International Standard 5221

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Air distribution and air diffusion — Rules to methods of measuring air flow rate in an air handling duct

Distribution et diffusion de l'air — Règles pour la technique de mesure du débit d'air dans un conduit aéraulique

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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 developing International Standards is carried out through ISO technical committees. Every member body interested in a subject for which a technical committee has been authorized has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work.

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

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Poland
Romania
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Sweden
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USA

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0 Introduction

These rules result from several special considerations, which should be kept in mind :

a) The fluid is air, its temperature and pressure being almost those at ambient conditions.

b) Since the flow rates are sometimes relatively small, the Reynolds numbers to be considered may sometimes correspond to relatively small values (for instance some thousands).

c) The widest possible freedom of choice is provided in order to have methods which can be applied either to laboratory testing or to site testing.

d) The methods of measuring air flow rates in a duct have reached a higher degree in the matter of accuracy than is sometimes necessary for the requirements of air distribution and air diffusion.

This International Standard, partially derived from International Standards already published (see clause 2), has been prepared taking into account these considerations but without keeping all the specifications because of the reduced requirements concerning uncertainty on flow quality which are limited to a value of ± 2 % or even more for some devices (see clauses 7.8 and 7.9).

The values indicated for the uncertainty of the coefficients given must be increased for the uncertainty of the air flow rate itself when inappropriate manometers are used.

Finally it should not be forgotten that the values which are mentioned throughout this International Standard would be seriously in error if the flow approaching the measuring device is not free from swirl and that some of the measuring devices herein described do not offer any guarantee on this point without the addition of a suitable accessory.

In cases where low Reynolds numbers occur and where reduced requirements concerning accuracy are acceptable, such as measurement of leakage flow rates, special information has been given in an annex to this International Standard.

1 Scope and field of application

This International Standard gives different methods of measuring air flow rate in an air handling duct which, without the need of calibration, meet various specific requirements in the field of air distribution and air diffusion.

For the purpose of this International Standard an "air handling duct" is defined as a tight section of straight ductwork such that the general conditions for device installation can be met. The cross-section of the duct may be circular or, excluding for device 14, rectangular.

2 References

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

ISO 5167, *Measurement of fluid flow by means of orifice plates, nozzles and Venturi tubes inserted in circular cross-section conduits running full.*

3 Proposed measuring devices

This International Standard proposes the use of one of the following devices :

1) Orifice plate with corner taps (see 7.0 and 7.1)

2) Orifice plate with flange taps (see 7.0 and 7.2)

3) Orifice plate with D and $D/2$ tappings (see 7.0 and 7.3)

4) ISA 1932 nozzle (see 7.4)

5) "Long-radius" nozzle (see 7.5)

6) Classical Venturi tube (see 7.6)

7) Venturi nozzle (see 7.7)

8) Orifice plate with conical entrance (see 7.8)

9) "Quarter circle" orifice plate (see 7.9)

10) Orifice plate located at the inlet end of the system (see 7.10)

11) "Quarter circle" nozzle located at the inlet end of the system (see 7.11)

12) Inlet cone (see 7.12)

13) Venturi nozzle with sonic throat (see 7.13)

14) Pitot-static tube (see 7.14)

4 General formulae of calculation

These devices depend on three different principles :

a) for the first twelve devices mentioned, the flow rate measurement requires the measurement of the differential pressure Δp between the upstream and the downstream (or throat) sides of the device,

b) for the thirteenth device, the air reaches a velocity equal to the speed of sound at the throat and the flow rate measurement thus requires only knowledge of the state of the fluid upstream of the device,

c) for the fourteenth device, used in the velocity area method, the differential pressure measured at a number of points permits the discharge velocity to be determined through the corresponding local velocities and hence, the flow rate.

For the devices 1 to 12 the formulae giving the flow rate is :

$$q_m = \alpha \, \varepsilon \, \frac{\pi}{4} \, d^2 \sqrt{2 \varrho_1 \, \Delta p}$$

where

q_m is the mass rate of flow;

α is the flow coefficient;

ε is the expansibility (expansion) factor;

d is the diameter of orifice or throat;

ϱ_1 is the mass density of the fluid upstream of the device (section of the upstream pressure tap);

Δp is the differential pressure between the upstream and downstream pressure taps.

