International Standard 7145

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Determination of flowrate of fluids in closed conduits of circular cross-section — Method of velocity measurement at one point of the cross-section

Détermination du débit des fluides dans les conduites fermées de section circulaire — Méthode par mesure de la vitesse en un seul point

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Foreword

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

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Determination of flowrate of fluids in closed conduits of circular cross-section — Method of velocity measurement at one point of the cross-section

1 Scope and field of application

1.1 Scope

This International Standard specifies a method for the determination of the volume rate of flow of a single phase fluid of a substantially constant density (Mach number $\leqslant 0,25$) under steady fully developed flow conditions in a closed conduit of circular cross-section running full by measurement of the flow velocity in a single point.

The method provides for the possibility of placing the primary velocity measuring device either at the point where it is assumed the mean axial velocity prevails, i.e. at a distance of 0,242 R from the wall of the conduit (R being the radius of the conduit), or on the axis of the conduit.

If there are doubts about the symmetry of the flow it is advisable to use at least two measuring points located symmetrically on one circumference at the distance from the wall specified above.

1.2 Field of application

The method specified in this International Standard does not apply unless the following conditions have been fulfilled :

a) The conduit shall have a straight length sufficiently long so that, in the measuring section, a distribution of velocities corresponding to fully developed turbulent flow can be observed (see 2.3.5).

Hydraulic resistance coefficient λ of the conduit should not exceed 0,06.

b) The flow must be turbulent and the Reynolds number, Re_D, should exceed or be equal to the following values :

λ	$> 0,03$	0,025	0,02	0,01
Re_D	10^4	3×10^4	10^5	10^6

When the velocity is measured on the conduit axis, the flow should be in fully rough turbulent regime (see 2.3.6). The Reynolds number, Re_D, should then exceed or be equal to :

λ	0,06	0,05	0,04	0,03	0,025	0,02	0,01
Re_D	3×10^4	5×10^4	10^5	3×10^5	5×10^5	10^6	5×10^7

c) The experimental data on which this International Standard is based principally relate to conduits of diameter equal to or greater than 300 mm, but there is every reason to believe that the method can be applied to conduits of smaller diameter.

d) In any point of the measuring cross-section, the angle between the direction of local velocity and the axis should not exceed 5°.

This condition can be verified either with the probe used for the measurements, if the design permits this, or with a different type of probe. It can be assumed that if the condition required is verified for a given flow q, then this condition is also met within the range $q/3$ to $3q$.

1.3 Accuracy of the method

As a guide, it can be considered that determination of flow from velocity measurement at a single point, carried out in accordance with the requirements of this International Standard, will lead to an uncertainty (at a confidence level of 95 %) not exceeding ± 3 %. However, the uncertainty on the flow shall be calculated for each individual application of this International Standard depending on the type of primary device, on the method of use and if necessary, on the method of calibration as well as on the measuring conditions.

2 Symbols and definitions

2.1 References

The vocabulary and symbols used in this International Standard are defined in the following International Standards :

ISO 3354, *Measurement of clean water flow in closed conduits — Velocity-area method using current-meters.*

ISO 3966, *Measurement of fluid flow in closed conduits — Velocity-area method using pitot-static tubes.*

ISO 4006, *Measurement of flow of fluids in closed conduits — Vocabulary and symbols.*

ISO 5168, *Measurement of fluid flow — Estimation of uncertainty of a flow-rate measurement.*

The definitions appearing in 2.3 are given only for terms used in a special sense for which it would seem useful to repeat the definition of meaning.

