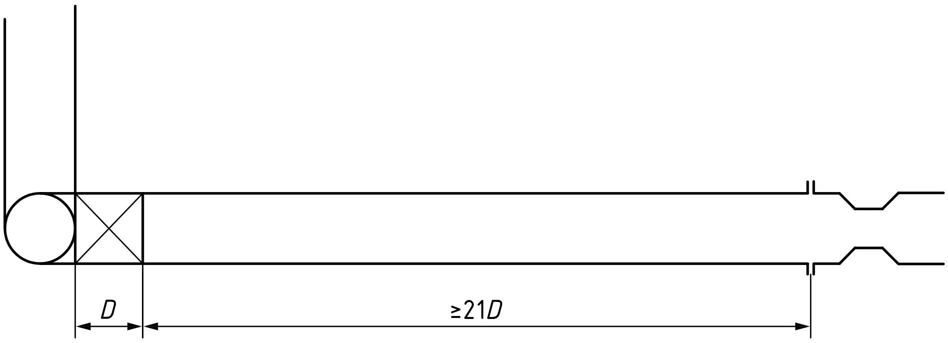
6.2.9 By way of example, two cases of the application of 6.2.8 a) and b) are considered. In each case fitting 2 is two bends in perpendicular planes and the Venturi tube has a diameter ratio 0,75.

If fitting 1 is a full bore ball valve fully open [see Figure 4 a)], the distance between the Venturi tube and the valve shall be at least 5,5*D* (from Table 1) and that between the valve and the two bends in perpendicular planes shall be at least 9*D* [from 6.2.8 a)]; the distance between the Venturi tube and the two bends in perpendicular planes 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 Venturi tube to the two bends in perpendicular planes [see Figure 4 b)].

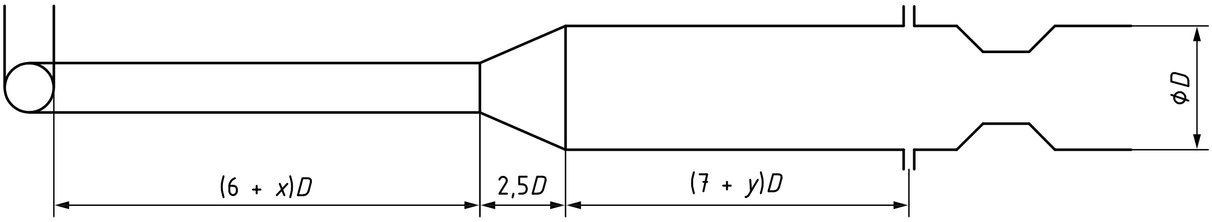
If fitting 1 is an expander from 0,67*D* to *D* over a length of 2,5*D* [see Figure 4 c)], the distance between the Venturi tube and the expander shall be at least 7*D* (from Table 1) and that between the expander and the two bends in perpendicular planes shall be at least 9 × 0,67*D* [from 6.2.8 a)]; the distance between the Venturi tube and the two bends in perpendicular planes 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) $x \geq 0, y \geq 0, x + y \geq 6{,}5$



b)



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

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 conformity test given in ISO 5167-1:2022, 7.4.1, in which case it can be used downstream of any upstream fitting, or through meeting the requirements of ISO 5167-1:2022, 7.4.2, which gives additional possibilities outside the conformity 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 and alignment of the classical Venturi tube

6.4.1.1 Over a distance of at least 2.5D upstream of the upstream pressure tapping(s), the upstream pipe that joins the entrance cylinder 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 this pipe.

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

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 0,005*D*. 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 shall be less than 0,007 5*D*. Therefore, mating flanges would require the bores to be matched and the flanges aligned on installation. Dowels or self-centring gaskets could be used.