For device 13 (see 7.13), the basic formula used is :

$$q_m = K \, C \, \frac{\pi}{4} \, d^2 \, \frac{p_{\mathrm{am}}}{\sqrt{\Theta_{\mathrm{am}}}}$$

where

K is a critical flow function of air;

C is the coefficient of discharge;

p_{am} is the absolute stagnation pressure in the free space upstream of the device;

Θ_{am} is the absolute stagnation temperature in this free space.

For device 14 (see 7.14), the basic formula used for the calculation of local velocity, is :

$$u = \alpha \, \varepsilon \sqrt{\frac{2 \Delta p}{\varrho}}$$

where ε is the correction factor for compressibility which can be determined by the relation :

$$\varepsilon = \left[1 - \frac{1}{2\gamma} \, \frac{\Delta p}{p} + \frac{\gamma - 1}{6\gamma^2} \left(\frac{\Delta p}{p} \right)^2 \right]^{1/2}$$

in which

Δp is the differential pressure indicated by the Pitot-static tube;

ϱ is the density of air;

p is the local pressure (absolute pressure);

γ is the heat capacities ratio;

α is the calibration factor of Pitot-static tube.

In the case of ambient air, the following formula can be given :

$$\varepsilon = 1 - 0{,}18 \, \frac{\Delta p}{p}$$

Coefficient α can generally be taken equal to 1, a value from which it differs, if ever, only by some thousandths at a maximum under the conditions mentioned in 7.14.

The discharge velocity, i.e. the volume flow rate through the considered cross-section divided by its area, can then be determined from the local velocity values, either by graphical integration, or numerical integration, or by an arithmetic method. The volume rate of flow is deduced at the same time by obtaining the product of the discharge velocity and the area of the section.

5 Symbols and units

See table 1.

6 General conditions for the installation of the various devices

6.1 Subsonic pressure-difference devices (devices 1 to 12)

Certain devices are disposed between two straight lengths of duct, whereas other devices such as 10, 11 and 12 are located at the upstream end of a duct. This latter location has the advantage of substantially reducing cumbersomeness of the test system to be used for the flow rate measurement.

It should be noted that one of the possible serious errors with such devices is a swirling flow at the approach to the device and that it is essential to obtain protection against such effects by means of proper anti-swirl devices (crosspiece straightener within a circular duct, with a length of $2D$ and eight radial blades; honeycombs; AMCA straightener, etc.) which are located at a distance from the flow rate measuring device in order that the flow pattern at the approach to the measuring device is close to the pattern of a fully developed flow.

Table 1

Symbol	Represented quantity	Dimensions[1)]	Corresponding SI unit	Symbol	Represented quantity	Dimensions[1)]	Corresponding SI unit
C	Coefficient of discharge	—		Re_D	Reynolds number of the flow referred to D $Re_D = \frac{4q_m}{\pi \varrho_1 D \nu}$	—	
c_p	Heat capacity at constant pressure	$L^2 T^{-2} \Theta^{-1}$	$J \cdot kg^{-1} K^{-1}$				
c_V	Heat capacity at constant volume	$L^2 T^{-2} \Theta^{-1}$	$J \cdot kg^{-1} K^{-1}$	Re_d	Reynolds number of the flow referred to d $Re_d = \frac{4q_m}{\pi \varrho_1 d \nu}$	—	
d	Diameter of orifice or throat of primary device at operating conditions, or diameter of Pitot tube stem	L	m	U	Discharge velocity	$L T^{-1}$	$m \cdot s^{-1}$
				u	Local flow velocity (see 7.14)	$L T^{-1}$	$m \cdot s^{-1}$
D	Upstream duct diameter of primary device (or upstream diameter of a classical Venturi tube), or diameter of the circular section of a duct, at operating conditions	L	m	α	Flow coefficient for devices 1 to 12 or calibration factor for device 14	—	
				β	Diameter ratio $\beta = \frac{d}{D}$	—	
g	Acceleration due to gravity	$L T^{-2}$	$m \cdot s^{-2}$	γ	Specific heat capacities ratio $\frac{c_p}{c_V}$	—	
k	Absolute roughness	L	m				
l	Length	L	m	ε	Expansibility (expansion) factor	—	
Ma	Local Mach number $Ma = \frac{\mu}{\sqrt{\frac{\kappa p}{\varrho}}}$	—		Θ	Absolute temperature of the fluid	Θ	K
				κ	Isentropic exponent	—	
p	Pressure of the fluid	$ML^{-1} T^{-2}$	Pa	μ	Dynamic viscosity of the fluid	$ML^{-1} T^{-1}$	$Pa \cdot s$
Δp	Differential pressure ($\Delta p = p_1 - p_2$)	$ML^{-1} T^{-2}$	Pa	ν	Kinematic viscosity of the fluid	$L^2 T^{-1}$	$m^2 \cdot s^{-1}$
q_m	Mass rate of flow	$M T^{-1}$	$kg \cdot s^{-1}$	ϱ	Mass density of the fluid	ML^{-3}	$kg \cdot m^{-3}$
q_V	Volume rate of flow	$L^3 T^{-1}$	$m^3 \cdot s^{-1}$	φ	Total angle of the divergent (for a Venturi-nozzle)	—	°
R	Radius	L	m				