2.2 Symbols

Symbol	Quantity	Dimensions[1)]	SI units
A	Area of the cross-section of the conduit	L^2	m^2
a	Height of any high spot or protrusion on the external wall of the conduit	L	m
D	Diameter of the conduit	L	m
d	Diameter of the active part of the primary device	L	m
e	Uncertainty, as an absolute value	2)	2)
E	Uncertainty, as a relative value	—	—
k	Uniform equivalent roughness	L	m
P	External perimeter of the conduit	L	m
q_V	Volume flow rate	L^3T^{-1}	m^3/s
R	Radius of the conduit	L	m
Re_D	Reynolds number, $Re_D = \frac{UD}{\nu}$	—	—
s	Standard deviation	2)	2)
U	Mean axial velocity	LT^{-1}	m/s
u^*	Friction velocity, $u^* = U \sqrt{\frac{\lambda}{8}}$	LT^{-1}	m/s
v	Local fluid velocity	LT^{-1}	m/s
v_0	Local velocity at centre of conduit	LT^{-1}	m/s
v^*	Local non dimensional velocity, $v^* = \frac{v}{U}$	—	—
y	Distance from one measurement point to the wall	L	m
y^*	Non dimensional distance from one measurement point to the wall, $y^* = \frac{y}{R}$	—	—
λ	Universal coefficient of head loss as defined by the formula $\Delta p = \lambda \frac{L}{D} \times \frac{1}{2} \varrho U^2$ where Δp is the pressure drop on the tube length L and ϱ is the fluid density	—	—
ν	Kinematic viscosity of the fluid	L^2T^{-1}	m^2/s

1) L = length, T = time

2) The dimensions and units are those of the quantity to which the symbol refers, and which will be indicated by an index.

2.3 Definitions

2.3.1 primary velocity measuring device : Any device that changes a local flow velocity into a physical quantity suitable for measurement (for example, differential pressure, frequency of an electric signal, etc.).

NOTE — Throughout the rest of this document, the expression "primary device" is used instead of "primary velocity measurement device".

2.3.2 measuring point : Any point where the local velocity of the flow is measured.

2.3.3 mean axial velocity : Ratio of the volumetric flowrate and the area of the measuring section

$$U = \frac{q_V}{A}$$

2.3.4 point of mean axial velocity : In a cross-section of the conduit this is a point where the local velocity of the flow is equal to the mean axial velocity.

2.3.5 fully developed flow : The flow in which the distribution of velocities does not change from one cross-section to another. It is generally obtained at the outlet of a straight length of conduit of sufficient length (see 4.1).

2.3.6 fully rough turbulent flow : In a conduit of given relative roughness, this occurs when the hydraulic resistance coefficient is independant of the Reynolds number and may be assumed to be present when

$$Re_D > 500 \times 10^{\frac{1}{2\sqrt{\lambda}}}$$

or

$$Re_D > 1\,850 \frac{D}{k}$$

3 Principle

3.1 General

The principle of the determination of flow by measurement of the local velocity at a single point is based on the existence of laws applicable to all conduits, provided that all parameters remain within the limits indicated in 1.2, which relate the value of the local velocity at a given point in the cross-section to the value of the mean axial velocity in this section.

Two variants on this method, which differ in the position of the measuring point, are described in 3.2 and 3.3. It should however be emphasized that these two methods are not equivalent as the second one requires previous calibrations.

3.2 Measurement at the point of mean axial velocity

From a large number of experimental results it has been possible to establish that under turbulent conditions and within the limits indicated in 1.2 the position of the circle centred on the pipe axis at which the local velocity is equal to the mean axial velocity remains fixed as the flowrate changes, and is the same for any pipe. This circle is at a distance from the wall $y_1 = (0{,}242 \pm 0{,}013)\,R$, R being the radius of the cross-section.

The principle of the method therefore consists of :

a) Selecting a measurement cross-section (see 4.1).

b) Measuring the dimensions of this cross-section in order to obtain its area A (see 4.2).

c) Selecting, at the above-mentioned distance y_1 from the wall, the point of measurement of velocity (see 4.4.1).

d) Measuring the local velocity v_1 of the flow, according to the special conditions required by the primary device used (see 4.3).

e) Calculating the volume rate of flow equal to the product of the cross-sectional area and the measured velocity (v_1) taken as being the mean axial velocity (U) :

$$q_V = A \times U = A \times v_1$$

f) Determining the uncertainty associated with this flow measurement (see clause 5).

3.3 Measurement on the axis of the conduit

If the above method cannot be applied, the local velocity of the flow can be measured at the centre of the measurement cross-section on the axis of the conduit. However, it is then necessary to carry out calibrations by previous determination of the ratio U/v_0 of the mean axial velocity at the velocity at the centre. This ratio remains approximately constant for a given pipe in fully rough turbulent conditions.