6.4.1.2 If the entrance cylinder extends at least 2,5*D* upstream of the upstream pressure tappings, 6.4.1.1 does not apply. However, in this case the mean diameter of the upstream pipe (or fitting) that joins the entrance cylinder shall still be measured where it joins the entrance cylinder: this diameter shall be within 2 % of the classical Venturi tube entrance cylinder diameter *D*, as specified in 5.2.2. Moreover, 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 0,01*D*. 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 shall be less than 0,015*D*. Therefore, mating flanges would require the bores to be matched and the flanges aligned on installation. Dowels or self-centring gaskets could be used.

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

Any portion of the upstream pipe within 3*D* of the upstream pressure tapping(s) shall have a relative roughness of $Ra/D \leq 3,2 \times 10^{-4}$.

7 Flow calibration of Venturi tubes

7.1 General

For users of Venturi tubes of the geometry described in this document that require a lower discharge coefficient uncertainty than that stated in 5.7, or for users of devices where the geometry differs from that described in this document, the Venturi tube shall be calibrated.

The purpose of a flow calibration is to determine the discharge coefficient of an individual Venturi tube and its associated uncertainty.

Where the geometry of the Venturi tube differs from that described in this document, the expansibility equation given in Formula (2) could induce an increased uncertainty.

Calibrated meters shall only be used within the calibrated Reynolds number range.

NOTE For gas applications (other than those at ambient process conditions), an ambient-temperature water calibration is unlikely to produce the required Reynolds number range. The Reynolds number range should be used to help determine the choice of test facility.

7.2 Test facility

The Venturi tube shall be calibrated in such a manner as to ensure appropriate traceability for the user of the Venturi tube for the intended application.

NOTE For guidance on what might be appropriate, ISO/IEC 17025 is applicable.

7.3 Meter installation

The Venturi tube should be installed with, as a minimum, the upstream and downstream straight lengths specified in Clause 6.

If the Venturi tube is to be used with a flow conditioner a package consisting of at least $4D$ of pipe upstream of the flow conditioner, the flow conditioner, the pipe between the flow conditioner and the Venturi tube, the Venturi tube and at least $2D$ of pipe downstream of the Venturi tube shall be calibrated.

The orientation of the Venturi tube is irrelevant.

If the Venturi tube in operation will be installed in pipe work that differs significantly from the installation guidelines in this document, the operational pipe design should be replicated at the calibration facility in order to reduce the uncertainty of the Venturi tube in its installation.

7.4 Design of the test programme

The Venturi tube should be calibrated, as a minimum, over the entire Reynolds number range the meter is expected to see in operational service. The number of test points (i.e. nominal Reynolds numbers at which data are collected) shall be appropriate for the metering application. The test facility can calibrate the Venturi tube using liquid or gas, or both liquid and gas in separate tests to cover the required Reynolds number range.

The calibration data of a Venturi tube are not transferrable to another Venturi tube. If the meter has multiple sets of tappings, each set shall be calibrated as if it were a separate meter. Extrapolation of the calibration shall not be permitted.

7.5 Reporting the calibration results

The calibration test report should, as a minimum, provide tabulated results of the differential pressure, Reynolds number, and discharge coefficient values. The provision of graphs is also recommended for ease of analysis.

The discharge coefficient versus Reynolds number relationship determined in the calibration process shall be implemented according to the user's requirements. If this relationship is not constant to within the user's tolerance, then a non-constant mathematical expression should be used which will require an iterative solution. Consistent with 7.4, the user shall not extrapolate this mathematical expression.

7.6 Uncertainty analysis of the calibration

7.6.1 General

All uncertainties calculated as part of this flow calibration shall be stated to $k = 2$ (approximately 95 % confidence level).

7.6.2 Uncertainty of the test facility

The uncertainty of the instrumentation used by the test facility shall be calculated and recorded for each test point of the flow calibration. The uncertainty in the flow measurement shall be computed from this data utilizing a method detailed in either ISO 5168 or ISO/IEC Guide 98-3. Both the chosen method and the results shall be recorded in the calibration report.

Where both liquid and gas tests are separately used to cover the Reynolds number range, the uncertainties of each test facility for the relevant test points shall be clearly detailed in the calibration report.