Indices 1 and 2 refer to the fluid conditions at the upstream and downstream tappings for devices 1 to 12 respectively.

6.1.1 Inserted subsonic pressure-difference devices (devices 1 to 7)[2)]

The devices inserted in the duct require, in fact, recourse to the use of long straight lengths on both sides of the device, these lengths being greater when an adjacent fitting causes the swirl in the flow (for example, successive bends in different planes).

It should be noted furthermore that the minimum lengths required increase with the diameter ratio β of the device.

Tables 2 and 3 indicate the minimum straight lengths required between various fittings located upstream or downstream of the subsonic devices mentioned above, expressed as multiples of the diameter D.

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1) M = Mass, L = length, T = time, Θ = temperature.

2) See ISO 5167, subclause 6.2.

Table 2 — Case of orifice plates, nozzles or Venturi nozzles

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

β	On upstream side of the primary device					On downstream side
	Single 90° bend or tee (flow from one branch only)	Two or more 90° bends in the same plane	Two or more 90° bends in different planes	Reducer ($2D$ to D over a length of $1,5\,D$ to $3D$)	Expander ($0,5\,D$ to D over a length of $1D$ to $2D$)	All fittings included in this table
$\leqslant$ 0,20	10 (6)	14 (7)	34 (17)	5 *	16 (8)	4 (2)
0,25	10 (6)	14 (7)	34 (17)	5 *	16 (8)	4 (2)
0,30	10 (6)	16 (8)	34 (17)	5 *	16 (8)	5 (2,5)
0,35	12 (6)	16 (8)	36 (18)	5 *	16 (8)	5 (2,5)
0,40	14 (7)	18 (9)	36 (18)	5 *	16 (8)	6 (3)
0,45	14 (7)	18 (9)	38 (19)	5 *	17 (9)	6 (3)
0,50	14 (7)	20 (10)	40 (20)	6 (5)	18 (9)	6 (3)
0,55	16 (8)	22 (11)	44 (22)	8 (5)	20 (10)	6 (3)
0,60	18 (9)	26 (13)	48 (24)	9 (5)	22 (11)	7 (3,5)
0,65	22 (11)	32 (16)	54 (27)	11 (6)	25 (13)	7 (3,5)
0,70	28 (14)	36 (18)	62 (31)	14 (7)	30 (15)	7 (3,5)
0,75	36 (18)	42 (21)	70 (35)	22 (11)	38 (19)	8 (4)
0,80	46 (23)	50 (25)	80 (40)	30 (15)	54 (27)	8 (4)

Fittings	Minimum upstream straight length required
Abrupt symmetrical reduction having a diameter ratio $\geqslant 0,5$	30 (15)
Thermometer pocket of diameter $\leqslant 0,03\,D$	5 (3)
Thermometer pocket of diameter between $0,03\,D$ and $0,13\,D$	20 (10)

* As no fitting can be located within $5D$ of the upstream pressure taps the value for "nil additional limit error" is applicable.

NOTES

1 The values without brackets are values for "nil additional limit error". The values in brackets are values for "additional limit error of ± 0,5 %".

2 All straight lengths are expressed in multiples of diameter D. They must be measured from the upstream face of the primary element.

6.1.1.1 If the primary element is situated in an air handling duct connecting it to an open enclosure or to a large container situated upstream, either directly or by means of accessories, the total length of duct between the open enclosure and the primary element should in no case be less than $30\,D$.[1]

If there is an accessory, the straight lengths have furthermore to correspond to the requirements for straight lengths between this accessory and the primary element given in the tables above.