The principle of the method therefore consists of :

a) Selecting a measurement cross-section (see 4.1).

b) Measuring the dimensions of this cross-section in order to obtain its area A (see 4.2).

c) Measuring the local velocity of flow at the centre of the cross-section v_0, in accordance with the special conditions required by the primary device used (see 4.3).

d) Calculating the mean axial velocity U by multiplying the velocity measured at centre v_0 by the previously determined calibration coefficient (see 4.4.2).

e) Calculating the volume rate of flow equal to the product of the cross-sectional area and the mean axial velocity :

$$q_V = A \times U = A \times v_0 \times \left(\frac{U}{v_0}\right)$$

f) Determining the uncertainty associated with this flow measurement (see section 5).

4 Procedure

4.1 Selection of the measurement cross-section

The measurement cross-section shall be situated on a straight length of the conduit. In order to have the best chance of a fully developed flow, the length of the straight section upstream from the measurement cross-section shall be as large as possible and in all cases at least equal to the values specified in the table below :

Type of disturbance upstream from the measuring cross-section	Minimum upstream straight length*	
	For a measurement at the point of mean axial velocity	For a measurement on the axis of the conduit
90° elbow or a t-bend	50	25
Several 90° coplanar bends	50	25
Several 90° non-coplanar bends	80	50
Total angle convergent 18 to 36°	30	10
Total angle divergent 14 to 28°	55	25
Fully opened butterfly valve	45	25
Fully opened plug valve	30	15

* Expressed in multiples of the diameter of the conduit.

Downstream from the measurement cross-section, the straight length shall be at least equal to five duct diameters whatever the type of disturbance.

4.2 Determination of the area of the measurement cross-section

4.2.1 Calculation of the area from the mean diameter

Normally the area of the measurement cross-section shall be calculated from the mean diameter of the conduit which is taken to be equal to the arithmetic mean of measurements made on four diameters of the cross-section at approximately equal angles to each other. If the difference between the length of two consecutive diameters is greater than 0,5 %, the number of diameters measured shall be doubled.

4.2.2 Calculation of the area from the perimeter

If there is no possibility of directly measuring the inside diameter of the conduit, it is allowed to determine the area of the measurement cross-section by measuring the external perimeter P if necessary corrected with ΔP defined below while taking account of the thickness of the wall e, from the equation :

$$A = \frac{\pi}{4}\left(\frac{P - \Delta P}{\pi} - 2e\right)^2$$

If this method is used, the external surface of the conduit shall have any roughness carefully removed. If there are any local highspots such as welding beads, a correction ΔP calculated for each highspot from the following formula is subtracted from the measured value for the perimeter :

$$\Delta P = \frac{8}{3} a \sqrt{\frac{a}{D}}$$

where a is the height of the highspot.

This method cannot be used when the number and position of the protrusions does not allow the measuring tape to contact the spaces between the protrusions or when the height of any protrusion exceeds 1 % of the pipe diameter.

4.3 Specifications regarding the primary device

4.3.1 Choice of the primary device and its support

The primary device shall be chosen taking account of the properties of the fluid measured and the possible presence of matter in solution or suspension. The method of fixing shall be examined taking into account the possible interference between the support and primary device (effects on calibration, blockage effect), and in order that there is no likelihood of vibration throughout the range of flows being considered.

The primary device will normally be a current-meter or pitot-static tube; in these cases it shall be installed and used in accordance with the requirements of the appropriate standard (ISO 3354 and ISO 3966 respectively) unless specific relaxations are permitted in this International Standard. Other primary devices for measuring local velocity cannot be used unless it has been verified that they are completely satisfactory for the measuring conditions by means of a calibration carried out either in situ or in similar flow and installation conditions. This calibration must permit an uncertainty of no greater than ± 1 % in the local velocity measurements.

4.3.2 Dimensional limitations

The effects of the transverse gradient of velocities and the blockage effect due to the primary device and its support result in dimensional limitations in the equipment used.

In the case of a pitot tube placed at the point of mean axial velocity, the ratio between the diameter of the head and the diameter of the conduit shall not exceed 0,02. If the pitot tube is placed on the axis of the conduit, this ratio may, if necessary, rise to 0,06.

In the case of a current meter, the ratio between the diameter of the propeller and the diameter of the conduit shall not exceed 0,11 whatever the position of measurement.

4.4 Determination of the mean axial velocity

The local velocity measurements and the corrections applied to them must be carried out in accordance with the relevant International Standard for the primary device used.