7.6.3 Uncertainty of the Venturi tube

The calibration procedure and the calculated uncertainty of the Venturi tube under test shall be recorded in the calibration report. As so few measurements are taken at each Reynolds number, an appropriate statistical methodology shall be used, as, for instance, standard deviation should only be used for larger data sets.

Annex A
(informative)

Table of expansibility [expansion] factor

Table A.1 — Venturi tubes — Expansibility [expansion] factor, ε

Diameter ratio		Expansibility [expansion] factor, ε, for p_2/p_1 equal to								
β	β^4	1,00	0,98	0,96	0,94	0,92	0,90	0,85	0,80	0,75
for κ = 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 κ = 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 κ = 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 κ = 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 β 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 [β, Re_D and Ra/D] in order to allow an assessment of the flow rate. 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, β

From an examination of the results available for Venturi tubes with diameter ratios of approximately $\beta \geq 0{,}75$ [2], 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 flow rate, it is recommended to double the uncertainty on C when β 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.

NOTE There can be humps or dips in the calibration curve for C which generally occur as a function of the velocity past the throat pressure tappings, rather than the Reynolds number (see, for example, Figures 7.3 and 7.6 of Reference [4]). Further research is required in this area.

B.3.2 Classical Venturi tube with an "as cast" convergent section

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

When Re_D increases above 2×10^6, earlier data suggested that the discharge coefficient does not appear to change with Reynolds number nor does the uncertainty. However, more recent work has reduced confidence in this statement, and calibration as per Clause 7 is recommended.

For an approximate estimation of the flow rate, the values of the discharge coefficient C and the relative expanded uncertainty at $k = 2$ (approximately 95 % confidence level) given as guidance in Table B.1 may be used.

---

[2] Values given below are based on tests carried out on Venturi tubes of diameter ratio β 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 %
4×10^4	0,957	2,5
6×10^4	0,966	2
1×10^5	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 2×10^5, 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 2×10^5 and 4×10^5.

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 flow rate the values of the discharge coefficient and the relative expanded uncertainty at $k = 2$ (approximately 95 % confidence level) 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] %
5×10^4	0,970	3
1×10^5	0,977	2,5
2×10^5	0,992	2,5
3×10^5[b]	0,998	1,5
5×10^5 to 10^6	0,995	1

[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 $\beta \geq 0{,}67$, 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 fabricated convergent section

The influence of the Reynolds number is as described below.

When Re_D decreases below 2×10^5 the discharge coefficient C decreases slightly while the uncertainty in C increases.

Although there is relatively less information on this type of Venturi tube, the values of the discharge coefficient and the relative expanded uncertainty at $k = 2$ (approximately 95 % confidence level) given as guidance in Table B.3 may be used to obtain an estimate of the flow rate.

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

Above $Re_D = 2 \times 10^6$, it is advisable to take the relative expanded 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 %
4×10^4	0,96	3
6×10^4	0,97	2,5
1×10^5	0,98	2,5

B.3.5 Classical Venturi tube with a profile as specified for an “as cast” convergent section but with the entrance cylinder and convergent section machined

This Venturi tube has the same profile as specified 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.

In order to allow an assessment of the flow rate the values of the discharge coefficient and the relative expanded uncertainty at $k = 2$ (approximately 95 % confidence level) 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
6×10^4	0,978	2
10^5	0,980	1,5
$1{,}5 \times 10^5$	0,987	1
2×10^5 to 5×10^5	0,992	1
5×10^5 to $3{,}2 \times 10^6$	0,995	1[a]

[a] When Re_D increases above 10^6, it is likely that the uncertainty increases but the data are very limited. Above $Re_D = 2 \times 10^6$ it is advisable to take the relative expanded uncertainty as equal to 2 %.

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 fabricated 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 β 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 ξ 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 ξ 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 ξ 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 ξ for two Venturi tubes having angles of the divergent section φ 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.