6.1.1.2 If several accessories other than 90° elbows follow one another upstream from the primary element, the following rule must be applied : between the accessory (1) which is closest to the primary element and the primary element itself, maintain a minimum straight length, such as indicated for the accessory (1) in question and the real value of β in tables 2 and 3. Also maintain between this accessory (1) and the preceding accessory (2), a straight length equal to half the value indicated in the tables 2 and 3 for the accessory (2) applicable to a primary element with a diameter ratio $\beta = 0,7$, whichever the real value of β. This rule does not apply when accessory (2) is a sudden symmetrical reduction, which case is treated in the above paragraph.[2]

If one of the minimum retained straight lengths corresponds to a value between brackets, one has to add the supplementary limit error of ± 0,5 % to the error on the flow coefficient.

6.1.1.3 Each pressure measuring section includes at least one pressure tap. The drilling axis of the latter shall be perpendicular to the axis of the duct and the edge of the hole shall present a sharp deburred edge. The dimension of the taps other than corner taps shall be such that their diameter remains in any case less than 0,08 times the pipe diameter D and preferably smaller than 12 mm. For corner taps, either individual taps whose diameter lies between 1 and 10 mm, and simultaneously between $0,005\,D$ and $0,03\,D$ if $\beta \leqslant 0,65$ and between $0,01\,D$ and $0,02\,D$ if $\beta > 0,65$, or annular slots can be used.

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[1] In the absence of experimental data, it seemed advisable to adopt for classical Venturi tubes the same prescriptions required for orifice plates and for nozzles.

[2] In the case of several 90° elbows, refer to tables 2 and 3 which can apply, whatever the length between two consecutive elbows may be.

Table 3 — Case of classical Venturi tubes

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

Diameter ratio β	Single 90° short radius bend[1]	Two or more 90° bends in the same plane[1]	Two or more 90° bends in different planes[1][2]	Reducer $3D$ to D over a length of 3,5 D	Expander 0,75 D to D over a length of D
0,30	0,5[3]	1,5 (0,5)	(0,5)	0,5[3]	1,5 (0,5)
0,35	0,5[3]	1,5 (0,5)	(0,5)	1,5 (0,5)	1,5 (0,5)
0,40	0,5[3]	1,5 (0,5)	(0,5)	2,5 (0,5)	1,5 (0,5)
0,45	1,0 (0,5)	1,5 (0,5)	(0,5)	4,5 (0,5)	2,5 (1)
0,50	1,5 (0,5)	2,5 (1,5)	(8,5)	5,5 (0,5)	2,5 (1,5)
0,55	2,5 (0,5)	2,5 (1,5)	(12,5)	6,5 (0,5)	3,5 (1,5)
0,60	3,0 (1,0)	3,5 (2,5)	(17,5)	8,5 (0,5)	3,5 (1,5)
0,65	4,0 (1,5)	4,5 (2,5)	(23,5)	9,5 (1,5)	4,5 (2,5)
0,70	4,0 (2,0)	4,5 (2,5)	(27,5)	10,5 (2,5)	5,5 (3,5)
0,75	4,5 (3,0)	4,5 (3,5)	(29,5)	11,5 (3,5)	6,5 (4,5)

[1] The radius of curvature of the bend should be equal to or greater than the duct diameter.

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

[3] Since no fitting can be placed closer than 0,5 D to the upstream pressure taps of the Venturi tube, the "zero additional tolerance" value is applicable in this instance.

NOTES

1 The values without brackets are values for "nil additional limit error". The values in brackets are values for "additional limit error of ± 0,5 %".

2 All straight lengths are expressed in multiples of diameter D. They must be measured from the plane of the upstream pressure taps of the classical Venturi tube. The roughness of the duct, at least for the length indicated in the previous table should not exceed that of commercially available ducts (approximately $\frac{k}{D} \leqslant 10^{-3}$).

3 Downstream straight lengths : the accessories or obstacles (indicated in table 3) situated downstream at least four times the throat diameter from the plane of the pressure taps at the throat do not affect the accuracy of measurements.

6.1.1.4 The annular slots are usually flush on their entire perimeter without discontinuity. If this is not the case, each annular chamber shall communicate with the interior of the pipe by openings whose axes form equal angles with respect to one another, the number of which is at least four, and whose individual opening surface is at least equal to 12 mm^2.