4.4.1 Measurement at the point of mean axial velocity

Wherever possible, and in particular if the indication given by the primary device is unaffected by the transverse gradient of velocities and if the straight length available upstream of the measuring plane is sufficient, the measurement shall be made at a point where the local velocity is assumed to be equal to the mean axial velocity.

For this purpose, the primary device shall be installed at a distance of 0,242 R from the internal wall of the conduit with a tolerance of less than $\pm$ 0,01 R, this distance being calculated with respect to the diameter on which the primary device is installed and not with respect to the mean diameter of the conduit.

4.4.2 Measurement on the axis of the conduit

If the primary device does not provide the required accuracy in view of the transverse gradient of velocities, or if its dimensions do not satisfy the requirements of 4.3.2 for a measurement at the point of mean axial velocity, or again if the straight length available is between the values appearing respectively in the two columns of the table in 4.1, it is still possible to measure the flow by placing the primary device on the axis of the conduit. However, it is then necesary to carry out calibrations by previously determining the ratio of the mean axial velocity to the velocity at the centre.

This ratio in principle remains constant throughout the entire area of rough turbulent conditions. It is however recommended, wherever possible, to verify it by carrying out this calibration for two or three conditions that differ as widely as possible and covering the range of flows considered.

Calibration can be obtained either by measuring the velocity at the point of mean axial velocity as indicated in 4.4.1 or by using any other standard method of measuring flowrate which has an uncertainty of less than $\pm$ 2 %. The accuracy of the subsequent flow measurements will depend directly on the accuracy of the method of flow measurement used for calibration purposes.

NOTE — Calibration by measurement at the point of mean axial velocity is not possible unless the straight length upstream is greater than the values given in the first column of the table in 4.1.

5 Uncertainties of measurement

This clause defines certain types of fundamental statistical terms used in this International Standard and specifies the method to be used in evaluating the uncertainty of the measurement of a volume rate of flow from the list of sources of error that might occur when measuring the local velocity and calculating the flow.

Annexes B and C give examples of calculating the overall uncertainty, their sole purpose being to illustrate the method of calculation set out below, and which are not meant to provide standard values for the various uncertainties, in this respect each individual case must be the subject of a careful study.

5.1 Definition of standard deviation[1)]

5.1.1 If a variable X is measured several times, each measurement being independent of the others, the standard deviation s_x of the distribution of n measurements X_i is estimated by :

$$s_x = \left[\frac{\sum_{i=1}^{i=n} (\overline{X} - X_i)^2}{n-1} \right]^{1/2}$$

where

$\overline{X}$ is the arithmetic mean of n measurements of the variable X;

X_i is the value obtained for the ith measurement of the variable X;

n is the total number of measurements of X.

For brevity, s_x is normally referred to as the standard deviation of X.

5.1.2 If several measurements of the variable X are not available or if these measurements are too few to allow direct calculation of the standard deviation on a statistical basis, and if the range within which the measurements lie is known, the standard deviation may be taken as one quarter of the range.

5.2 Propagation of errors

Let $X_1, X_2, \ldots, X_k$ be the various independent quantities which when known permit calculation of the flow q_V; this can be expressed as a given function of these variables :

$$q_V = f(X_1, X_2, \ldots, X_k)$$

Let $s_1, s_2, \ldots, s_k$ be the estimations of the standard deviations on the quantities $X_1, X_2, \ldots, X_k$; an estimation of the standard deviation s_{q_V} of the flowrate measurement is given by :

$$s_{q_V} = \left[\left(\frac{\partial q_V}{\partial X_1} s_1 \right)^2 + \left(\frac{\partial q_V}{\partial X_2} s_2 \right)^2 + \ldots + \left(\frac{\partial q_V}{\partial X_k} s_k \right)^2 \right]^{1/2}$$

where $\frac{\partial q_V}{\partial X_1}, \frac{\partial q_V}{\partial X_2}, \ldots, \frac{\partial q_V}{\partial X_k}$ are partial derivatives.

5.3 Definition of uncertainty

5.3.1 Within the meaning of this International Standard, the uncertainty on the measurement of a variable is defined as twice the standard deviation of this variable. The uncertainty shall be calculated and presented under this designation in any measurement claimed to be in accordance with this International Standard.

1) The standard deviation defined here is what statisticians more accurately call the "estimation of standard deviation".