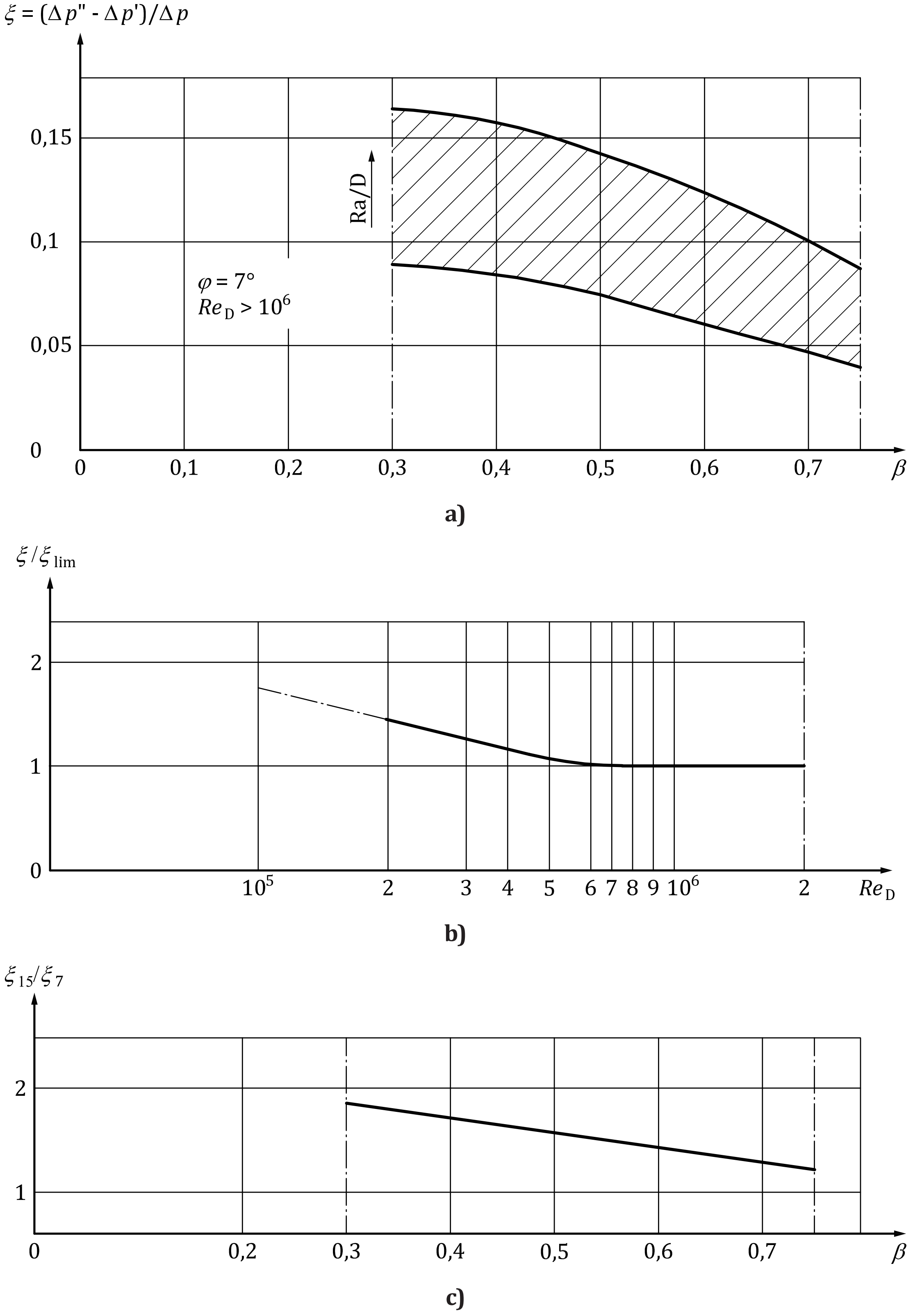


Figure C.1 — Values of the pressure loss across a classical Venturi tube

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