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

6.2 Venturi-nozzles with sonic throat (devices 13)

For these devices it is enough to measure the absolute pressure and temperature in the chamber of diameter D at least equal to three times the throat diameter d and to check that the ratio of the absolute pressures downstream and upstream of the device does not exceed a critical value (see 7.13). If substantial pressure fluctuations prevail downstream of the device, the measurement and the value of the flow rate are not affected by them and the knowledge of the nature and the upstream state of the fluid allows the measured value of the flow rate to be obtained when the throat size is known.

The device shall be installed in the duct at a position such that the flow conditions immediately upstream are free from swirl.

6.3 Pitot-static tube (devices 14)

The section chosen to carry out the measurements shall be situated in a straight length and be perpendicular to the duct axis . It shall be of a simple form, either circular or rectangular for example.

It shall be situated in an area where the measured velocities are within the normal range of the employed device.

In the proximity of the measuring section, the flow shall be noticeably parallel to the duct axis (angle generally less than 5°) and shall present neither excessive turbulence nor swirl. The measuring section has consequently to be chosen at a sufficient distance from any fitting which could create dissymmetry, swirl or turbulence and might therefore seriously alter the data obtained from the tube which is parallel to the duct axis within 5°.

The straight length which may be necessary to satisfy these conditions varies according to flow velocity, upstream fittings, turbulence level and degree of swirl, if any.

7 Characteristics and employment limitations of the different devices

7.0 Common characteristics of devices under clauses 7.1, 7.2 and 7.3

The orifice plate shall conform with the drawing in figure 1.

The principal specifications relating to the plate are :

- Plane upstream face, its roughness (total height) being inferior to 0,000 3 d within a circle of diameter 1,5 d, which is concentric to the orifice.
- Plane downstream face parallel to the upstream face.
- $e \leqslant E \leqslant 0{,}05\,D$

  $(0{,}005\,D \leqslant e \leqslant 0{,}02\,D)$
- $30° \leqslant F \leqslant 45°$
- If $E \leqslant 0{,}02\,D$, bevelling not compulsory.
- Sharp upstream edge G.
- Determination of d as the mean of the measurements of four diameters at least angularly distributed (none of the four measurements differing from the average by more than $5 \times 10^{-4}\,d$).

The orifice plate which is described above can be associated to one of the three pressure tap types mentioned under 7.1, 7.2 and 7.3.

Reference shall be made to ISO 5167 for specifications related to pressure taps.

The conditions for use of the three types of orifice plates are :

$$0{,}012\,5\ m \leqslant d$$

$$0{,}050\ m \leqslant D$$

$$0{,}20 \leqslant \beta \leqslant 0{,}75$$

$$\frac{k}{D} \leqslant 10^{-3}$$

$$\frac{\Delta p}{p_1} \leqslant 0{,}25$$

The Reynolds number Re_D shall be greater than or equal to a minimum value of $1{,}26 \times 10^6\,\beta^2\,D$.

The flow coefficient α is given by the Stolz formula :

$$\alpha = \alpha_\infty + 0{,}002\,9\,(1 - \beta^4)^{-0{,}5}\,\beta^{2{,}5}\left(\frac{10^6}{Re_D}\right)^{0{,}75}$$

where

$$\alpha_\infty = (1 - \beta^4)^{-0{,}5}\,[0{,}595\,9 + 0{,}031\,2\,\beta^{2{,}1} - 0{,}184\,0\,\beta^8 + 0{,}090\,0\,l_1\,D^{-1}\,\beta^4(1 - \beta^4)^{-1} - 0{,}033\,7\,l'_2\,D^{-1}\,\beta^3]$$

in which

l_1 is the distance of the upstream pressure tap to the upstream face of the orifice plate;

l'_2 is the distance of the downstream pressure tap to the downstream face of the orifice plate.

NOTE — When

$$0{,}050\ m \leqslant D \leqslant \frac{2{,}286}{39}\ m\,(\approx 0{,}059\ m)$$

the term

$$(1 - \beta^4)^{-0{,}5}\,[0{,}090\,0\,l_1\,D^{-1}\,\beta^4\,(1 - \beta^4)^{-1}]$$

is to be replaced by

$$(1 - \beta^4)^{-0{,}5}\,[0{,}039\,0\,\beta^4\,(1 - \beta^4)^{-1}]$$

Table 4 gives values of coefficient α_∞ and of $2{,}9\,(1 - \beta^4)^{-0{,}5}\,\beta^{2{,}5}$ for a series of values of β and D.

Because of the rounding off to within 10^{-3} of the values of α_∞, linear interpolation is permitted between two successive values of β.

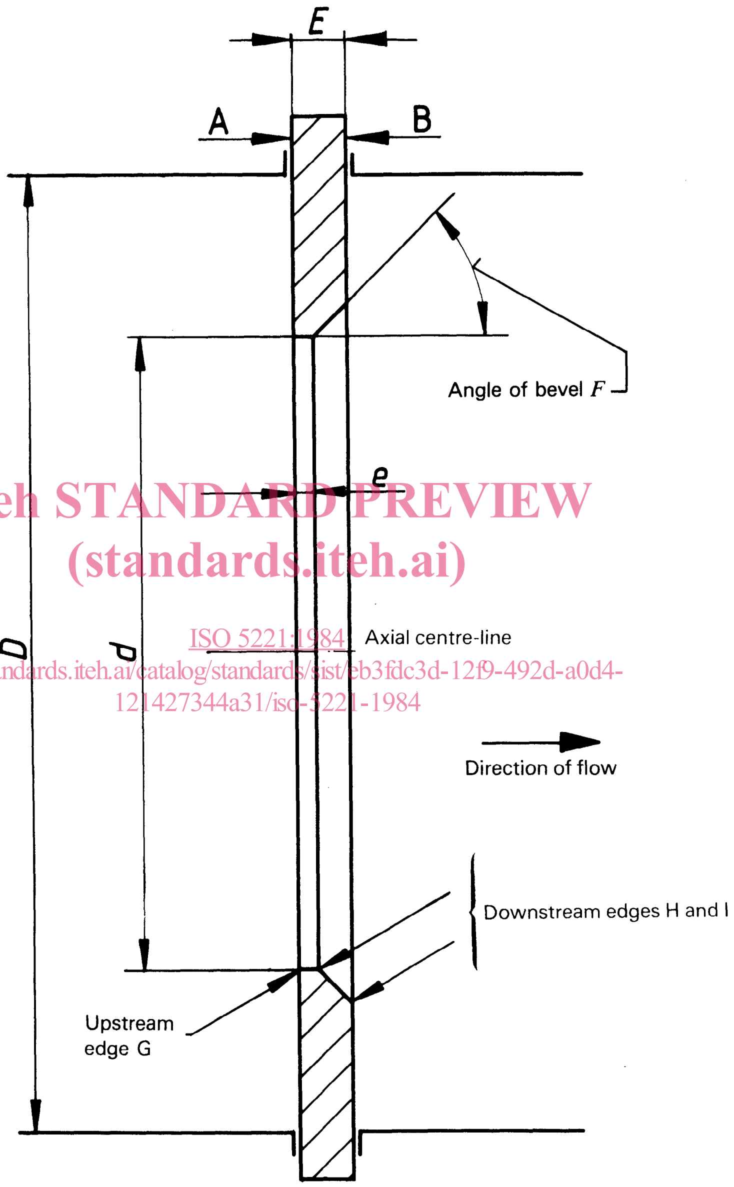

Figure 1 — Standard orifice plate

Table 4 — Values of coefficient α_∞ and of $2{,}9\,(1-\beta^4)^{-0{,}5}\,\beta^{2{,}5}$ for orifice plates as a function of β and D

β	Corner taps	Flange taps							D and $\frac{D}{2}$ taps	$2{,}9\,(1-\beta^4)^{-0{,}5}\,\beta^{2{,}5}$
	$D = \infty$	D = 0,600	D = 0,400	D = 0,200	D = 0,150	D = 0,100	D = 0,060	D = 0,050		
0,20	0,597	0,597	0,597	0,597	0,597	0,597	0,597	0,597	0,597	0,052
0,25	0,599	0,599	0,599	0,599	0,599	0,599	0,599	0,599	0,599	0,091
0,30	0,601	0,601	0,601	0,601	0,601	0,601	0,601	0,601	0,601	0,144
0,32	0,602	0,602	0,602	0,602	0,602	0,602	0,602	0,602	0,602	0,169
0,34	0,603	0,603	0,603	0,603	0,603	0,603	0,603	0,603	0,603	0,197
0,36	0,605	0,605	0,605	0,605	0,605	0,605	0,605	0,604	0,605	0,227
0,38	0,606	0,606	0,606	0,606	0,606	0,606	0,606	0,606	0,606	0,261
0,40	0,608	0,608	0,608	0,608	0,608	0,608	0,608	0,608	0,608	0,297
0,41	0,609	0,609	0,609	0,609	0,609	0,609	0,609	0,609	0,609	0,317
0,42	0,610	0,610	0,610	0,610	0,610	0,610	0,611	0,610	0,610	0,337
0,43	0,612	0,612	0,612	0,612	0,612	0,612	0,612	0,612	0,612	0,358
0,44	0,613	0,613	0,613	0,613	0,613	0,613	0,613	0,613	0,613	0,380
0,45	0,614	0,614	0,614	0,614	0,614	0,614	0,614	0,614	0,614	0,402
0,46	0,616	0,616	0,616	0,616	0,616	0,616	0,616	0,616	0,616	0,426
0,47	0,617	0,617	0,617	0,617	0,617	0,617	0,618	0,617	0,617	0,450
0,48	0,619	0,619	0,619	0,619	0,619	0,619	0,619	0,619	0,619	0,476
0,49	0,620	0,620	0,621	0,621	0,621	0,621	0,621	0,621	0,621	0,502
0,50	0,622	0,622	0,622	0,622	0,623	0,623	0,623	0,623	0,623	0,530
0,51	0,624	0,624	0,624	0,624	0,624	0,625	0,625	0,625	0,625	0,558
0,52	0,626	0,626	0,626	0,626	0,626	0,627	0,627	0,627	0,627	0,587
0,53	0,628	0,628	0,628	0,629	0,629	0,629	0,629	0,629	0,629	0,618
0,54	0,631	0,631	0,631	0,631	0,631	0,631	0,632	0,631	0,632	0,650
0,55	0,633	0,633	0,633	0,633	0,634	0,634	0,634	0,634	0,634	0,683
0,56	0,635	0,636	0,636	0,636	0,636	0,636	0,637	0,637	0,637	0,717
0,57	0,638	0,638	0,638	0,639	0,639	0,639	0,640	0,640	0,640	0,752
0,58	0,641	0,641	0,641	0,641	0,642	0,642	0,643	0,643	0,643	0,789
0,59	0,644	0,644	0,644	0,645	0,645	0,645	0,646	0,646	0,646	0,827
0,60	0,647	0,647	0,647	0,648	0,649	0,649	0,650	0,649	0,649	0,867
0,61	0,650	0,650	0,651	0,651	0,651	0,652	0,653	0,653	0,653	0,908
0,62	0,654	0,654	0,654	0,655	0,655	0,656	0,657	0,656	0,657	0,951
0,63	0,657	0,658	0,658	0,658	0,659	0,659	0,661	0,660	0,661	0,995
0,64	0,661	0,661	0,662	0,662	0,663	0,664	0,665	0,665	0,665	1,042
0,65	0,665	0,665	0,666	0,666	0,667	0,668	0,670	0,669	0,669	1,090
0,66	0,669	0,670	0,670	0,671	0,671	0,672	0,674	0,674	0,674	1,140
0,67	0,674	0,674	0,674	0,675	0,676	0,677	0,680	0,679	0,679	1,193
0,68	0,678	0,679	0,679	0,680	0,681	0,682	0,685	0,684	0,685	1,247
0,69	0,683	0,684	0,684	0,685	0,686	0,688	0,691	0,690	0,690	1,304
0,70	0,688	0,689	0,690	0,691	0,692	0,693	0,697	0,696	0,696	1,337
0,71	0,694	0,695	0,695	0,697	0,697	0,699	0,703	0,702	0,703	1,426
0,72	0,700	0,701	0,701	0,703	0,704	0,706	0,710	0,709	0,709	1,492
0,73	0,706	0,707	0,707	0,709	0,710	0,713	0,717	0,716	0,717	1,560
0,74	0,712	0,713	0,714	0,716	0,717	0,720	0,725	0,724	0,725	1,633
0,75	0,719	0,720	0,721	0,723	0,725	0,728	0,733	0,732	0,733	1,709

The expansibility factor ε is calculated using the empirical formula

$$\varepsilon = 1 - (0{,}41 + 0{,}35\,\beta^4)\,\frac{\Delta p}{\kappa p_1}$$

Figure 2 gives the expansifility factor ε for κ = 1,4.